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Techno-economic evaluation of building energy refurbishment processes from a life cycle perspective

Bizi zikloaren ikuspegitik eraikinen birgaitze energetikoen prozesuen analisi teknoekonomikoa

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Summary / *Laburpena* / Resumen

SUMMARY

Based on the new energy performance limitations determinate by the Directive 2010/31/EU (art 9: Nearly zero-energy buildings), the buildings become more energy efficient and the impact of the operational stages is reduced, increasing the relevance of the environmental and economic impact of the other life cycle stages. In this context, according to the European Commission (*CEC, 2014a; CEC, 2014b*) or studies related to the "Life Cycle Zero Energy Building (*Hernandez & Kenny, 2010*), the Life Cycle methodology could be the best framework available to assess the environmental and economic impact of buildings which will be built up from 2018.

However, the scenario posited in this research work is not centred on proposing any methodology to assess the behaviour of new buildings. The aim of this project is to propose the most suitable assessment methodology to allow decisions to be taken in choosing between the different energy-efficient retrofitting strategies for buildings.

As part of its analysis of the state of the art in terms of energy-efficient retrofitting of buildings, the second chapter of the thesis assessed the features of the different existing assessment systems for retrofitting. After assessing the potential and weaknesses of each system, this piece justified its decision not to use MCVSE (Multi-Criteria Voluntary Sustainability Evaluation) assessment systems in its work. It therefore proposed a basic methodology centring exclusively on the standardised quantitative assessment systems currently on the market. This means basing the methodology on a system that makes it possible to measure the environmental and economic impacts and envisages the use of different impact indicators to take final decisions.

This initial decision raises one of the key questions in this thesis, one that will form an important part of the final conclusions: in prioritising between the different strategies for energy-efficient retrofitting of a building, does the impact generated over all stages in the building's life cycle need to be quantified, or is it enough to quantify the impact related to the operational energy use stage? How far can the evaluation system boundary be simplified without placing at risk the rigour of the results and the decisions based on them? What is the relationship between the increased "accuracy" of the end results after implementing this methodology and the time and effort (economic investment) involved in including this methodology throughout the retrofitting process?

In order to seek an answer to these questions on the basis of the EN 15978 and prEN 16627 standards (regulations for environmental and economic analysis of buildings with life cycle approach), this research work proposed a quantitative methodology to allow assessment of the impact generated at each stage in the life cycle of an energy-efficient retrofitting of a building.

The methodology proposed was validated using a building constructed in San Sebastian (Spain) in 1963. On the basis of the building's geometry and the construction and functional features defined, together with a quantification of the environmental and economic impact of the existing building and the same building after retrofitting using the different strategies, the impact generated at each stage of its life cycle was quantified. In this way, on the basis of a criterion for calculation that allows for optimisation of the evaluation system boundary, the percentage impact of each stage was calculated as part of the overall impact reduction of the refurbished building during its life cycle, so allowing the importance of each of them to be shown. However, given the possible disadvantages of treating these results based on a single case of study as overall conclusions, the research proposes an exhaustive sensitivity analysis presenting new scenarios related to most of the parameters that have a direct influence on the method of calculation. Among others, new values related to parameters like Reference Service Life value (RSL_b), Estimated Service Life of the product value (ESL_m), Embodied energy data (EE), Energy price increment (EPI), distance of the product transportation (D_m), climate zone, energy demand (OE), inflation rate (IR) and environmental conversion factor (CF) were defined. After analysing all the new scenarios defined using these data (775 environmental and 682 economic scenarios), the results obtained make it possible to give an answer concerning the relationship between the increased accuracy of the results and the quantification of all the stages in the life cycle.

The first conclusion shows that in 98% of the environmental scenarios currently assessed (in accordance with the scope of this methodology), the impact generated at the stages of transport (A4), construction process (A5) and end of life (C1-4) can be quantified at less than 1% of the final results. The same is the case with a economic assessment with a perspective on life cycle, where the results show that in 99% of scenarios the impact generated at the stages of transport (A4) and end of life (C1-4) can be quantified at less than 5% of the final results.

Regarding the relevance of the other stages, this study has identified two totally different retrofitting groups or scenarios. On the one hand there are scenarios where after implementing the different retrofitting strategies the reduction in impact in the operational energy use stage is less. This means those where the relative weight of the operational energy use stage is very small. In these cases, as well as quantifying the reduction in impact during the operational energy use stage (B6), the impact generated in other stages in its life cycle such as production (A1-3), construction process (A5), maintenance (B2) and replacement (B4) needs to be quantified. The results obtained show that in some cases the impact in the production or replacement stage can reach 50-60% of the total reduced impact, making it a central factor in the process of decision-making and prioritising strategies. The same applies to the other stages, the impact of which account for less than 10% of the total final impact.

However, in the second group or scenario the reduction in impacts is very high because the greater importance of the operational energy use stage changes the results completely. In 74% of environmental studies and 19% of economic studies the impact of the building during its life cycle after retrofitting accounts for more than 90% of the reduction, which means that all the other stages (product, transport, construction proccess, maintenance, replacement and end of life) in its life cycle make up less than 10% of its impact. In other words, these results show that in scenarios of this type the difference in results yielded by calculations based on the life cycle methodology and a method whose scope is limited to assessing only the operational use stage will be less than 10%.

Therefore, the first part of the thesis has shown that due to the variation in results from the sensitivity analysis, it is very hard to get a single result to define the relationship between the accuracy of the results and the increased effort involved in applying the life cycle methodology. There are many results that show the need to include different stages of the life cycle in decision-making. For example, they highlight the need to apply this methodology to buildings for retrofitting located in climate zones whose Heating Degree Days value is less than 2000. On the other hand, the results for retrofitted buildings located in cold climate zones or buildings with a large reduction in impact during the operational energy use stage show that applying this complex methodology does not add rigour to the end results. For all these reasons, as with the content outlined in this thesis, a need is shown to fix the scope of the system for assessing and prioritising retrofitting strategies on the basis of recommendations related to the climate or the thermal or energy features of the current building stock. In this way, on the basis of a single methodology based on life cycle, new retrofitting policies, regulations, economic assistance or new Energy Performance Certification systems in each member state can be adapted to the general features of each scenario, so ensuring maximum return on each decision-making process.

In the second part of the validation of the methodology defined by the thesis, together with discussion of the importance of simplifying the scope of the life cycle methodology in the end results, a lot of work went into showing the influence of uncertainty or lack of information in the inputs used to calculate the impact of the different stages of the life cycle on the end results. To this end, this methodology proposes the use of 4 impact indicators: 2 environmental (reduction of the Non Renewable Primary Energy use and Net Energy Ratio) and 2 economic (Internal Rate of Return and Life Cycle Payback). Based on the building in San Sebastián mentioned above and the retrofitting strategies defined in the research, the results for the 4 indicators were calculated, yielding the necessary information to be able to prioritise between the different retrofitting strategies and take a final decision.

The results obtained show that the values for the different impact indicators used to prioritise different retrofitting strategies can vary considerably, even showing deviations of ±200% or more. However, these deviations are not evidence of a lack of quality in the life cycle analysis or insufficient rigour in the results. They simply reflect uncertainty over some aspects including the Life Cycle Assessment (LCA) data source (process data, input-output o hybrid), variations in energy prices, the length of the building’s useful life or how a building’s energy demands will develop over the course of its life cycle.

In turn, the lack of information that exists concerning many of the stages that make up the life cycle was stressed. For example, regarding the production stage, while new Environmental Product Declarations (EPD) are being developed for the products and systems used in the different energy-efficient retrofitting strategies, it is still very difficult to obtain this information in many EU countries (Spain, for example). In relation to this point, it is also very difficult to obtain detailed environmental and economic information on many of the processes and stages in the life cycle, and values from highly generic databases must be used.

This is why, as mentioned in the “future works” section, this thesis stresses the need to improve data quality, expand the content with environmental and economic information on the different stages in the life cycle in each member state’s databases on construction materials and energy systems and roll out new policies to help quantify the impact generated in all the processes that form part of the life cycle of a building to be retrofitted. These new policies on quantifying impacts in a rule-based, standardised way will make it possible to reduce the current high degree of uncertainty and help to integrate life cycle methodology into new processes to prioritise strategies for the energy-efficient retrofitting of buildings.

Keywords: building energy refurbishment, economic and environmental life cycle assessment, evaluation scope optimization, multicritery decision making, data quality, uncertainty, cut-off rules.

LABURPENA

2010/31/EU zuzentarauan (9. artikulua: ia zero energiako eraikina) zehaztutako eraikinen portaera energetikoaren mugetan oinarrituz, eraikinak gero eta energetikoki eraginkorrago bihurtu eta haien erabilera etaparen inpaktua ia zeroko balioetara murriztuko da, honela, bizi zikloaren beste etapen ingurumen eta ekonomia inpaktuen garrantzia handituz. Hau da, 2018tik aurrera eraikiko diren eraikin berrien ingurumen eta ekonomia portaera lantzean, Europako Batzordeak (*CEC, 2014a; CEC, 2014b*) edo "Bizi zikloan zehar zero energiako eraikinen" (*Hernandez & Kenny, 2010*) inguruan egindako lanek proposatutako lan lerroei jarraituz, ezinbestekoa izango da eraikinen portaera bizi zikloaren ikuspegitik ebaluatzea. Hala ere, ikerketa lan honetan proposatutako egoerak ez du eraikin berrien portaera ebaluatzeko metodologiarik proposatzen, lan honen helburua baita gaur egungo eraikinen birgaitze energetikoetan erabiliko diren estrategien artean aukeratzeko ebaluazio metodologia egokiena proposatzea.

Eraikinen birgaitze energetikoaren inguruko literatura sakon aztertu ondoren, tesiaren bigarren atalean, birgaitzeen portaera aztertzeko gaur egun merkatuan dauden ebaluazio sistemen ezaugarriak landu dira. Haien artean, sistema kualitatiboetan oinarritutako Borondatezko Irizpide Anitzeko Jasangarritasun Ebaluazio (BIAJE) sistemek dituzten ahuleziak aztertu ostean, birgaitze estrategiak lehenesteko ebaluazio metodologia horien erabilera ekidin izana arrazoitu da. Ondorioz, proposatuko den metodologiaren abiapuntua gaur egun estandarizatuta dauden ebaluazio sistema kuantitatiboetan oinarritzea da. Hau da, ingurumen eta ekonomia inpaktuak zenbatu eta hainbat adierazleren bidez erabakiak hartzea ahalbidetzen duten sistemetan oinarritzea.

Erabaki hori hartzean, tesiaren giltza eta azken ondorioen zati garrantzitsuetako bat osatuko duten galderak sortu dira: beharrezkoa al da eraikin baten birgaitze energetikoko estrategien artean aukeratzeko garaian eraikinaren bizi zikloko etapa guztietan sorturiko inpaktuak zenbatzea, edo nahikoa litzateke erabilera etaparekin loturiko inpaktuak zenbatzea? Zer puntutaraino sinplifikatu daiteke ebaluazio sistemaren irismena, emaitzen zehaztasuna eta, ondorioz, harturiko erabakiak arriskuan jarri gabe? Zein da metodologia honen bidez lorturiko emaitzen zehaztasunaren eta berau erabiltzeak dakarren esfortzu eta denboraren (inbertsio ekonomikoa) arteko erlazioa?

Galdera horiei erantzuteko asmoz, EN 15978 eta prEN 16627 estandarretan oinarrituz (eraikinen bizi zikloaren ingurumen eta ekonomia analisiaren arautegiak), ikerketa lan

honek metodologia kuantitatibo bat proposatu du, eraikin baten birgaitze energetikoaren bizi zikloko etapa bakoitzaren inpaktua ebaluatzea ahalbidetzeko.

1963an Donostian eraikitako etxebizitza bloke batean oinarriturik, lan honetan proposatutako metodologia balioztatu da. Eraikinaren geometria, eraikuntza eta erabilera ezaugarrietan oinarrituz, eraikinaren gaur egungo eta zenbait birgaitze estrategia aplikatu ondorengo ingurumen eta ekonomia inpaktua aztertzeaz gain, bizi zikloan zehar, eraikinaren etapa bakoitzean sortuko diren inpaktuak zenbatu dira. Era horretan, ebaluazio sistemaren irismena optimizatzeko garaturiko kalkuluetan oinarriturik, bizi zikloko etapa bakoitzaren ehunekoaren eragina landu da, etapa bakoitzaren garrantzia islatzek asmoz. Hala ere, egoera bakar baten analisia eginik lorturiko emaitzak ondorio orokor bezala erabiltzeak dakartzan arazoak ikusirik, lan honetan sentiberatasun analisi sakon bat proposatu da, metodologia kalkuluan zehar eragin zuzena izango duten parametro gehienen inguruko egoera berriak proposatzeko. Besteak beste, aipatzekoak dira eraikinaren bizi iraupena (RSL_b), produktuen aurreikusitako bizi iraupena (ESL_m), produktuen barne energia (EE), energiaren prezioaren eboluzioa (EPI), produktuen garraio distantzia (D_m), gune klimatikoa, energia eskaria (OE), inflazio tasa edo ingurumen konbertsio faktoreen (CF) inguruan proposatutako balioak. Datu berri horiek sorturiko egoera hauen guztien azterketa egin ostean (775 ingurumen eta 682 ekonomia egoera), emaitzen zehaztasun gehikuntza eta bizi zikloaren etapa guztiak zenbatzearen arteko erlazioaren inguruko erantzun bat erdiesten da.

Lehen ondorioak erakusten du ingurumenaren ikuspegitik ebaluatu diren agertokien % 98n (metodologiaren irismenaren arabera), garraio (A4), eraikuntza prozesu (A5) eta deuseztatzeak (C1-C4) sortutako inpaktuaren kuantifikazioak % 1eko baino gutxiagoko inpaktua izango duela azken emaitzetan. Gauza bera gertatzen da bizi zikloaren ikuspegia duen ebaluazio ekonomiko batean, non lortutako emaitzek erakusten baitute agertokien % 99ren garraio (A4) eta deuseztatze (C1-C4) etapetan sortutako inpaktuaren kuantifikazioak % 5eko baino gutxiagoko eragina izango duela azken emaitzetan.

Beste etapen garrantziari dagokionez, azterlan honetan bi birgaitze talde edo agertoki erabat desberdin finkatu dira. Batetik, agertoki jakin batzuk daude, non, birgaitze estrategiak ezarri ondoren, eraikinaren erabilera etaparen inpaktuaren murrizketa txikiagoa izango den. Hau da, erabilera etaparen (B6) pisu erlatiboa oso txikia duten agertokiak. Kasu horietan, birgaitutako beste bizi etapa batzuetan sortutako inpaktua kuantifikatzeaz gainera, beharrezkoa da kuantifikatzea bizi zikloaren beste etapa batzuetan sortutako inpaktuak, besteak beste, ekoizpena (A1-A3), eraikuntza prozesua (A5), mantentzea (B2) eta ordezkatzea (B4). Lortutako emaitzek erakusten dute, zenbait kasutan, produkzio edo ordezkatze etapako inpaktuak birgaitzearen inpaktu osoaren % 50-60 gainditu dezakeela, eta horrela, erabakiak hartzeko eta estrategien artean lehenesteko prozesuaren zutabeetako bat bihur daiteke. Gauza bera gertatzen da beste etapekin, haien inpaktuak azken inpaktu osoaren % 10 baino gehiago islatzen baitu. Hala ere, erabilera etapak duen garrantzia handiagatik, inpaktua murrizten duen bigarren talde edo agertokiak emaitzak guztiz bestelakoak islatzen ditu. Haietan ikus daiteke nola ingurumen azterlanean % 74an eta azterlan ekonomikoen % 19n, eraikinaren erabilera etapan zehar izaten den murrizketa bizi ziklo osoan eraikina birgaitu ondoren murriztutako inpaktuaren % 90etik gora dela; horrek frogatzen du bizi zikloko beste etapa guztiek (ekoizpena, garraioa, eraikuntza prozesua, mantentzea, ordezkatzea eta deuseztatzea) inpaktuaren % 10 baino gutxiago dutela. Hau da, emaitzek aditzera ematen duten bizi zikloko analisiaren irismena guztiz sinplifikatu, eta eraikinaren erabilera etapa aztertzera bakarrik mugatutako kalkuluetan lorturiko emaitzen eta bizi ziklo analisian oinarritutako kalkuluetako emaitzen arteko aldea %10ekoa baino txikiagoa izango dela.

Beraz, tesiaren lehen zatiak frogatu du sentiberatasun analisian lortzen diren emaitzen bariazioaren ondorioz, oso zaila dela bizi zikloko metodologia ezartzea eskatzen duen emaitzen zehaztasunaren eta ahaleginaren gehitzearen arteko harremana definituko duen emaitza bakar bat lortzea. Ugariak dira erabakiak hartzeko prozesuan bizi zikloaren etapen zati handi bat txertatzeko beharra islatzen duten emaitzak. Esate baterako, berokuntza egun gradu balioa 2000tik beherako duten eskualde klimatikoetan kokatuta dauden eraikinetan metodologia hau ezartzeko beharra azpimarratu da. Aitzitik, eskualde klimatiko hotzetan edo erabilera etapan zehar inpaktuaren murrizketa handia duten eskualdeetan kokatutako eraikinetako emaitzek frogatzen dute metodologia konplexu hau aplikatzeak ez diola zehaztasunik ematen azken emaitzei.

Horregatik guztiagatik, tesi honetan zehar garatu denaren antzera, beharrezkoa da birgaitze estrategien ebaluazio eta leheneste sistemen irismena ezartzea, klimaren araberako edo gaur egungo eraikuntza parkearen prestazio termiko edo energetikoen araberako gomendioetan oinarrituz. Horrela, bizi zikloan oinarritutako metodologia bakar batean, birgaitze politika berrietan, laguntza ekonomikoetan edo estatu kide bakoitzeko Energia Portaera Ziurtagiri berrietan oinarrituz agertoki bakoitzeko ezaugarri nagusiak egokitu ahal izango dira, eta, horrela, ahalik eta gehien optimizatu erabakiak hartzeko prozesu bakoitzaren errendimendua.

Tesiak proposaturiko metodologia balioztatzeko bigarren atalean, azken emaitzetan bizi zikloaren metodologiaren irismenaren sinplifikazioak duen garrantziari buruzko eztabaidarekin batera, lanean bereziki ahalegindu gara azken emaitzetan bizi zikloaren etapetako inpaktua kalkulatzeko orduan ezartzen diren inputen ziurgabetasunaren edo informaziorik ezaren eragina erakusten.

Horretarako, metodologia honetan zehar 4 inpaktu adierazle erabiliko dira: 2 ingurumen adierazle (berriztagarria ez den oinarrizko energia inpaktuaren murriztea eta energia gabi ratioa), eta 2 ekonomia adierazle (barne errendimenduaren tasa eta bizi zikloko inbertsioaren berreskuratze epea). Aurrez aipaturiko Donostiako eraikin berbera eta lanean zehar zehazturiko birgaitze estrategiak oinarri harturik, 4 adierazleentzako emaitzak lortu dira, eta estrategien artean lehenetsi, eta azken erabaki bat hartzeko beharrezko informazioa lortu da. Lortutako emaitzek erakusten dute birgaitze estrategien artean lehentasunak ezartzeko orduan erabilitako adierazleen balioak nabarmen alda daitezkeela, zenbaitetan % ±200eko desbideratzeetara iritsi baitaitezke. Hala ere, desbideratze horiek ez dute bizi zikloaren analisiaren kalitate apala edo emaitzen zehaztasunik eza erakusten. Besterik gabe, hainbat alderdiri buruzko ziurgabetasuna erakusten dute, besteak beste, BZA datuen iturria, energiaren prezioaren bariazioa, eraikinaren bizi baliagarriaren balioa edo bizi zikloan zehar eraikin baten eskari energetikoak jasango duen bilakaera.

Horrez gain, oraindik ere bizi zikloa osatzen duten etapa askoren inguruko informazio gabezia islatu da. Adibidez, ekoizpenaren etapari dagokionez, garatzen ari diren Produktuaren Ingurumen Adierazpenen (PIA) kopuruaren gehikuntza nabaria izan arren, oraindik ere EBko herrialde askotan ia ezinezkoa da birgaitze estrategietan erabiltzen diren produktu eta sistemen informazioa eskuragarri izatea (Espainiako adibidea). Alderdi horrez gain, oso zaila da oraindik ere bizi zikloaren beste etapa edo prozesu askoren ingurumen eta ekonomia informazio xehatua lortzea, azterlanaren sarrera datuen atal nagusi bat datu base orokorretan oinarritzen baita.

Horregatik, “ondorengo lanak” atalean erakusten den bezala, tesi honen bitartez honako alderdi hauek azpimarratu nahi dira: datuen kalitatea hobetu egin behar da, zabaldu egin behar da edukia, estatu kide bakoitzeko eraikuntza eta energia osagaien datu baseen barruan bizi zikloko etapen ingurumen eta ekonomia informazioarekin, eta politika berriak txertatu behar dira birgaitu beharreko eraikin baten bizi zikloa osatzen duten prozesu guztietan sortutako inpaktuaren kuantifikazioa errazteko asmoz. Modu estandarizatuan eta normalizatuan inpaktuen kuantifikazioa egiteko politika berri horiek egungo ziurgabetasun handia murrizten utziko dute, eta bizi zikloko metodologia hau txertatzen lagunduko dute, eraikinen birgaitze energetikorako estrategiak lehenesteko prozesu berrietan zehar.

Gako-hitzak: eraikinen birgaitze energetikoa, bizi zikloaren ingurumen eta ekonomi analisia, ebaluazio irismenaren optimizazio, irizpide anizdun leheneste prozesua, datuen kalitatea, ziurgabetasuna, mozte arauak.

RESUMEN

En base a las nuevas limitaciones del comportamiento energético determinados por la directiva 2010/31/EU (art 9: edificios casi cero energía), los edificios serán cada vez más eficientes energéticamente y su impacto durante la etapa de uso será reducida, aumentando la relevancia del impacto medio ambiente y económico de las otras etapas del ciclo de vida. En este contexto, según la Comisión Europea (*CEC, 2014a; CEC, 2014b*) o estudios relacionados con el "Edificio Cero Energía durante el Ciclo de Vida (*Hernandez & Kenny, 2010*), la metodología del ciclo de vida podría ser el mejor marco disponible para evaluar la impacto ambiental y económico de los edificios que se construirán a partir de 2018.

Sin embargo, el escenario que se propone durante este trabajo de investigación no se centra en proponer ninguna metodología para evaluar el comportamiento de los nuevos edificios, sino que el objetivo de este trabajo es proponer la metodología de evaluación más adecuada que permita tomar decisiones a la hora de seleccionar entre las diferentes estrategias de rehabilitación energética de edificios.

Dentro del análisis del estado del arte sobre la rehabilitación energética de los edificios, durante el segundo capítulo de la tesis se han analizado las características de los diferentes sistemas de evaluación actuales para rehabilitaciones. Tras la evaluación del potencial y debilidad de cada sistema, este trabajo ha justificado la decisión de evitar el uso de los sistemas voluntarias de evaluación de la sostenibilidad durante este trabajo. Por lo tanto, se ha propuesto que la línea base de la metodología que se propondrá se centre exclusivamente en los sistemas de evaluación cuantitativos estandarizados del mercado actual. Es decir, basar la metodología en un sistema que permita cuantificar los impactos ambientales y económicos y que mediante la aplicación de diferentes indicadores de impacto permita tomar las decisiones finales.

Esta decisión inicial conlleva a definir una de las preguntas clave de esta tesis, el cual formará parte de un elevado apartado de las conclusiones finales: A la hora de priorizar entre las diferentes estrategias de rehabilitación energética del edificio, ¿es necesario cuantificar el impacto generado durante todas las etapas del ciclo de vida del edificio o sería suficiente con cuantificar el impacto relacionado con la etapa de uso? ¿Hasta qué punto se puede simplificar el “alcance del sistema de evaluación” sin poner en riesgo el rigor de los resultados y las decisiones derivadas? ¿Cuál es la relación entre el incremento de la “precisión” de los resultados finales tras aplicar esta metodología y el esfuerzo y tiempo (inversión económica) que supone integrar esta metodología durante todo el proceso de rehabilitación?

Con el objetivo de buscar una respuesta a estas preguntas, en base a los estándares EN 15978 y prEN 16627 (reglamentos para el análisis ambiental y económico de edificios mediante la metodología de ciclo de vida), este trabajo de investigación ha propuesto una metodología cuantitativa, permitiendo la evaluación del impacto generado durante cada una de las etapas del ciclo de vida de una rehabilitación energética de un edificio.

La validación de la metodología propuesta se ha realizado a través de un edificio construido en San Sebastián en 1963. En base a la geometría del edificio y las características constructivas y funcionales definidas, junto con la cuantificación del impacto ambiental y económico del edificio actual y del edificio tras ser rehabilitado mediante las diferentes estrategias, se ha cuantificado el impacto generado en cada una de las etapas del ciclo de vida. De esta forma, en base al criterio de cálculo que permite la optimización del sistema de evaluación, se ha calculado el porcentaje de impacto de cada etapa respecto al impacto global reducido en el edificio rehabilitado durante su ciclo de vida del edificio, permitiendo reflejar la relevancia de cada una de ellas. Sin embargo, viendo los inconvenientes que puede generar a la aplicación de estos resultados basados en un único caso de estudio como resultados globales de simplificación del alcance del sistema, el trabajo propone un exhaustivo análisis de sensibilidad donde se proponen nuevos escenarios relacionados con la mayoría de los parámetros que influyen de forma directa en la metodología de cálculo. Entre otras, se han definido nuevos valores relacionados con parámetros como la vida útil del edificio (RSL_b), vida útil estimado de los productos (ESL_m), datos de energía embebida (EE), incremento del precio de la energía (EPI), distancia de transporte de los productos (D_m), zona climática, demanda energética (OE), tasa de inflación (IR) y el factor de conversión ambiental (CF). Tras realizar el análisis de todos los nuevos escenarios definidos mediante estos nuevos datos (775 escenarios medioambientales y 682 escenarios económicos), los resultados obtenidos permiten alcanzar una respuesta respecto la relación entre el incremento de la precisión de los resultados y la cuantificación de todas las etapas del ciclo de vida.

La primera conclusión muestra que en el 98% de los escenarios ambientalmente evaluados (según el alcance de esta metodología), la cuantificación del impacto generado durante las etapas de transporte (A4), puesta en obra (B5) y fin de vida (C1-4) influirá menos del 1% en los resultados finales. Lo mismo sucede en una evaluación económica con perspectiva de ciclo de vida, donde los resultados muestran que la cuantificación del impacto generado durante las etapas de transporte (A4) y fin de vida (C1-4) del 99% de los escenarios influirá menos del 5% en los resultados finales.

Respecto a la relevancia de las otras etapas, este estudio ha determinado dos grupos o escenarios de rehabilitación totalmente diferentes. Por una parte están los escenarios donde tras la aplicación de las diferentes estrategias de rehabilitación la reducción del impacto de la etapa de uso del edificio sea menor. Es decir, aquellos donde el peso relativo de la etapa de uso es muy pequeño. En estos casos, junto con cuantificar el impacto reducido durante la etapa de uso (B6) del edificio rehabilitado, resulta necesario cuantificar el impacto generado en otras etapas del ciclo de vida como la producción (A1-3), puesta en obra (A5) (solo en análisis económicos), mantenimiento (B2) y remplazamiento (B4). Los resultados obtenidos muestran que en algunos casos el impacto de la etapa de producción o remplazamiento puede llegar a superar el 50-60% del impacto total de la rehabilitación, convirtiéndose en uno de los pilares del proceso de toma de decisiones y priorización entre estrategias. Lo mismo sucede con las otras etapas, cuyo impacto refleja más del 10% del impacto final total.

Sin embargo, el segundo grupo o escenario donde la reducción de los impactos es muy elevada debido a la gran importancia de la etapa de uso refleja unos resultados totalmente diferentes. En ellas se puede ver como en el 74% de los estudios ambientales y el 19% de los estudios económicos, la reducción del impacto durante la etapa de uso del edificio refleja más del 90% del impacto reducido tras rehabilitar el edificio durante su ciclo de vida, demostrando que todas las otras etapas del ciclo de vida (producción, transporte, puesta en obra, mantenimiento, remplazamiento y fin de vida) reflejan menos del 10% del impacto. Es decir, estos resultados muestran que en este tipo de escenarios la diferencia de resultados obtenidos entre los cálculos basados en la metodología de ciclo de vida y una metodología donde su alcance se limita únicamente a la evaluación de la etapa de uso, será menor del 10%.

Por lo tanto, la primera parte de la tesis ha demostrado que debido a la variación de resultados que se obtienen del análisis de sensibilidad, resulta muy difícil obtener un único resultado que defina la relación entre la exactitud de los resultados y el incremento del esfuerzo que supone aplicar la metodología de ciclo de vida. Son numerosos los resultados que reflejan la necesidad de integrar gran parte de las etapas del ciclo de vida durante la toma de decisiones. Por ejemplo, se destaca la necesidad de aplicar esta metodología en edificios a rehabilitar ubicados en zonas climáticas cuyo valor de Grados Día sea inferior a 2000. De lo contrario, los resultados de los edificios rehabilitados ubicados en zonas climáticas frías o edificios con gran reducción del impacto durante su etapa de uso demuestran que aplicar esta metodología compleja no aporta rigurosidad en los resultados finales.

Por todo ello, de modo similar a lo que se ha desarrollado durante esta tesis, se refleja la necesidad de fijar el alcance del sistema de evaluación y priorización de las estrategias de rehabilitación en base a recomendaciones por clima o prestaciones térmicas o energéticas del parque edificatorio existente. De esta forma, en base a una única metodología basada en el ciclo de vida, las nuevas políticas de rehabilitación, regulaciones, ayudas económicas o los nuevos sistemas de certificación energética de cada estado miembro podrán ser adaptadas a las características generales de cada escenario, optimizando al máximo el rendimiento de cada proceso de toma de decisiones.

Durante la segunda parte de la validación de la metodología propuesta durante la tesis, junto con la discusión sobre la relevancia de la simplificación del alcance de la metodología de ciclo de vida en los resultados finales, un elevado esfuerzo del trabajo se ha centrado en mostrar la influencia de la incertidumbre o carencia de información de los inputs que se aplican a la hora calcular el impacto de las diferentes etapas del ciclo de vida en los resultados finales

Para ello, esta metodología propone el uso de 4 indicadores de impacto: 2 ambientales (reducción de la energía primaria no renovables y Net Energy Ratio) y 2 económicos (tasa interna de rentabilidad y retorno de la inversión durante el ciclo de vida). En base al mismo edificio de San Sebastián mencionado con anterioridad y las estrategias de rehabilitación definidos durante el trabajo, se han calculado los resultados para los 4 indicadores, obteniendo la información necesaria para poder priorizar entre las diferentes estrategias de rehabilitación y tomar una decisión final.

Los resultados obtenidos muestran que los valores de los diferentes indicadores de impacto utilizados a la hora de priorizar entre las diferentes estrategias de rehabilitación pueden variar notablemente, llegando a mostrar desviaciones de ±200% o mayores. Sin embargo, estas desviaciones no muestran la baja calidad del análisis de ciclo de vida o la carencia de rigor de los resultados. Simplemente es el reflejo de la incertidumbre sobre aspectos como la fuente de datos de Análisis de Ciclo de Vida (datos de proceso, input-output o híbrido), variación del precio de la energía, el valor de vida útil del edificio o la evolución que sufrirá la demanda energética de un edificio durante su ciclo de vida.

A su vez, se ha destacado la carencia de información que existe aún sobre muchas de las etapas que forman el ciclo de vida. Por ejemplo, respecto a la etapa de producción, aunque cada vez se estén desarrollando nuevas Declaraciones Ambientales de Producto (DAP) de los productos y sistemas que se aplican en las diferentes estrategias de rehabilitación energética, aún resulta muy difícil disponer de esta información en muchos países de EU (por ejemplo España). Junto con este punto, aún resulta muy difícil obtener información ambiental y económica detallada de muchos procesos y etapas del ciclo de vida, teniendo que aplicar valores de bases de datos muy genéricos.

Es por ello, que como se muestra en la sección de “siguientes trabajos”, desde esta tesis se hace hincapié en que hay que mejorar la calidad de datos, ampliar el contenido con información ambiental y económica de las diferentes etapas del ciclo de vida dentro de las bases de datos de los elementos constructivos y sistemas energéticos de cada estado miembro e integrar nuevas políticas que faciliten la cuantificación del impacto generado en todos los procesos que formen parte del ciclo de vida de un edificio a rehabilitar. Estas nuevas políticas de cuantificación de impactos de forma estandarizada y normalizada permitirán reducir la elevada incertidumbre actual y facilitará la integración de la metodología de ciclo de vida durante los nuevos procesos de priorización de estrategias de rehabilitación energética de edificios.

Palabras claves: rehabilitación energética de edificios, análisis de ciclo de vida ambiental y económico, optimización del alcance de la evaluación, toma de decisiones multicriterio, calidad de datos, incertidumbre, reglas de corte.

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Table of contents / *Gaien aurkibidea*

Table of figures / *Irudien aurkibidea*

Table of tables / *Taulen aurkibidez*

Nomenclature / *Nomenklatura*

A_m	Surface of the constructive element *m* (m^2) / *m itxituraren azalera (m^2).*
AEU1	Annual operational stages Energy Uses impact of the baseline / *Oinarrizko eraikinaren erabilera etaparen urteko energia erabileraren inpaktua.*
AEU2	Annual operational stages Energy Uses impact of the refurbished building / *Eraikin birgaituaren erabilera etaparen urteko energia erabileraren inpaktua.*
AEE1	Annual Embodied Energy embodied energy impact of the baseline / *Oinarrizko eraikinaren urteko barne energiaren inpaktua.*
AEE2	Annual Embodied Energy impact of the materials and systems applied during the refurbishment strategy / *Birgaitze estrategian erabilitako material eta sistemen urteko barne energiaren inpaktua*
B_{B6}	Baseline operational energy use stages impact / *Oinarrizko eraikinaren erabilera etaparen inpaktua.*
B_{B6_EN}	Baseline operational energy use stages environmental impact / *Oinarrizko eraikinaren erabilera etaparen ingurumen inpaktua.*
B_{B6_EC}	Baseline operational energy use stages economic impact / *Oinarrizko eraikinaren erabilera etaparen inpaktu ekonomikoa.*
BZA	*Bizi zikloaren analisia* / Life Cycle Assessment.
BZI	*Bizi zikloaren inbentarioa* / Life Cycle Inventory.
C_n	Cost in year n / *n-garren urteko kostua.*
CC_m	Economic impact associated to installation process of each refurbishment strategy / *Birgaitze estrategia bakoitzaren muntadura prozesuari loturiko inpaktu ekonomikoa.*
CDD	Cooling degree days / *Hozteko egun gradua.*
CED	Cooling annual energy demand / *Urteko hozkuntza energia eskaria.*
CF_y	Conversion factor of the energy source / *Energia iturriaren konbertsio faktorea.*
d	Expected real discount rate per annum / *Aurreikusitako urteko deskontu tasa erreala.*
D_m	Product and systems transport distance (km) / *Produktu eta sistemen garraiatze distantzia (km).*
DL_b	Distribution energy losses / *Banaketan galdutako energia.*
DW_m	Transport distance of waste from site to waste management facility (km) / *Hondakinen garraio distantzia eraikinetik hondakinen kudeaketa gunera (km).*
EU	European Union / *Europar Batasuna (EB).*
EC_m	Economic cost of each *m* material and system applied during the improvement actuation, expressed per unit of material or system / *Birgaitze prozesuan erabilitako m material edo sistemaren kostu ekonomiko edo prezioa, material edo sistema bakoitzaren unitatearekiko adierazia.*
EC_t	Economic cost of the transport process per t and km / *Garraiatze prozesuaren kostu ekonomikoa (tona eta km-ko).*
ECO	Economic / *Ekonomikoa.*

ECW_t	Economic impact of the waste management proccess (€/kg) / *Hondakinen kudeaketa prozesuaren inpaktu ekonomikoa (€/kg).*
ED_b	Baseline operational annual energy demand / *Oinarrizko eraikinaren erabilera etaparen urteko energia eskaria.*
EE_m	Embodied environmental impact of each *m* material and system applied during the improvement actuation, expressed per unit of material or system (in kg, m^2 or m^3) / *Birgaitze prozesuan erabilitako m material edo sistemaren ingurumen barne inpaktua, material edo sistema bakoitzaren unitatearekiko adierazia (kg, m^2 edo m^3).*
EL_{C1-4_EC}	Economic impact associated to end of life stage of each refurbishment strategy / *Birgaitze estrategia bakoitzaren deuseztapen etaparen inpaktu ekonomikoa.*
EL_{C1-4_EN}	Environmental impact associated to end of life stage of each refurbishment strategy / *Birgaitze estrategia bakoitzaren deuseztapen etaparen ingurumen inpaktua.*
EMP_m	Estimated Maintenance Period of each refurbishment strategy / *Birgaitze estrategia bakoitzaren aurreikusitako mantentze periodoa.*
ENV	Environmental / *Ingurumen.*
ENW_m	Environmental impact of the waste management process / *Hondakinen kudeaketa prozesuaren ingurumen inpaktua.*
EP_y	Price of the energy source (€) / *Energia iturriaren prezioa (€).*
EPBD	Energy Performance of buildings directive / *Eraikinen eraginkortasun energetikoaren inguruko zuzentaraua.*
EPC	Energy Performance Certification / *Energia Portaera Ziurtagiria (EPZ).*
EPD	Environmental Product Declaration / *Produktuaren Ingurumen Adierazpena (PIA).*
EPI_y	Price Increment of the energy source (%) / *Energia iturriaren prezioaren igoera (%).*
ESL_b	Estimated service life of the material (years) / *Aurreikusitako erabilera bizitza (urteak).*
FU	Functional Unit of the case study / *Landutako kasuaren unitate funtzionala.*
HDD	Heating degree days / *Berokuntzako egun gradua.*
HED	Heating annual energy demand / *Urteko berokuntza energia eskaria.*
HS	Heated surface (m^2) / *Berotutako azalera (m^2).*
HVAC	Heating, ventilation and air condition / *Berokuntza, aireztapena eta hozkuntza (BAH).*
IA_t	Environmental impact of the transport process per t and km / *Garraiatze prozesuaren ingurumen inpaktua (tona eta km-ko).*
IC_{A1-3}	Initial economic cost of each refurbishment strategy / *Birgaitze estrategia bakoitzaren hasierako kostu ekonomikoa.*
ICC_{A5}	Initial economic impact associated to the construction stage of each refurbishment strategy / *Birgaitze estrategia bakoitzaren eraikuntza prozesuaren hasierako inpaktu ekonomikoa.*
ICE_{A5}	Initial environmental impact associated to the construction stage of each refurbishment strategy / *Birgaitze estrategia bakoitzaren eraikuntza prozesuaren hasierako ingurumen inpaktua.*

$IEE_{A1\text{-}3}$	Initial embodied environmental impact of each refurbishment strategy / *Birgaitze estrategia bakoitzaren hasierako ingurumen barne inpaktua.*
IR	Inflation rate (%) / *Inflazio tasa (%).*
IRR	Internal Rate of Return / *Barne itzulera tasa.*
ITC_{A4}	Initial transportation economic impact associated to each refurbishment strategy / *Birgaitze estrategia bakoitzaren garraiatze prozesuaren hasierako inpaktu ekonomikoa.*
ITE_{A4}	Initial transportation environmental impact associated to each refurbishment strategy / *Birgaitze estrategia bakoitzaren garraiatze prozesuaren hasierako ingurumen inpaktua.*
k	Refurbishment strategies / *Birgaitze estrategiak.*
LCA	Life Cycle Assessment / *Bizi zikloaren analisia.*
LCC	Life Cycle Costing / *Bizi zikloaren ekonomia analisia.*
LCI	Life Cycle Inventory / *Bizi zikloaren inbentarioa.*
LCIA	Life Cycle Inventory Assessment / *Bizi zikloaren inpaktuen ebaluazioa.*
LC-PB	Life Cycle PayBack / *Bizi zikloko berreskurapen epea.*
MC_{B2}	Economic impact associated to maintenance process of each refurbishment strategy / *Birgaitze estrategia bakoitzaren mantentze prozesuaren inpaktu ekonomikoa.*
MC_m	Maintenance economic cost of each refurbishment strategy / *Birgaitze estrategia bakoitzaren mantentzearen kostu ekonomikoa.*
MCVSE	Multi-Criterial Voluntary Sustainability Evaluation / *Borondatezko Irizpide Anitzeko Jasangarritasun Ebaluazioa (BIAJE).*
n	Number of years between the base date and the occurrence of the cost / *Oinarri data eta kostua gertatuko den arteko urte kopurua.*
NER	Net Energy Ratio / *Energi ratio netoa.*
NPV_a	Net Present Value at r_a / r_a *puntuan uneko balio garbia.*
NPV_b	Net Present Value at r_b / r_b *puntuan uneko balio garbia.*
p	Period of analysis / *Analisi iraupena.*
ρ	Performance of the energy generation system (%) / *Energia sortzeko m sistemaren eraginkortasun energetikoa (%).*
PIA	*Produktuaren Ingurumen Adierazpena* / Environmental Product Declaration.
q	Discount factor / *Deskontu faktorea.*
Q_m	Quantity of materials and systems in each refurbishment strategy (kg-m^2-m^3) / *Birgaitze estrategia bakoitzeko material eta sistemen zenbatekoa (kg-m^2-m^3).*
Q_{mt}	Quantity of materials and systems in each refurbishment strategy (t) / *Birgaitze estrategia bakoitzeko material eta sistemen zenbatekoa (t).*
r_a	Lower discount rate / *Deskontu tasa baxua.*
r_b	Higher discount rate / *Deskontu tasa altua.*
$R_{A1\text{-}3}$	Impact generated during the product stage / *Ekoizpen etapan sorturiko inpaktua.*
R_{A4}	Impact generated during the transportation stage / *Garraiatze etapan sorturiko inpaktua.*

R_{A5} Impact generated during the construction process stage / *Eraikuntza prozesuaren etapan sorturiko inpaktua.*

R_{B2} Impact generated during the maintenance stage / *Mantentze etapan sorturiko inpaktua.*

R_{B4} Impact generated during the replacement stage / *Ordezkapen etapan sorturiko inpaktua.*

R_{B6} Refurbished building operational energy use stages impact / *Birgaitutako eraikinaren erabilera etaparen inpaktua.*

R_{B6_EC} Refurbished building operational energy use stages economic impact / *Birgaitutako eraikinaren erabilera etaparen inpaktu ekonomikoa.*

R_{B6_EN} Refurbished building operational energy use stages environmental impact / *Birgaitutako eraikinaren erabilera etaparen ingurumen inpaktua.*

R_{C1-4} Impact generated during the end of life stage / *Deuseztapen etapan sorturiko inpaktua.*

RC_{B4} Recurrent economic cost of each refurbishment strategy / *Birgaitze estrategia bakoitzaren ordezkapenaren kostu ekonomikoa.*

RCC_{B4} Recurrent economic impact associated to installation process of each refurbishment strategy / *Birgaitze estrategia bakoitzaren muntadura prozesuari loturiko ordezkapenaren inpaktu ekonomikoa.*

RCE_{B4} Recurrent environmental impact associated to construction waste management of each refurbishment strategy / *Birgaitze estrategia bakoitzaren muntadura prozesuan sorturiko hondakinen kudeaketa prozesuari loturiko ordezkapenaren inpaktu ekonomikoa.*

RE_k Renewable energy generated by refurbishment strategies / *Birgaitze estrategien bidez sorturiko energia berriztagarria.*

REE_{B4} Recurrent embodied environmental impact of each refurbishment strategy / *Birgaitze estrategia bakoitzaren ordezkapenaren barne energiaren ingurumen inpaktua.*

RSL_b Reference service life of the building (years) / *Eraikinaren erabilera bizitza (urteak).*

RTC_{B4} Recurrent transport economic impact associated to each refurbishment strategy / *Birgaitze estrategia bakoitzaren garraiatze prozesuaren ordezkapenaren inpaktu ekonomikoa.*

RTE_{B4} Recurrent transport environmental impact associated to each refurbishment strategy / *Birgaitze estrategia bakoitzaren garraiatze prozesuaren ordezkapenaren ingurumen inpaktua.*

SLCA Social Life Cycle Assessment / *Bizi zikloaren analisi soziala.*

U_m Thermal transmittance of the envelope element (W/(m^{2}k)) / *Itxitura elementuaren transmitantzia termikoa (W/(m^{2}k)).*

WP_m Percentage of waste generated in each refurbishment strategy (%) / *Birgaitze estrategia bakoitzean sorturiko hondakin portzentaia (%).*

CHAPTER 0 – STRUCTURE

Thesis structure scheme

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0. ATALA – EGITURA

Tesiaren egituraren eskema

0. Thesis structure scheme / *Tesiaren egituraren eskema*

The research work developed during this thesis will consists of 6 general sections. During the first section it will be developed a small global reading of the state of the existing European building and cities. It will be detected their different weaknesses and problems related to amongst others with air quality, mobility, aging or the high energy consumption of existing buildings.

The second section will focus on evaluating different aspects such as the definition, benefits, strategies, policies and methodologies for assessing the performance of energy refurbishments that it was developed in recent decades in Europe.

After completing the analysis of the state of art, during the third section the author makes a critical review of various points evaluated during the second point of the study. The author will propose a new concern on the need to reach a consensus in which should be the appropriate methodology to assess different strategies for energy refurbishment of buildings.

With the idea and objective of work defined, the fourth section is based on defining the structure and content of the new methodology. In this manner, based on the life cycle approach and on the application of different

Tesi honetan garatutako ikerketa lana 6 puntu orokorretan banatzen da. Lehenengo zatian, hiri eta eraikin europarren gaur egungo egoeraren irakurketa orokor bat garatzen da, airearen kalitatea, mugikortasuna, gizartearen zahartzea eta eraikinen kontsumo energetiko handiarekin loturiko gabeziak eta arazoak antzemanez.

Bigarren atala eraikinen birgaitze energetikoaren inguruko definizioa, onurak, estrategiak, araudiak eta birgaitze hauen portaera lantzeko sorturiko metodologia desberdinen inguruan oinarrituko da.

Artearen egoeraren analisia burutu ondoren, hirugarren zatian zehar, bigarren zatian ebaluatutako zenbait punturen berraztertze kritikoa egiten da. Berraztertze honek kezka berri batera eramaten du ikerkuntza lana: eraikinen birgaitze energetikoen estrategiak aztertzeko metodologia egokiena zein izango litzatekeen adostu behar da.

Lanaren ideia eta helburua definitu ondoren, laugarren zatian, ikerketa lan honetan zehar proposatuko den metodologia berriaren egitura eta edukia zehazten dira. Era honetan, bizi zikloaren ikuspegian oinarrituz eta ingurumen eta ekonomia adierazle ezberdinak aplikatuz, hainbat aktoreri aukera emango zaie eraikinen birgaitze environmental and economic impact indicators, the stakeholders will be given the opportunity to assess between the different strategies for the energy refurbishment of buildings, evaluate their impacts and prioritize between them.

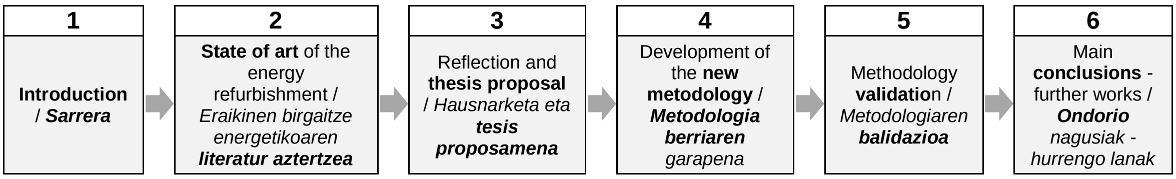
During the fifth section this new methodology will be validated through the analysis of a case study, where through a thorough sensitivity analysis, the results will allow to define different final conclusions shown in the sixth section.

Finally, together with the conclusions, the author will proposes a new line of work related to the conclusions reached during the development of this work.

energetikoko estrategia ezberdinak aztertu, hauek sorturiko inpaktuak zenbatu eta beraien artean lehenesteko.

Bosgarren zatian, metodologia berri hau balioztatuko da eraikin baten birgaitzearen analisiaren bidez. Hemen lortutako emaitzen ondorioz, sentsibilitate azterketa sakon baten bidez, seigarren zatian azaldutako amaierako ondorio ezberdinak definituko dira.

Azkenik, autoreak lortutako ondorioekin zerikusia duten eta lan honen garapenaren ondorioz sortutako azterketa bide berriak proposatuko dira.



CHAPTER 1 – INTRODUCTION

Overview of the current building stock and cities

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1. ATALA – SARRERA

Gaur egungo eraikinen eta hirien erradiografia orokorra

1. Overview of the current building stock and cities / *Gaur egungo eraikinen eta hirien erradiografia orokorra*

A comprehensive diagnosis of the existing European cities clearly reflects an urgent need for action with regards to their different components. The age of cities, neighbourhoods and buildings is increasing; the mechanical, thermal, energy or functional services of existing buildings, urban spaces and infrastructures are becoming deteriorated; and there is an ever growing scarcity when it comes to adapting these urban, architectural or technological components in order to meet society's needs.

The activity increase in cities, the migration of people from rural areas into urban areas, the mobility system, the low energy awareness of stakeholders, the change of the socioeconomic system, the fact that we put the economic power before environmental and social aspects, the new needs of new generations, etc. have led to the existence of critical and pain points within the defining system of cities, including aspects related to social adjustment problems, cities air pollution, energy poverty, technical deficiencies or high energy consumption.

Gaur egungo hiri europarren diagnosi orokor batek argi eta garbi adierazten du hirien osagai ezberdinetan premiaz esku hartzeko beharra. Hirien, auzoen eta eraikinen adina gorantz doa eta ondorioz, eraikinen, hiri espazioen eta azpiegituren ezaugarri mekanikoak, termikoak, energetikoak eta funtzionalak hondatzen ari dira. Honekin batera, gero eta gabezia gehiago daude hirietako elementu arkitektoniko edo teknologikoak gizartearen behar berrietara egokitzeko.

Hirietako aktibitatearen igoerak, herrietatik hirietarako biztanleriaren mugimenduak, mugikortasun sistemak, erabiltzaileen sentsibilitate energetiko baxuak, sistema ekonomiko - sozialaren aldaketak, ingurugiroa eta gizartearen aspektuen aurrean dagoen indar ekonomikoak, etab. hiria osatzen duen sistemaren barruan puntu ahul eta kritikoen sorkuntzan eragin nabarmena izan du. Hauen artean azpimarratu beharrekoak dira irisgarritasun arazoak, gizarte egokitzapena, hirietako airearen kutsadura, pobrezia energetikoa, urritasun teknikoak edo kontsumo energetiko altua.

Figure / Irudia 1 Scheme of some of the critical aspects of the current cities / *Gaur egungo hirien puntu kritiko ezberdin batzuen eskema.*

Accesibility in building, district and infraestructures

Accessibility is the degree to which a product, device or service is available to as many people as possible (*United Nation, 2006*). The disability rights movement advocates equal access to social, political, and economic life which includes not only physical access but access to the same tools, services, organizations and facilities for which everyone pays.

Although there are barriers such as technology, labour, health, transport or education itself, this thesis evaluates only barriers related to the architectural elements of a city and its buildings. That

Eraikin, auzo eta azpiegituretako irisgarritasuna

Produktu, gailu edo zerbitzuak jendearentzako eskuragarri duten maila neurtzen du irisgarritasunak (United Nation, 2006). “Ezintasunaren eskubide mugimenduak” bizitza sozial, politiko eta ekonomikoan eskuragarritasun berdintasuna defendatzen du, ez bakarrik eskuragarritasun fisikoa, baizik eta eskuragarritasuna edukitzea tresna, zerbitzu, erakunde eta instalazio guztietara.

Nahiz eta teknologian, lanean, osasunean, garraioan edo hezkuntzan oztopo ezberdinak egon, lan honek hiri eta eraikinetako elementu is, any architectural barriers that limit the free movement of people.

Building accessibility

Accessible housing refers to the construction or modification of housing to enable independent living for persons with disabilities. Accessibility is achieved through architectural design, but also by integrating accessibility features such as modified furniture, shelves and cupboards, or even electronic devices in the home. Most existing and new housing, even in the wealthiest nations, lack basic accessibility features unless the designated, immediate occupant of a home currently has a disability. However, there are some initiatives to change typical residential practices so that new homes incorporate basic access features such as zero-step entries and door widths adequate for wheelchairs to pass through.

In a building, there are several points where you have to be careful with the accessibility: building entrance on a route; common and public use areas; doors usable by a person in a wheelchair; route into and through the dwelling unit; light switches, electrical outlets, thermostats and other environmental controls in accessible locations; reinforced walls in bathrooms for later installation of grab bars, and usable kitchens, bedrooms and

arkitektonikoekin erlazionatutako oztopoak bakarrik aztertuko ditu. Hau da, pertsonen mugimenduen askatasuna murrizten duten oztopoak.

Eraikinetako irisgarritasuna

Etxebizitza irisgarriei buruz hitz egiten denean, ezintasunen bat duten pertsonek bizitza guztiz independentea eraman dezaketen guneei buruz ari gara. Irisgarritasuna altzari edo gailu egokituez gain, batez ere diseinu arkitektoniko egoki baten bidez lortzen da. Eraikin zaharrek eta berriek oinarrizko irisgarritasun gabezia ugari dituzte. Hala ere, arautegi eta kontzientziazio ekintzen bidez aurrerapausoak ematen ari dira. Honen adibide da gaur egungo etxeek sarrera irisgarriak dituztela eta ateen zabalerak gurpildun aulkiak pasatzeko prestatuak daudela.

Eraikin batean irisgarritasunaren inguruan arreta berezia behar duten puntu ugari daude, adibidez: sarrera eta ibilbideak, gune publikoak, gurpildun aulkientzako ateak, etxebizitzaren ateraino doan ibilbidea, argi etengailuak, termostatoa eta ingurunea kontrolatzeko gailuen posizioa, komunetan barra zurrunak jarri ahal izateko horma indartuen aplikazioa edo sukalde, logela eta bainugela irisgarrien diseinua. Hau guztia kontuan izanik, XX. mendearen erdialdetik aurrera, Europar Batasunak gaur egungo gizartearen parte diren pertsona guztiei eguneroko bizitza bathrooms. Therefore, since the mid-twentieth century, the European Union has insisted on the need to establish regulations or guidelines to facilitate daily life to all kinds of people who make up our society, guidelines that allow remove architectural barriers... These guidelines include the Law on Social Integration of the Disabled, which provides the necessary resources to undertake the reforms to allow the autonomy to those people limited in their functionality and other, to raise public awareness of the urgency of universal design accessible to everyone.

Difficulties in adapting the buildings and neighbourhoods to the new user

The European Union's population structure is changing and becoming progressively older. Europeans are living longer and healthier lives than ever before and this pattern is expected to continue on the back of continued medical breakthroughs and improved standards of living.

We are at the start of a population phenomenon that is modifying demographic structures and it has wide social, economic, energy and cultural implications. It is a silent revolution advancing along the XXI century and it demands major changes in our society regarding the group protagonist of the population: the elderly.

A steady increase in life expectancy

erraztuko dien araudi eta legedi ezberdinak garatzearen alde dihardu lanean, oztopo arkitektonikoak ezabatzeko zuzenbide ezberdinak proposatuz. Hauen artean azpimarratzekoa da Ezgaituen Integrazio Sozialaren Legea. Zuzenbide honetan, pertsonen autonomia ziurtatzeko beharrezko diren erreformak burutzeko baliabideak eskaintzen dira eta gizarteari irisgarritasun unibertsala guztiontzat beharrezkoa dela erakusten zaio.

Etxebizitzak eta auzoak erabiltzaile berrietara egokitzeko zailtasunak

Europar Batasuneko biztanleriaren egitura aldatuz doa eta apurka gero eta zaharragoa bihurtzen ari da. Europarrak gero eta urte gehiagoz bizi dira eta sanoago daude eta medikuntzako aurrerapenak eta bizi maila hobeagoa dela eta, horrela jarraituko dela espero da.

Fenomeno edo egitura sozialaren aldaketa honek eragin sozial, ekonomiko, energetiko eta kultural nabarmena du. XXI. mendean zehar aurreraka doan iraultza isil bat da eta gizartean aldaketa garrantzitsuak eskatzen ditu protagonista bihurtzen doan biztanle talde berriarentzat: pertsona adinduak.

Azkenengo mendean zehar Europar

across the EU during the last century led to increased longevity, while in more recent decades the EU has experienced falling fertility rates. These two developments impact upon demographic ageing, a process that has become established in the EU in the last 30 or 40 years and which is expected, by many, to become further entrenched during the next half century, as the absolute number and the relative importance of the population of older persons continues to grow.

In 2010, according to Eurostat data (Eurostat, 2008), in the European Union (EU-27) the percentage of persons aged 65 or over reached the 17.4% of the population (87 million persons). These data can be compared with data from 1 January 1985, when there were 59.3 million persons aged 65 and over in the EU-27 (12.8% of the total population).

Batasunean bizi itxaropena gero eta handiagoa da eta bestalde, ugalkortasun tasek behera egin dute. Bi eragile hauek azken 30 edo 40 urteetan zehar demografia garatzen ari den aldaketan zerikusi zuzena dute eta datu berrien arabera, prozesu edo gizarte aldaketa honek bide berdina jarraituko duela dirudi, gizarteko pertsona zaharren zenbaki absolutua eta garrantzia areagotuz

2010ean, Eurostateko datuen arabera (Eurostat, 2008) Europar Batasunean (EB-27) 65 urtetik gorakoen ehunekoa biztanleriaren %17.4 zen (87 milioi pertsona). Datu hauek 1985eko urtarrilaren 1eko datuekin alderatuz gero, ikus daiteke nola orain dela 30 urte biztanleriaren %12,8a 65 urtetik gorakoa zen (59.3 milioi pertsona). Hau da, 65 urtetik gorako ia 28 milioi pertsona gehiago daude EBn.

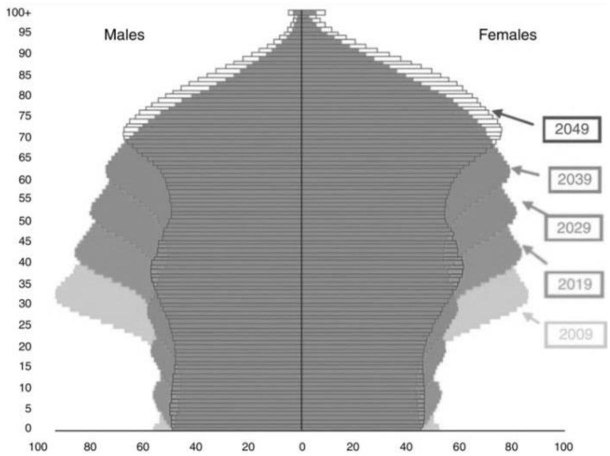


Figure / Irudia 2 Spanish population pyramid / *Espainiar biztanleriaren piramidea*

We must add to this characteristic of the European population that many of the services, infrastructures, cities or buildings were built before the implementation of the regulations defining the guidelines to meet the needs of the elderly. They have not considered the new needs of the aging society, thus many of them can not leave their buildings. Given this truth, in order to solve and adapt our cities and housing to this "new" society, there is a need to refurbish part of the existing buildings, because existing architectural barriers often make difficult or impossible their daily lives activities.

Europar biztanleriaren ezaugarri honi zerbitzuak, azpiegiturak, hiriak edo eraikinak pertsona zaharren beharrak asebetetzeko ildoak definitzen dituen legearen aurretik eraiki zirela gehitu behar zaio eta ondorioz ez zirela kontuan hartu gizartearen gehiengo baten beharrak, hau da pertsona zaharren beharrak. Honen ondorio larrienetako bat da jende ugarik bere etxetik ezin irten ahal izatea. Hau ikusirik, beharrezkoa da eraikita dagoenaren zati bat birgaitzea etxebizitza eta hiriak gizarte "berri" honetara egokitu daitezen eta gaur egun dauden oztopo arkitektonikoek ez dezaten eguneroko bizitza garatzea zaildu edo ezindu.

Cities Air pollution

Air pollution means the presence of one or more unwanted substances (solid particles, liquid droplets, or gases) in air. Air pollutants have a negative impact on humans, animals and plants, and on air quality, possibly causing disease, death to humans, damage to other living organisms such as food crops, or the natural or built environment. Indoor air pollution and urban air quality are listed as two of the world's worst toxic pollution problems in the 2008 Blacksmith Institute World's Worst Polluted Places report (*Blacksmith Institute, 2014*). According to the 2014 World Health Organization (*WHO, 2012*), air pollution in 2012 caused the deaths

Hirietako airearen kutsadura

Airea kutsatua egoteak esan nahi du airean nahigabeko substantziaren bat (partikula solidoak, likidoak edo gasak) edo gehiago daudela. Aire kutsatzaileek eragin kaltegarria dute gizaki, animalia eta landareengan eta airean daudenean gaixotasunak, gizakien heriotza eta beste organismo bizietan edo ingurune natural edo eraikietan kalteak eragin ditzakete. Barneko aire kutsadura eta hirietako aire kalitatea munduko bi kutsadura toxikoenak bezala zerrendatu zituen 2008ean Blacksmith Institutuak (Blacksmith Institute, 2014). 2014ko Osasunerako Mundu Erakundearen artikulu baten arabera (WHO, 2012), 2012an airearen kutsadurak munduan of around 7 million people worldwide. The main sources of air pollution are the industries, agriculture and traffic, as well as energy generation.

- The agricultural sector is known for its extensive use of pesticides. This application causes emissions of many toxic chemicals.
- Industrial processes are responsible for emissions of carbon monoxide, carbon dioxide, sulphur dioxide, nitrogen oxides, small dust particles, Volatile Organic Compound (VOC), methane, ammonia and radioactive radiation.
- During energy generation chemicals such as methane are released into the air as a result of oil and natural gas extraction. The combustion of coal and natural gas for electricity production causes the release of sulphur dioxide, nitrogen oxides and carbon dioxide into the air.
- Traffic is held responsible for one-third of the greenhouse gas emissions. Emissions caused by traffic are mainly those of carbon dioxide, carbon monoxide, nitrogen oxides, VOC and small dust particles.
- Consumers are also partly responsible for air pollution. Firstly because the products they use have caused air pollution during their production and distribution and secondly because heating of houses and offices causes chemicals release into the air.

In addition, the weather (wind and temperatures) plays an important role in

zehar 7 milioi pertsona inguruen heriotza eragin zuen. Airearen kutsaduraren iturri nagusiak, energia sorkuntzarekin batera, industria, nekazaritza eta garraioak dira.

- *Nekazaritza sektorea ezaguna da pestizida ugari erabiltzeagatik. Hauen erabilerak substantzia kimiko toxiko ugari igortzen ditu.*
- *Prozesu industrialak karbono monoxidoa, karbono dioxidoa, sufre dioxido, nitrogeno oxido, hauts partikula txiki, Konposatu Organiko Lurrunkor (KOL), metano, amoniako eta erradiazio erradioaktiboaren isurpenen arduradunak dira.*
- *Energia sortzeko prozesuan zehar metanoa bezalako substantzia kimikoak airera askatzen dira petrolioa eta gas naturalaren erauzketaren emaitza modura. Elektrizitatea ekoizteko ikatza eta gas naturalaren errekuntzak sufre dioxidoa, nitrogeno oxidoa eta karbono dioxidoa askatzen ditu airera.*
- *Garraioak dira berotegi efektuko gas isurien heren baten erantzule. Garraioen ondorioz sortutako isuriak normalki karbono dioxidoa, karbono monoxidoa, nitrogeno oxidoa, KOL eta hauts partikula txikiak dira.*
- *Kontsumitzaileak ere aire kutsaduraren erantzukizunaren parte dira, lehenik beraiek erabiltzen dituzten produktuak beren ekoizpenean eta banaketa etapetan zehar aire kutsadura sortzen baitute eta bigarrengoz, bulego eta etxebizitzetako berogailuak pizteak*

the formation and disappearance of air pollution. This is mainly influenced by wind and temperatures. Air pollutants can be transported by wind, causing a pollution to spread widely. Rain can remove pollutants from air, causing soil and water pollution. Sunlight can aid the conversion of air pollutants to different substances.

substantzia kimikoak igortzen baititu airera.

Horretaz gain, eguraldiak paper garrantzitsu bat du aire kutsaduraren sorkuntzan eta desagertzean. Aire kutsatzaileak haizearen bidez garraiatu daitezke kutsadura hedatuz. Euriak kutsatzaileak airetik ezaba ditzake, lurzoruaren eta uraren kutsadura eraginez. Eguzki argiak aireko kutsatzaileak beste substantzia ezberdinetan bihurtzen lagun dezake.

Energy poverty

Originally, energy poverty was defined in the UK by Brenda Boardman in the early 1990s. According to this definition, fuel poverty household is "one that cannot afford to keep adequately warm at reasonable cost. The most widely accepted definition of a fuel poor household is one which needs to spend more than 10% of its income on all fuel use and to heat its home to an adequate standard or warmth". It is generally accepted that energy poverty arises out of a combination of low incomes and inefficient homes, although the specific energy needs of a household (expressed via demographic circumstances such as household size, gender, occupation or class) also play a role. Alongside decreasing the quality of life and influencing social attainment, energy poverty has a particularly strong detrimental effect on health (*Harrington et al., 2005*), often resulting in an increase

Pobrezi energetikoa

Jatorriz, Brenda Boardman-ek 1990eko hamarkadaren hasieran Erresuma Batuan pobrezia energetikoa definitu zuen. Definizio honen arabera, arrazoizko kostu baten bidez etxebizitza bat nahikoa bero ezin mantentzean datza pobrezi energetikoak. Honez gain, errentaren %10a baino gehiago etxebizitza batetako bero maila egokia mantentzeko energia kontsumoan oinarritzen denean, pobrezi energetikoaren definizioa ere guztiz onartua dago. Orokorrean, pobrezia energetikoa errenta baxua eta etxeen eraginkortasun energetiko ezaren konbinazio bat da, nahiz eta etxeetako energia behar zehatzek ere baduten zerikusia (besteak beste, etxearen tamaina, biztanleen sexua, lanbidea edo gizarte maila). Bizi-kalitatea jaitsi eta gizarte mailan izan dezakeen eraginaz gain, pobrezia energetikoak osasunean eragin oso kaltegarria du, askotan the rate of seasonal morbidity and mortality.

gaixotasun eta heriotza tasen igoerarekin lotura zuzena izanik (Harrington et al., 2005).

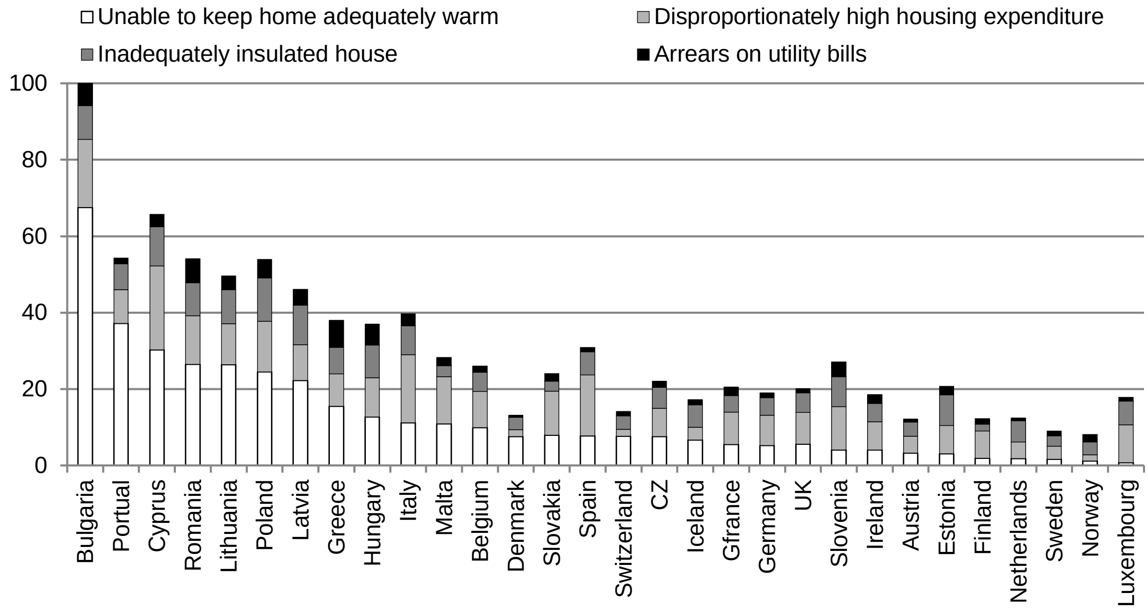


Figure / Irudia 3 Different European energy poverty-related problems indicators (2003-2009 average) / *EBko biztanleen pobrezia energetikoarekin lotura zuzena duten zenbait adierazle*. Source / *Iturria*: Own elaboration with data from (*EU-SILC, 2011*) - *en datuetan oinarritutako norbere garapena.*

According to the study conducted by the Association of Environmental Sciences (*ACA, 2010*) in Spain, energy poverty was present in 12% of households (5.3 million people). In addition, 7% of households (3.2 million people) declared unable to keep your home at a suitable temperature during the cold months. Finally, when it refers to housing occupied by elderly people, the values show that in 2010, 34% of aging people did not have a heating system (*IMSERSO, 2011*).

Ingurugiro Zientzien Elkarteak egindako azterketa baten arabera (ACA, 2010), Espainian 2010.urtean, etxeen %12an pobrezia energetikoa zegoen (5.3 milioi pertsona). Horrez gain, etxeen %7a (3.2 milioi pertsona) ez zen gai neguko hilabete hotzetan etxea tenperatura egokian mantentzeko. Azkenik, pertsona zaharrak bizi diren etxeetan, 2010ean pertsona zaharren %34ak ez zuen berogailu sistemarik (IMSERSO, 2011).

Current building deficiencies

One of the hallmarks of the European construction is a drastic decrease in new construction and the advanced age of existing cities and districts. The following data show clearly what happened during the last 10 years, what was the evolution of the construction and therefore, to where it needs to go the architecture, into refurbishment.

The annual growth rates in the residential sector are around 1% (*Power, 2008*) while most countries encountered a decrease in the rate of new build in the recent years, reflecting the impact of the current financial crisis on the construction sector. For the EU-28 the dwelling indices peaked in the last quarter of 2006 and then began a relatively continuous downturn which lasted almost 3 years. In 2009 the bottom of the cycle appears to have been reached.

Gaur egungo eraikinen gabeziak

Europako eraikuntzaren egoera aztertzean, azkenengo urteetako eraikin berrien eraikuntzaren jaitsiera eta gaur egungo hiri eta auzoen adina aipagarriak dira. Ondorengo datuek argi eta garbi adierazten dute azkenengo 10 urtetan gertatu dena, zein izan den eraikuntzaren garapena eta ondorioz, arkitekturak hartu beharreko bide berria: birgaitzea edo berritzea.

Etxebizitza sektorearen urteko hazkunde-tasa %1 ingurukoa izan da (Power, 2008), nahiz eta azken urteotan, krisi ekonomikoak eraikuntza sektorean izandako inpaktua islatuz, EBko herrialde gehienetan eraikuntza berrien tasaren jaitsiera bat nabarmendu da. Europar Batasunean (EB-28) etxebizitza indizeak 2006ko azken hiruhilekoan gora egin ondoren, ia 3 urte iraun zituen etengabeko jaitsiera bat hasi zuen. 2009. urtean zikloak hondoa jo zuela dirudi.

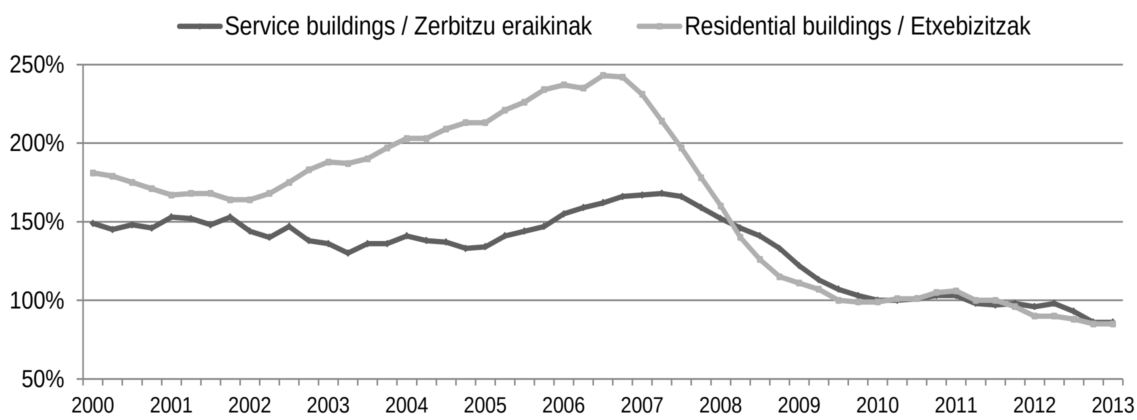


Figure / Irudia 4 EU-28, Building permits, floor area, (2010=100%) / *EB-28ko eraikitze baimenak, zoru azalera, 2010 = 100%.* Source / *Iturria*: Own elaboration with data from (Eurostat, 2013a)- *en datuetan oinarritutako norbere garapena.*

For the last 3 years the index remained rather stable at a level which was less than of the pre-crisis peak (see figure 4). The development of building permits is rather heterogeneous at the level of the individual Member States (see table 1). In several countries the indices for the number of buildings or the useful floor dropped by half or even more during individual years while in some countries even two digit growth rates were recorded for the same periods. Generally, the negative development between 2005 and 2012 was most pronounced in Ireland, Spain and Portugal. For example, in Spain, while construction increased on average by 12%/year between 2002 and 2006, it has been significantly affected by the crisis since 2007. Since this year it has decrease on average by 40%/year until 2010, reducing the new residential building construction until near 90% (*Spanish Ministry of Public Works, 2010*). However, in Poland, Lithuania, Romania, Austria and Luxembourg the development between 2005 and 2012 was even positive although all countries recorded negative rates of change in certain years. All these data show that the industry related to the new building is falling so that architecture, urban planning, engineering, construction industry and many of the decisions of the various stakeholders will need to focus on solving the deficiencies that present the current building and districts

Azken 3 urteotan indizea krisi aurreko gailurra baino maila baxuago horretan nahiko egonkor mantendu da (ikus 4. irudia). Europako estatu kide bakoitzak bere modura garatzen ditu eraikitzeko baimenak (ikus 1. taula). Hainbat herrialdetako eraikinen kopuruen edo lurzoru erabilgarrien indizea urte batetik bestera erdia edo gehiago jaitsi zen bitartean, beste herrialde batzuetan, epe berean bi puntuko hazkunde tasa epeak erregistratu ziren. Orokorrean, 2005 eta 2012 urteen artean gertatutako garapen negatiboa nabarmenagoa izan zen Irlanda, Espainia eta Portugalen. Espainian adibidez, eraikuntzak 2002 eta 2006 urteen artean %12ko gorakada jasan arren, 2007tik 2010era bitartean urtean batez beste %40 egin zuen behera, etxebizitza berrien eraikuntza kopurua %90 jaitsiz (Spanish Ministry of Public Works, 2010). Aldiz, Polonia, Lituania, Errumania, Austria eta Luxenburgon 2005 eta 2012 artean orokorrean garapen positiboa gertatu zen nahiz eta urteren batean garapen negatiboa erregistratu.

Datu hauek guztiak eraikuntza berriekin erlazionatutako industriaren gainbehera islatzen dute. Ondorioz, arkitekturak, hirigintzak, ingeniaritzak, eraikuntza sektoreak eta partaide ezberdinen erabakiak gaur egungo eraikin eta auzoek dituzten arazo edo gabeziak konpontzen saiatu beharko dira.

Table / Taula 1 Building permits - number of dwellings / *Eraikuntza baimenak – etxebizitza kopurua.* Source / *Iturria*: (*Eurostat, 2015*)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
EU-28	7.4	10.2	-11.4	-34.9	-29.0	-3.8	0.0	-12.1	-6.4	5.0
Belgium	14.2	3.3	-12.0	-3.5	-13.2	11.5	-9.8	4.2	5.5	7.3
Bulgaria	54.6	61.4	20.9	-23.1	-59.3	-36.3	-14.5	-3.2	15.8	29.1
CZE	4.9	8.7	2.1	0.2	-17.2	-23.5	-1.2	-15.6	-7.0	9.0
Denmark	23.7	0.2	-36.3	-33.8	-49.9	103.3	2.8	-27.0	-9.2	40.0
Germany	-10.5	2.4	-27.6	-5.4	3.0	6.4	21.4	3.2	12.3	3.5
Estonia	-2.7	40.4	-30.9	-38.6	-61.8	23.7	9.5	7.5	0.5	29.3
Ireland	-2.3	-20.7	7.2	-20.0	-40.1	-54.4	-37.0	-46.2	14.9	2.9
Greece	69.1	-39.7	-18.8	-23.2	-25.5	-16.2	-45.4	-45.2	-42.7	-18.8
Spain	11.1	21.9	-15.1	-57.2	-51.0	-30.2	-14.9	-26.3	-46.0	6.7
France	11.2	8.2	-4.2	-14.9	-18.5	15.3	17.9	-7.4	-12.7	-10.8
Croatia	14.5	9.7	-3.2	-0.7	-31.8	-20.8	1.0	-27.3	-21.7	1.7
Italy	3.8	-6.2	-4.3	-23.4	-26.2	-15.6	-5.9	-27.0	-34.8	-
Cyprus	19.4	0.9	8.2	-2.0	-17.1	-14.2	-38.2	-33.5	-30.0	-31.1
Latvia	62.9	32.3	5.2	-61.0	-40.2	-14.7	-5.1	22.9	29.4	-43.2
Lithuania	40.4	40.7	16.4	-17.3	-52.6	10.4	-12.4	38.0	18.4	-3.2
Luxembourg	21.3	-6.0	11.9	-18.4	-8.4	0.2	19.0	-1.1	-15.3	60.5
Hungary	-9.8	-13.5	-0.2	-0.4	-34.0	-38.6	-32.2	-15.6	-27.0	30.6
Malta	35.6	14.5	9.2	-40.0	-22.5	-15.8	-11.1	-22.3	-12.0	8.6
Netherlands	9.3	15.7	-8.7	-0.8	-16.7	-15.9	-8.7	-33.0	-29.9	50.3
Austria		7.7	-2.4	-0.2	-2.0	1.9	20.5	-13.0	15.8	4.1
Poland	9.5	38.6	47.4	-7.0	-23.6	-1.9	6.0	-10.8	-15.9	13.9
Portugal	-1.0	-4.1	-7.2	-27.5	-42.6	-8.4	-29.7	-33.1	-35.0	-6.1
Romania	27.0	17.3	10.8	7.7	-20.1	-13.5	-6.6	-4.0	-0.2	-0.3
Slovenia	2.5	18.6	22.1	-18.7	-29.7	-18.6	-21.3	-16.0	-0.4	-15.5
Slovakia	21.7	3.0	-9.8	59.7	-30.3	-20.1	-19.5	-0.3	13.5	8.6
Finland	6.5	-2.8	-10.9	-17.8	-10.9	15.1	-5.5	-11.7	-19.8	-15.0
Sweden	17.5	39.0	-34.3	-14.9	-11.7	28.9	1.5	-12.6	25.4	17.9
UK	0.5	1.5	-5.7	-35.2	-23.9	22.1	-5.9	-0.1	21.5	13.3
Norway	14.2	-0.7	-6.8	-27.1	-11.3	-2.2	37.2	-0.2	0.7	-5.9
Switzerland	6.0	-2.2	-3.3	8.3	-1.2	-1.5	12.3	16.4	-	-
Turkey	65.6	9.5	-2.8	-13.9	3.1	75.3	-28.3	18.2	8.6	21.5

The reflect of this is that because of the buildings aging, the weather reactions, poor quality of materials, lack of maintenance, chronic neglect and building defects leading to water ingress, condensation and dampness in the building fabric, part of the structures, facilities and enclosures of existing buildings, buildings suffer a high degree of deterioration, increasing the danger to the possibility of accidents or damage to passers or inhabitants of the same buildings. It is very difficult to generalize the origin (chemical, physical, mechanical, organic or noise) and a solution to each of the deficiencies or

Eraikinen zahartzea, erreakzio meteorologiakoa, materialen kalitate baxua, mantentze falta, utzikeriaren ondoriozko ur sarrera edo kondentsazio eta hezetasunen ondorioz, gaur egungo eraikin eta azpiegitura ugarik narriadura-maila handia jasaten dute, Hori dela eta, oinezkoentzako edo eraikinen erabiltzaileentzako istripu arriskua areagotu daiteke. *Patologia edo arazo hauen jatorri orokor bat (kimikoa, fisikoa, mekanikoa, organikoa, etab.) eta bakoitzaren konponbide zehatz bat zehaztea oso zaila da. Hala ere, beharrezkoa da puntu guzti hauetan lana egin eta birgaitzea, hauek baitira* constructive pathologies. However, it is necessary to act and restore each of these points since these problems impair the appearance of the work, destroy polishing, generate stains, affect and even eliminate metal sections, reduce the mechanical strength of the structure, destroy the seal, generate pollutants, affect health, worsen the thermal behavior of the building and decrease the thermal comfort of the inhabitants.

Energy performance of the existing building stock

Energy security and climate change are driving a future that must show a dramatic improvement in the energy performance in Europe's buildings. The 27 Member States have set an energy savings target of 20% by 2020, mainly through energy efficiency measures. The European Union has also committed to 80-95 % GHG reduction by 2050 as part of its roadmap for moving to a competitive low-carbon economy in 2050 (*Directive 2010/31/EU, 2010*).

The housing sector is one of the major sources of environmental impacts Worldwide, as well as in the European Union, the building stock is responsible for 40 % of the primary energy consumption and about 25 % of the CO_2 emissions (*IEA, 2013*). In the EU, residential buildings are responsible for 27 % of European energy demand

eraikinaren aspektua hondatzen dutenak, orbanak edo zikinguneak sortzen dituztenak, elementu metalikoak herdoiltzen dituztenak, substantzia kutsakorrak sortzen dituztenak, osasuna honda dezaketenak, eraikinaren portaera termikoa okertzen dutenak eta eraikinaren erabiltzaileen konfort termikoa murrizten dutenak.

Gaur egungo eraikinen portaera energetikoa

Energia hornikuntza segurtasunak eta klima aldaketak erakusten dute etorkizuneko Europako eraikinen portaera energetikoa asko hobetu behar dela. Europako estatu kideek (EB-27) 2020rako energia eraginkortasun neurrien bidez %20ko energia aurrezteko helburua jarri dute. Bestalde, Europar Batasunak 2050rako berotegi efektuko gasak %80-95an murrizteko konpromisoa hartu du 2050rako karbono gutxiko ekonomia lehiakor baterako bidean (Directive 2010/31/EU, 2010).

Eraikuntza sektorea mundu maila zein Europar Batasuneko ingurumenean eragin handienetarikoa duen iturria da, oinarrizko energia kontsumoaren %40aren eta CO_2 isurien %25aren arduradun delarik (IEA, 2013). Europar Batasunean, etxebizitzak energia eskariaren %27aren (berokuntza, (including space heating, cooking, lighting, water heating, and electrical appliances) and for 68% of the total final energy use in buildings. The dominant energy end use in European homes is space heating, which is responsible for around 70% of the final energy consumption in residential buildings (*EEA, 2015*).

sukaldeko tresnak, argiztapena, etxeko ur beroa eta elementu elektrikoak) eta eraikinen amaierako energia erabileraren %68aren arduradun dira. Europako etxebizitzen azken energi erabilera nagusia espazioaren berokuntzan oinarritzen da eta, amaierako energia kontsumoaren %70aren arduraduna da (EEA, 2015).

However, due to the influence of the weather, development of different sectors and energy policies, these general values which represent a European average can vary greatly.

Hala ere, klimaren, sektore desberdinetan emandako aurrera pausoen edo zenbait politika energetikoen eragina dela eta, Europako batez besteko bat azaltzen duten balio hauek asko alda daitezke estatu kide bakoitza aztertzerakoan.

Table / Taula 2 Final energy consumption percentage by sector in the EU, Spain and Basque Country / Amaierako energia kontsumoaren ehunekoa sektoreka EB, Espainia eta Euskadin. Sources / *Iturriak*: (*Eurostat, 2013b*), (*IDAE, 2010*), (*EVE, 2010*).

	Households ***Etxebizitzak***	**Services** ***Zerbitzuak***	**Transport** ***Garraioa***	**Industry** ***Industria***	**Agriculture** ***Nekazaritza***
EU / *EB*	27	13	34	24	2
Spain /*Espainia*	17	9	40	31	3
Basque Country / *Euskadi*	11	7	34	47	1

For example, in the case of Spain, due to its less severe winter weather, the space heating only represents the 47.1% of the total energy consumption in residential buildings (compared to 70% of the European average) and other points of energy consumption as the water heating or appliances increase their importance, reflecting respectively the 27.4% and 20.6% of final energy consumption of the Spanish residential buildings. In table 3, it can also be seen

Espainian adibidez, neguko klima ez hain gogorra dela eta, berokuntza etxebizitzen energia kontsumoaren %47.1a da (EBko %70arekin alderatuz). Ondorioz, ur berokuntzaren eta aparatu elektrikoen garrantzia areagotzen da handi, hurrenez hurren Espainiako etxebizitzen azken energia kontsumoaren %27.4 eta %20.6 direlarik. Eraikin baten adinak, kokapenak eta klimak etxebizitzen kontsumo energetikoa how the age of a building and its geographic and climatic location influence directly when it is evaluated the energy consumption of residential buildings. These values show that the building stock formed by old buildings, mainly prior to 1960, is the most energy-intensive, and it consumes 56.2% of the European energy consumed by residential buildings.

zenbatesterakoan eragin zuzena izan dezaketela ikus daiteke 3. taulan. Datu hauen arabera, energia kontsumo handiena duen eraikin stock-a etxebizitza zaharrez osatua dago, batez ere 1960 baino lehen eraikitakoez, Europako etxebizitzen kontsumo energetiko guztiaren %56aren arduradun delarik.

Table / Taula 3 The average energy consumption (GWh per annum) of residential buildings in the three major European zones / *Europako hiru gune nagusietako etxebizitzen energia kontsumoaren bataz bestekoa (GWH urteko)*. Source / *Iturria*: (*BPIE, 2011*)

	North & West / *Ipar & mendebalde*	**South / *Hegoalde***	**Central & East / *Erdi & Ekialde***	**Total / *Guztira***	**Percentage / *Ehunekoa (%)***
Pre 1960	1193504	228933	183937	1606374	56.2
1961-1990	506461	198250	266647	971358	33.9
1991-2010	136319	41581	52551	230452	8.1
2011-2020	28390	11718	11394	51501	1.8

Finally, clarify that the energy consumption of the building sector has increased by around 1%/year since 1990 and specially the electricity consumption, which is increased by 2.4%/year (+60%) (see figure 5). The reasons are parameters such as the economic crisis or inhabitant behaviour, which are totally independent of the main parameters of energy calculation as the weather and thermal behaviour of a building.

Azkenik, energia kalkuluaren parametro garrantzitsuenak diren klima edo eraikinen portaera termikoarengatik guztiz independenteak diren krisi ekonomikoa edo biztanleriaren jokaera bezalako parametroen ondorioz, eraikinen sektoreko kontsumo energetikoa urtean %1 igo da 1990tik. Aipatzekoa da kontsumo elektrikoak urtean izan duen %2.4ko igoera (ikus 5. irudia).

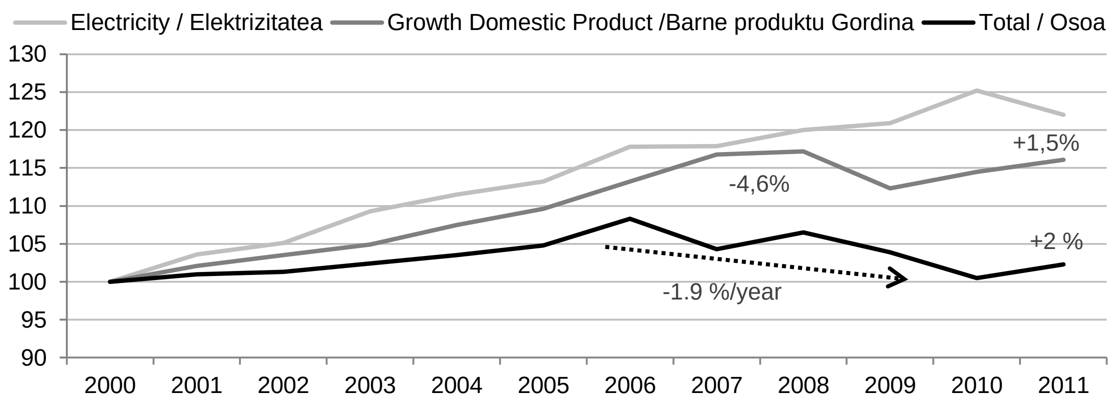


Figure / Irudia 5 Energy consumption trends EU buildings. 100% = 2000 year / EBko eraikinen kontsumo energetikoaren joera, %100=2000.urtea. Source / *Iturria*: Own elaboration with data from (*Eurostat, 2011*) - *en datuetan oinarritutako norbere garapena.*

This figure shows how between the years 2000-2012 it have been able to distinguish 3 different stages in the context of the energy consumption of buildings: 1 (2000-2006), Regular increase of +1.4%/year in the total energy consumption of buildings at normal climate; 2 (2006-2010), Decreasing trends (-1.9%/year), not fully explained by economic growth (+2%/year until 2008; -4.3% in 2009 and +2% in 2010); and 3 (2011), Return to growth in 2011 (+2%) in line with GDP (+1.5%).

2000 eta 2012 urteen artean, 3 etapa desberdindu daitezke eraikinaren kontsumo energetikoaren arloan: 1 (2000-2006), Energia kontsumoaren %1,4ko hazkunde jarraitua klima arruntetan; 2 (2006-2010). energia kontsumoak jaisteko joera azaldu zuen (%1,9/urteko), baina ez dator guztiz bat ekonomiak jasandako hazkundearekin (%2/urteko 2008rarte, %4.3ko jaitsiera 2009an eta %2ko igoera 2010ean); eta 3 (2011). Energia kontsumoak berriro igoera jasan zuen 2011 urtean (%2).

Others

Finally, you can not forget other problems or weaknesses that are part of the system of our existing cities. Among which are aspects such as contaminated soils, problems of social cohesion, high unemployment, lack of safety, low urban quality...

Beste batzuk

Azkenik ezin dira ahaztu gure hiriak osatzen dituzten sistemaren parte diren beste arazo edo ahultasun batzuk. Hauen artean nabarmentzekoak dira lur kutsatuak, gizarte kohesioaren arazoak, langabezi tasa altuak, segurtasun gabezia, hiri kalitate baxua, etab. bezalakoak.

Reflection

The main consideration of this methodology focuses on the **Need to Act**. Because of the aforementioned scarcity, new regulations have been developed in recent years, new awareness campaigns have been implemented and the amount of refurbishment actions has increased considerably.

Hausnarketa

Metodologia honen hausnarketa nagusia ondoregoan datza: ***zerbait egiteko beharra****. Gabezia hauek guztiak direla eta, azkenengo hamarkadetan hainbat araudi garatu dira, sentsibilitate kanpaina ugari egin dira eta birgaitze proiektuek hazkunde nabarmena jasan dute.*

With regards to the rehabilitation of buildings, such actions have developed greatly from focusing only on aspects such as structural and constructive safety of the evaluated element in the beginnings, to the performances of recent years, in which the rehabilitation is aimed at improving the inhabitant's access to the Internet or integration of intelligent systems (see figure 6).

Eraikinen birgaitze proiektuek aurrera pauso interesgarria jasan dute, istripuak saihesteko helburuarekin, eraikinaren egitura eta eraikuntza arazoetan oinarritzen ziren hasiera bateko proiektuetatik, biztanleen interneteko sarbide hobekuntza edo sistema adimendunen integrazioan oinarritzen diren proiektuetaraino (ikus 6. irudia).

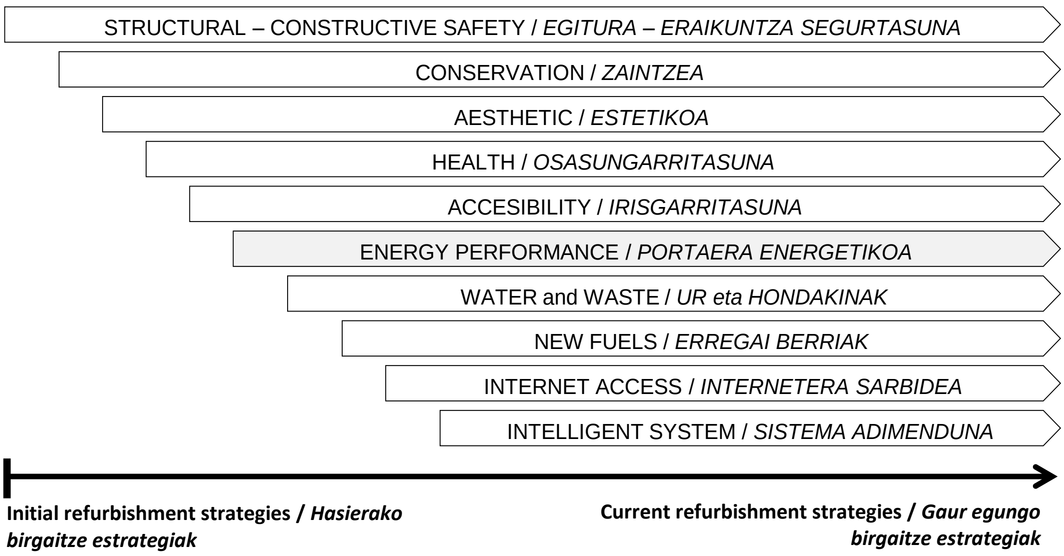


Figure / Irudia 6 Scheme of the evolution of the objectives of rehabilitation activities in buildings / *Eraikinen birgaitze proiektuen helburuek jasandako garapenaren eskema*.

This kind of refurbishment projects have influenced directly in different aspects such as:

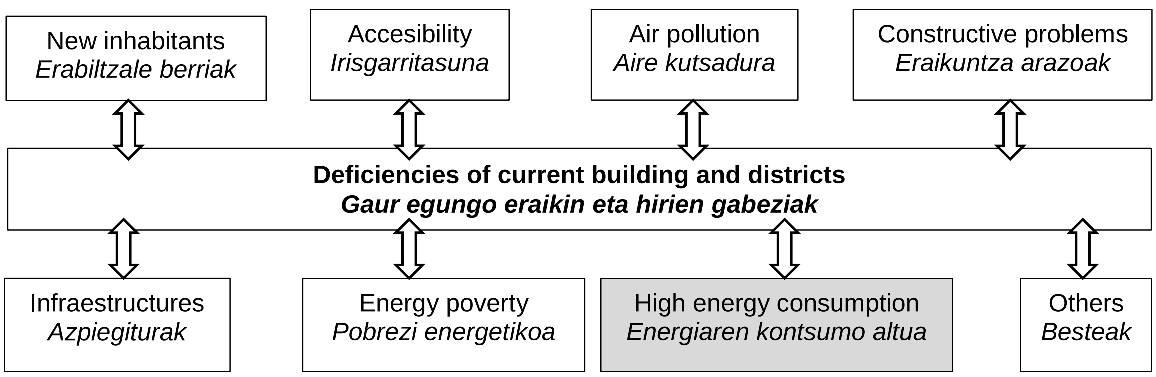
- Decrease the risk of pedestrians from falling elements of the envelope.
- Increase the health of the inhabitants.
- Increased the life quality of older people or people with partial or total disability.
- Increase the thermal and acoustic comfort of the inhabitants.
- Increase the ability to access to internet connection and to apply new smart technologies.

In other words, an ideal rehabilitation would focus on combining the majority of these aspects, thus improving the quality of life of end users.

Birgaitze hauek eragin zuzena izan dute ondorengo aspektu desberdinetan:

- *Oinezkoen istripu arriskuaren jaitsiera fatxadako elementuen erorketagatik.*
- *Bizilagunen osasun maila hobetu.*
- *Eraikinen eta etxebizitzen egokitzapena jende zaharraren edo ezinduen behar berrietara.*
- *Biztanleen konfort termiko eta akustikoaren gehikuntza.*
- *Interneterako sarbidea edo teknologia adimendu berrien aplikazioa edukitzeko gaitasuna handitzea.*

Hau da, birgaitze ideal aurreko puntu guzti hauek barne hartzen dituena izango litzateke, biztanleen bizi kalitatea asko hobetzea ahalbidetuz.



However, without wishing to pour scorn on any of the other types of rehabilitation, this research work shall only focus on the high energy consumption in the building sector, where the evaluation of energy rehabilitation performances is being highly published in Roadmap 2012

*Beste birgaitze motak gutxietsi gabe eta ikusirik 2012ko Europako Bidai Orria (*ECPT, 2012*), Energia Teknologiei buruzko Europako Estrategia Plana (ikus 7. irudia) (*EC, 2009*) edo eraikinen eraginkortasun energetikoaren inguruko* zuzentaraua *(*Directive 2012/27/EU, 2012*) batez ere birgaitze energetikoan*

(*ECPT, 2012*), European Strategic Energy Technology Plan (see figure 7) (*EC, 2009*) or Energy Efficiency Directive (*Directive 2012/27/EU, 2012*).

New energy requirements and the need to improve concepts such as the inhabitants' thermal comfort, have led to an increasing number of rehabilitation performances with a largely energetic perspective. While new buildings can be constructed with high performance levels, it is the older buildings, representing the vast majority of the building stock, which are predominantly of low energy performance and subsequently in need of renovation work.

oinarritzen direla, ikerketa lan hau eraikuntza sektorearekin zuzenean lotua dagoen energia kontsumo handian oinarrituko da.

Eskakizun energetiko berrien eta biztanleen konfort termikoa bezalako kontzeptuak hobetzeko beharraren ondorioz birgaitze prozesuek gero eta aspektu energetikoagoa dute. Eraginkortasun energetiko handiko eraikin berriak eraiki arren, arazoa gaur egun eraikita dauden ehuneko oso handi bat osatzen duten eraikin zaharren eraginkortasun energetiko baxua da, hauen birgaitze energetiko beharra handituz.

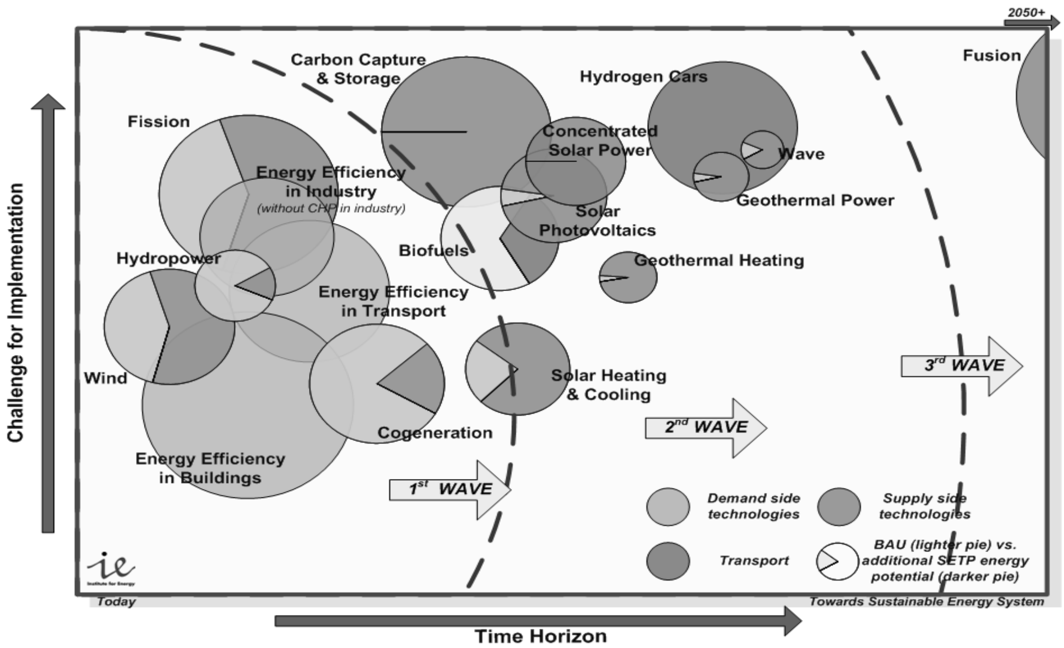


Figure / Irudia 7 European Strategic Energy Technology Plan driven potential scenario 2050 / *Energia Teknologiei buruzko Europako Estrategia Planaren potentziala, 2050 eszenatokia.* Source / *Iturria*: (*EC, 2009)*

Therefore, energy efficiency is undoubtedly one of the fastest, most efficient and cost-effective means to reduce the environmental impact and improve air quality, which would contribute significantly to increasing the quality of life of each inhabitant in some aspects.

The global shift to low environmental impact and decarbonized economies requires an intervention on existing buildings, reducing their energy consumption and environmental impact. This intervention shall not only update environmental services, but also increase the quality of existing buildings and their ability to meet the requirements of today's society with regards to habitability.

However, even though the number of administrative grants regarding such performances is increasing, new tools or environmental seals responsible for evaluating energy and/or environmental performances of renovated buildings are being developed, new materials and construction solutions are being used and stakeholders' awareness is increasing, there is still great uncertainty with respect to the calculation methodology and scope that should be used when evaluating energy rehabilitation performances of buildings.

Hori dela eta, biztanleen bizi kalitateko aspektu batzuk hobetzen laguntzeaz gain, birgaitze energetikoen bidez aurreztutako energia ingurumen-inpaktua gutxitzeko eta airearen kalitatea hobetzeko modu azkar, eraginkor eta errentagarrienetako bat izango da.

Ingurumen inpaktu baxuagoko ekonomiarantz mundu mailan ematen ari den aldaketak gaur egungo eraikinetan esku-hartzea eskatzen du, energia erabilera eta ingurumen inpaktua murriztuz. Esku-hartze honek ez du ingurumen ezaugarriak hobetzeko bakarrik balioko, baizik eta gaur egungo eraikinen kalitatearen hobekuntzan eta gizarteak dituen eskariei erantzuna ematerakoan ere eragin zuzena izango du.

Hala ere, nahiz eta gaur egun dauden laguntza administratiboak gero eta handiagoak izan, birgaitutako eraikinen portaera energetikoa aztertzen duten tresna edo ingurumen zigilu berriak garatu, material eta eraikuntza sistema berriak ikertu, partaide ezberdinen sentsibilitatea handitu, etab. oraindik ere zalantza ugari daude eraikinen birgaitze energetikoa analizatzerakoan erabili beharreko kalkulu metodologien eta hauen irismenaren inguruan.

CHAPTER 2 – ENERGY REFURBISHMENT

State of art of theEnergy Refurbishment of buildings

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2 ATALA – BIRGAITZE ENERGETIKOA

Eraikinen birgaitze energetikoaren inguruko literatur aztertzea

2. State of art of the Energy Refurbishment of buildings / *Eraikinen birgatze energetikoaren literatur aztertzea*

In order to understand the different aspects that are directly related to the concept of "building energy refurbishment", following are evaluated some topics that are going to help determining a refurbishment evaluation methodology.

Eraikinen birgaitze energetikoaren kontzeptuarekin zuzenki erlazionaturik dauden zenbait aspektu ulertzeko asmoz, ondoren birgaitzearen ebaluazio meteodologia zehazteko garaian beharrezkoak izango diren zenbait aldagai aztertuko dira.

Building Energy Refurbishment / *Eraikinen birgaitze energetikoa* →

1- What is? – Benefits / *Zer da? Onurak*
2- Strategies / *Estrategiak*
3- Regulations / *Araudiak*
4- Evaluation methodologies / *Ebaluazio metodologiak*

2.1. What is? – Benefits / *Zer da? Onurak*

Oliver Rapf, the Executive Director of BPIE (Buildings Performance Institute Europe), said that: "…*I believe that renovation of buildings to high energy performance standards could be one of the most cost effective investments a nation can make, given the benefits in terms of job creation, quality of life, economic stimulus, climate change mitigation and energy security…"*

However, as shown in table 4, with the same performance of energy refurbishment, each different sector of society, according to their sensitivity, concerns, profession, interests, limitations, experience or objectives, may have a very different perspective.

Oliver Rapf, BPIE-ko zuzendari exekutiboak honela zioen: "sinisten dut eraikinen birgaitze energetikoen errendimendu altuko estandarretan oinarritzea izango litzatekela nazioek egin ahal duten inbertsio errentagarriena, enplegu sortze, bizi kalitate, ekonomi estimulu, klima aldaketa arintze eta energia segurtasuna bezalako arloetan onurak lortuz.Hala ere, 4. taulan ikus daitekeen bezala, birgaitze energetiko berdin baten aurrean gizartearen sektore ezberdinek, beren sentsibilitate, jakintza, lanbide, interes, muga, esperientzi edo helburuen arabera, guztiz ezberdinak diren ikuspuntuak izan ditzakete.

Table / Taula 4 Different reflections or questions made by different stakeholders to the same energy refurbishment project/ *Ezaugarri berdinak dituen birgaitze energetiko proiektu baten aurrean aktore desberdinek garatutako hausnarketa edo galdera desberdinak*

Stakeholder	**Reflection – question**
People without job	Imminent future aspect related with job
Public entities, Administrations	Financial aid policies that should be performed. Type of refurbishment technology or strategy to encourage.
Architects, city planners, historians, municipal technicians	Decomposition of harmony and architectural composition of the existing city. Elimination of architectural heritage.
Product manufacturers	Environmental impact of each product throughout its life cycle
Final user	Possibility of improving the degree of thermal comfort of their homes. Reduction of the energy bill.
Final user Investors	Increase of the economic value of the refurbished building. Level of profitability and return values of the initial investment.

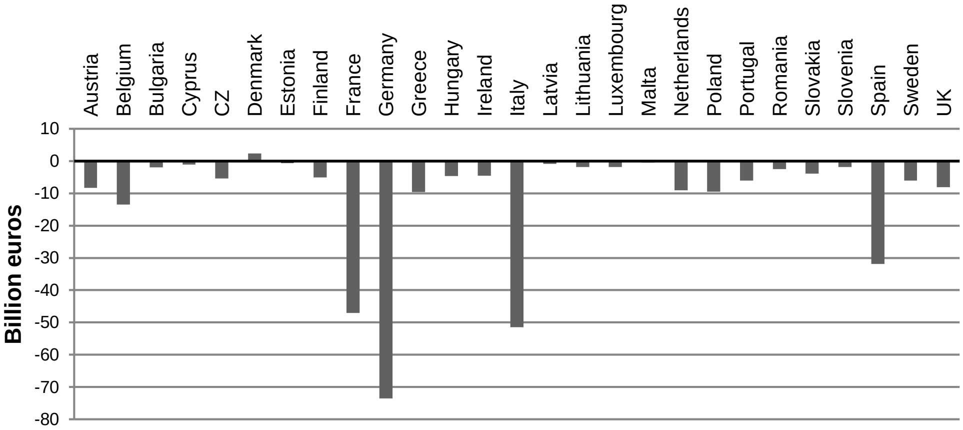
Although the concern of each stakeholder is different and each of them have a different goal or ending concern, by applying different strategies, the main objective of an energy refurbishment of a building is based on improving their energy performance. In this manner, an energy refurbishment project generates benefits directly and indirectly to the different pillars of the concept of sustainability.

Aktore bakoitzaren kezka, helburu edo egonezina ezberdina izan arren, eraikin baten birgaitze energetikoaren helburu nagusia, estrategia ezberdinetan erabiliz eraikin baten portaera energetikoa hobetzean datza. Era honetan, birgaitze energetikoak jasangarritasunaren kontzeptuaren oinarri ezberdinei modu zuzen edo zeharkakoan onurak ekarriko dizkio.

Energy Refurbishment Benefits / *Birgaitze energetikoen onurak*

Enviromental *Ingurumen*	Energetic *Energetiko*	Social *Sozial*	Economic *Ekonomiko*

Environmental Benefits	
Reduced air pollution	By reducing the need for energy production from fossil fuels, there is a reduction in the amount of pollutants such as SO2, NOx and particulates that are damaging to health, to buildings and the environment
Reduce emissions	Europe's roadmap towards a low carbon economy 2050 (*EC, 2011*), sets a target for reducing emissions in the European Union's buildings by between 88 and 91% by 2050
Energy Benefits	
Energy security	The reduction of the energy demand could increase the European energy security (*EC, 2010*)
Reduced peak loads	Energy demand reduction measures save a disproportionate amount at times of high demand

	Social Benefits
Reduced fuel poverty	Improving the energy efficiency of homes could be vital to achieving affordable warmth for families on low incomes. Between 50 million and 125 million people in Europe (10-25% of the total EU population) are estimated to be fuel poor (*EPEE, 2009*).
Health	Health benefits from warmer homes with less condensation and improved indoor air quality.
Increased comfort and productivity	Improvement in terms of increased comfort. It is well established that a better working environment leads to increased productivity.
Architecture -society relationship	The demolition of these urban areas by substituting new ones, influence directly in the social life of a high percentage of occupants. Therefore, refurbishment projects benefit directly in maintaining air quality and occupant architectural-social relationship.
	Economic Benefits
Energy cost saving	Renovation potential for net energy costs savings as much as €1300 billion (2012 value), arising to end users (*BPIE, 2011*).
Economic stimulus	The employment generated could be on average as much as 1.1 million net additional jobs throughout the period to 2050 (*WBCSD, 2009*).
Impact on Gross Domestic Product.	Energy Efficiency Directive impact assessment identified that achieving the targeted savings would result in an increase in the EU's GDP of €33.8 bn in 2020 (*Directive 2012/27/EU, 2012*).
Property values	Buildings with high energy performance could be more valuable than their less efficient counterparts
R&D	By creating the drive towards ever more efficient ways to reduce energy consumption in buildings, a major programme of building renovation will spur research & development
Impact on public finances	According to a Copenhagen Economics report (*Copenhagen Economic, 2012*), investment in building retrofits will have a positive impact on public budgets, equivalent to 0.5-1.0% of GDP.
Energy import bill	With virtually all Member States being reliant on energy imports to satisfy demand the energy savings achieved through building renovation will have a positive impact (see figure 8) on a nation's balance of payments.  **Figure / Irudia 8** Energy bill import dependency in 25 EU member States / *Energiaren inportazioaren menpekotasuna EB 25-ko estatuetan*. Source / *Iturria*: Own elaboration with data from (*Dowling & Russ, 2012)-ren datuetan oinarritutako norbere garapena.*

2.2. Energy refurbishmen strategies / *Birgaitze energetikoaren estrategiak*

The concept of how energy refurbish a building to meet the guidelines set by the various European and global directives and Roadmap, is totally related to the theory of "Trias Energetica" (see figure 9), which is a simple and logical concept that helps to achieve energy savings, reduce our dependence on fossil fuels, and save the environment.

Zuzentarau edo bidai orri Europarrek definituriko helburuak birgaitze energetikoen bidez nola lortuko diren kontzeptua "Trias Energetica" teoriarekin zuzenki erlazionatua dago (ikus 9. irudia). Erraz bezain logikoa den kontzeptu hau energiaren aurrezpen, erregai fosilekiko dependentzia murrizte eta ingurumena zaintzean oinarritzen da.

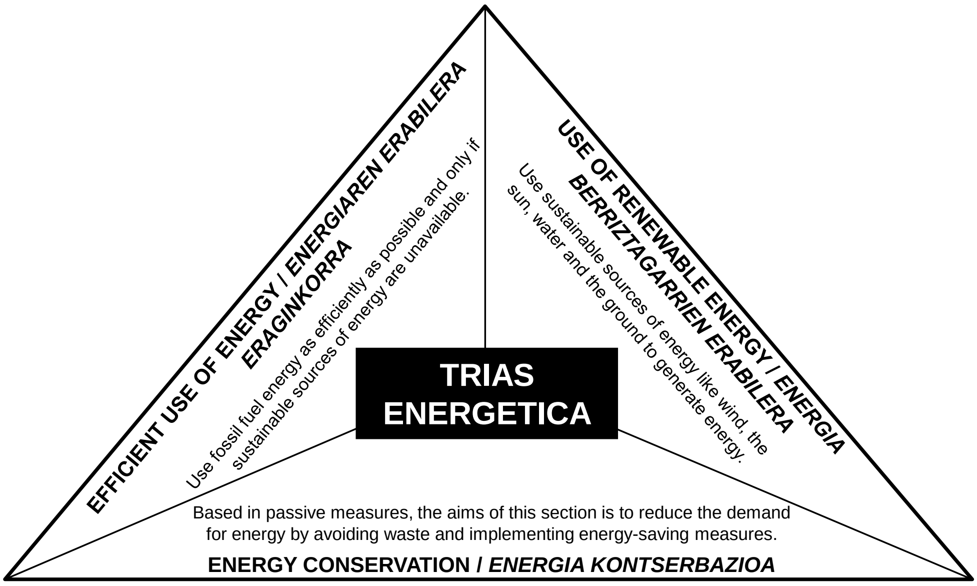


Figure / Irudia 9 Trias Energetica scheme / "*Trias Energetica" –ren eskema*

Energy conservation

Energy efficient buildings strategies and energy conservation are designed to provide a significant reduction of the energy need for heating and cooling, independently of the energy and of the equipment's that will be chosen to heat or cool the building. Many of the studies

Energia kontserbazio

Berotzeko eta hozteko behar den energia nabarmen murrizteko diseinatuta daude eraikin energetikoki eraginkorren estrategiak eta energia-metaketa, edozein direlarik ere eraikina berotzeko edo hozteko aukeratuko diren ekipamendua eta energia. Hori dute with a view to the evolution of architecture towards energy efficiency and sustainability (BPIE, Entranze, Eurima, Improbuilding ...) are based on this pillar, where these kind of passive refurbishment strategies improve the characteristics of different elements that directly affect in the building energy consumption and its influence is direct in three of the pillars of sustainability.

Of all possible measures to abate greenhouse gas emissions, those that use energy more efficiently bear the lowest “cost”. A recent study, conducted for the German economy, provides a map of the world's abatement opportunities ranked from least-cost to highest-cost options. Figure 10 compares a number of CO_2 reduction measures for the residential sector in terms of cost and reduction potential. This cost curve shows the full range of actions that technicians can take with technologies that either are available today or look very likely to become available in the near future. The width of the bars indicates the amount of CO_2 that could be abated while the height shows the cost per ton abated. The lowest-cost opportunities appear at the left of the graph and the highest-cost to the right. As can be observed in figure 10, they find considerable untapped potential in cost-effective energy efficiency measures, especially for the residential sector.

oinarri arkitektura izaten ari den eboluzioa —energia-eraginkortasuna eta -jasangarritasuna helburu dituena— aintzat hartzen duten azterketa askok. Azterketa horietan (BPIE, Entranze, Eurima, Improbuilding...), horrelako eraberritze-estrategia pasiboek hobetu egiten dituzte eraikinen energia-kontsumoan zuzenean eragiten duten hainbat elementuren ezaugarriak, eta horrek eragin zuzena du jasangarritasunaren oinarrietako hirutan.

Berotegi-efektuko gasen emisioak murrizteko aplika daitezkeen neurri guztien artean, energia modurik eraginkorrenean erabiltzen duten horiek dute "kosturik" txikiena. Alemaniako ekonomiari buruz berriki egin den azterketa batean emisio horiek murrizteko dauden aukeren munduko mapa bat egin da, aukerak kosturik gutxienetik kosturik handienera sailkatuz. 10. irudiak CO_2-emisioak murrizteko etxebizitza-sektorerako hainbat neurri konparatzen ditu, kostuari eta murrizteko potentzialari dagokienez. Kostuaren kurbak erakusten ditu eskura dauden edo etorkizun hurbilean ziur aski eskura egongo diren teknologiekin teknikariek gaur egun egin ditzaketen ekintza guztiak. Barren zabalerak murriztuko litzatekeen CO_2-kantitatea adierazten du, eta altuerak murriztutako tona bakoitzeko kostua. Kostu baxueneko aukerak grafikoaren ezkerrean ageri dira, eta kostu *altuenekoak, eskuinean. 10. irudian ikus daitekeen modura, uste dute energia-eraginkortasuneko neurri errentagarrietan erabili gabeko potentzial handia dagoela, batez ere etxebizitza-sektoreari dagokionean.*

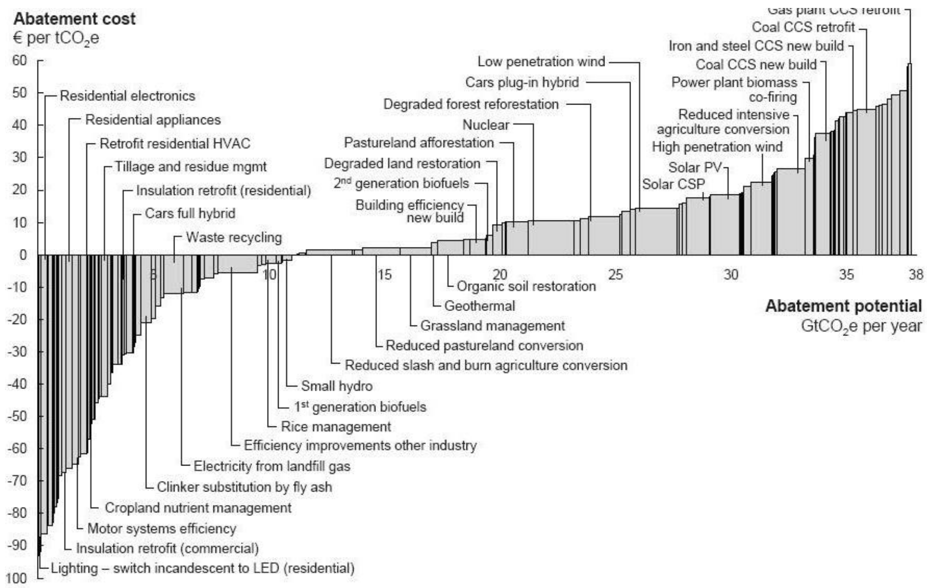


Figure / Irudia 10 The global "carbon abatement cost curve" / *Karbono murrizketa kostuaren kurbadura orokorra*. Source / *Iturria*: (Mckinsey & Vattenfall)

These strategies mainly based on the increment of the thermal resistance of the envelope, on the replacement of the current windows, on the reduction of air leakage or on the usage of bioclimatic strategies, are aimed at improving the life quality of inhabitants:

- Reducing the energy demand.
- Reducing the economic bill.
- Increasing the indoor air temperature in winter.
- Reducing the indoor air temperature in summer.
- Increasing the thermal comfort of the inhabitants.

Estrategia horiek biztanleen bizi-kalitatea hobetzea dute helburu, eta, batez ere, neurri hauetan oinarritzen dira: inguratzailearen bero-erresistentzia handitzea, leihoak aldatzea, aire-galera murriztea edo estrategia bioklimatikoak erabiltzea.

- *Energia eskaria murriztuz*
- *Faktura ekonomikoa murriztuz*
- *Neguan barruko aire tenperatura areagotuz*
- *Udaran barruko aire tenperatura murriztuz*
- *Bizilagunen konfort termikoa areagotuz.*

Use of renewable energy

The development of sources of renewable energy is a crucial part of the strategy to cut carbon emissions, but for these to work them also has to be economically viable. As the technology evolves and becomes more widespread the economies will improve. One of the key aspects for the success of integrating sources of renewable energy into the construction programs will be the ease with which they can be incorporated into building design. These kind of active refurbishment strategies are based in using sustainable sources of energy like wind, the sun, water and the ground to generate energy.

The second parameter that determines the type of renewable energy system is its "generation location", which differentiates between on site and off site systems.

Energia berriztagarrien erabilera

Energia-iturri berriztagarriak garatzea karbono-emisioak murrizteko estrategiaren ezinbesteko parte bat da, baina haiek erabili ahal izateko, ekonomikoki bideragarriak ere izan behar dute. Teknologia garatuz eta zabalduz doan heinean, ekonomiak hobetuz joango dira. Energia-iturri berriztagarriak eraikuntza-programetan sartzeak arrakasta izan dezan, gakoetako bat izango da zer erraztasunekin sar daitezkeen eraikinaren diseinuan. Horrelako eraberritze-estrategia aktiboak energia sortzeko energia-iturri berriztagarriak erabiltzean oinarrituta daude; esaterako, haizea, eguzkia, ura eta lurzorua.

Energia berriztagarriaren sistema-mota baldintzatzen duen bigarren parametroa hura "sortzen den lekua" da, eta hor barruko eta kanpoko sistemak bereizten dira.

Option	Supply site options	Examples
On-site	Using renewable energy sources available within the building's footprint	PV, solar hot water, and wind located on the building.
	Using renewable energy sources available at the site	PV, solar hot water, low-impact hydro, and wind located on-site, but not on the building
Off-site	Using renewable energy sources available off site generate energy on site	Biomass, wood pellets or biodiesel that can be imported from off site, which can be used on-site to generate electricity and heat.
	Purchasing off-site renewable energy sources	Utility-based wind, PV or other green purchasing options.

The implementation of such strategies (thermal solar panels, photovoltaic panels, biomass boilers or mini-wind) does not directly affect in the increment of thermal comfort of the inhabitants. However, their influence will be directly in aspects such as:

- Environmental: reduction of consumption of the non-renewable sources energy.
- Economical: generation of “free” energy (except the initial investment and the maintenance cost).

Efficient Technologies

The remaining step is to be efficient with the remaining resources, where fossil fuels have to make up the shortfall in energy supply this should be done as cleanly and as sparingly as possible. If there are no alternatives, then conventional fuels must be used as efficient as possible. In the ideal situation the use of conventional fuels will be diminished to zero. Among these technologies, the most used is the replacement of energy generation systems:

- Replacement of current energy generation systems by new systems with increased performance and / or other energy sources with a lower environmental impact or lower economic cost
- Replacement of individual systems for centralized systems.

Estrategia horiek ezartzeak (eguzki energía termikoa, eguzki energía fotovoltaikoa, biomasa galdara edo haize errota txikia) ez du zuzenean herritarren erosotasun termikoa handitzen. Baina eragin zuzena izango dute alderdi hauetan, adibidez:

- *Ingurumen: iturri ez berriztagarriko energia kontsumoaren murriztea.*
- *Ekonomiko: doako energia generazioa (hasierako inbertsio eta mantentze kostua ezik).*

Teknologia eraginkorrak

Geratzen den azken urratsa da geratzen diren baliabideekin eraginkorrak izatea. Erregai fosilek bete behar dute energia-hornikuntzaren gabezia, eta hori ahalik eta modurik garbienean eta neurriz egin beharko litzateke. Alternatibarik ez badago, orduan, erregai konbentzionalak ahalik eta modurik eraginkorrenean erabili behar dira. Egoera ideal batean, erregai konbentzionalen erabilera zerora murriztuko litzateke. Teknologia horien artean, erabiliena energia sortzeko sistemak ordezkatzekoa da:

- *Sistema eraginkor berrien bidez gaur egungo energía generazio sistemen ordezkatzea eta / edo ingurumen inpaktu edo koste ekonomiko txikiago duten beste energia iturri batzuen erabilera.*
- *Sistema zentralizatuen bidez banakako sistemen ordezkatzea*

If the rehabilitation was to be carried out at the district level, this would allow for the implementation of efficient technologies such as district heating, which is based on efficient and renewable generation systems (biomass boiler, cogeneration system or waste heat recovery system) and an optimized distribution. At the same time, if the demand for a cooling system was higher, district cooling strategies or trigeneration systems (generation of heat, cold and electricity) could be suggested.

Birgaitze-lana auzo mailan egin beharko balitz, teknologia eraginkorrak ezarri ahalko lirateke; esaterako, auzo-berokuntza, energia berriztagarriak sortzeko sistema eraginkorretan (biomasa galdara, kogenerazio sistema edo hondakinen bero berreskurapen sistema) eta banaketa optimizatu batean oinarritua dagoena. Aldi berean, hozte-sistema baterako eskaera handiagoa balitz, auzo mailako hozte-estrategiak edo trigenerazio-sistemak (bero, hozte eta elektrizitate generazioa) proposatu ahalko lirateke.

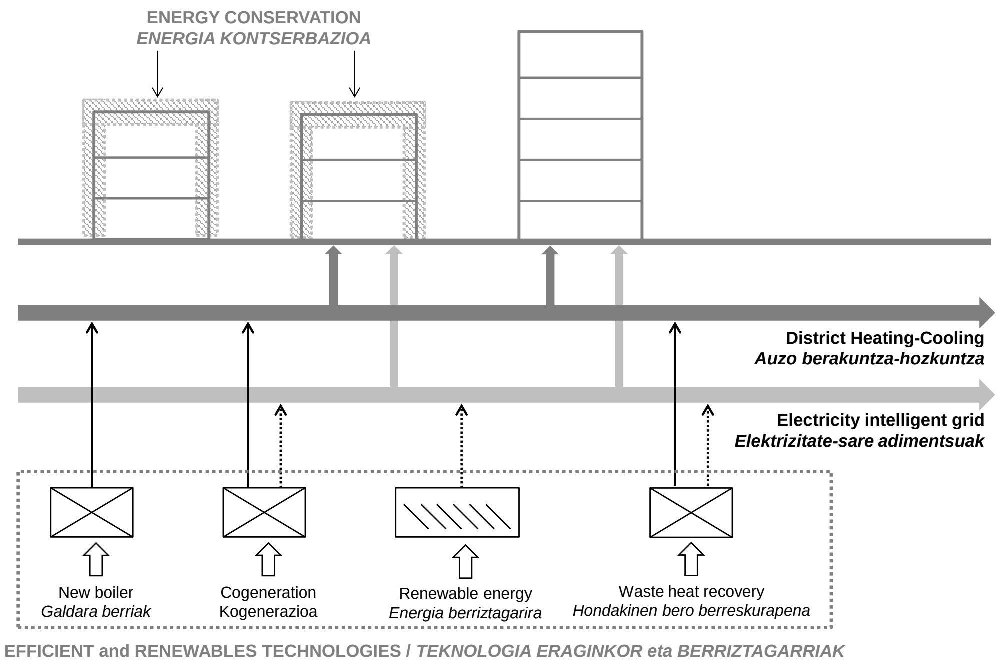


Figure / Irudia 11 Scheme of the different strategies for energy rehabilitation of existing buildings / *Gaur egungo eraikinen energia birgaitze estrategia ezberdinen eskema*

Together with these strategies, it must not be forgotten that one of key factors when trying to improve the energy performance of a building is the **Human**

Estrategia horiekin batera, ez dugu ahaztu behar eraikin baten energia-eraginkortasuna hobetzen saiatzerakoan faktore gakoetako bat

Factor, which could lead to a significantly improvement of the current situation through training and awareness increase.

giza faktorea *dela, zeinak uneko egoera asko hobetu bailezake trebakuntzaren bidez eta kontzientziazioa handituz.*

2.3. European buildings energy legislations / *Eraikinen Europako energia araudiak*

In order to regulate rehabilitation strategies and define the lines of work regarding aspects such as the reduction of environmental and energy impact generated by the different figures of existing buildings, the European Commission has been trying to establish ever demanding regulations and directives since the eighties.

Eraikin mota desberdinek sortzen duten ingurumen eta energia-inpaktua murrizteko alderdiei buruzko lan-ildoak zehazteko eta birgaitze-estrategiak arautzeko, Europako Batzordea gero eta arau eta zuzentarau zorrotzagoak ezartzen saiatzen ari da laurogeiko hamarkadaz geroztik.

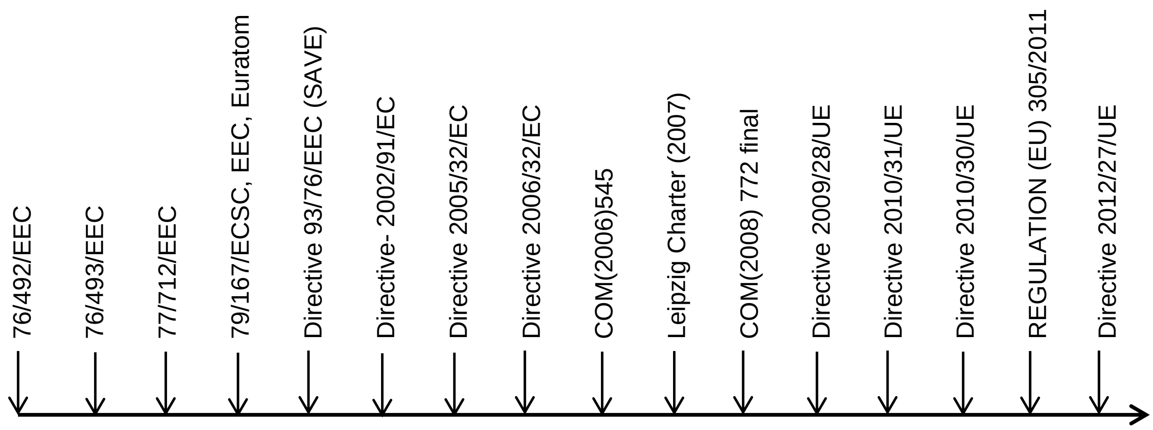


Figure / Irudia 12 Chronological summary of European building energy efficiency Directives and Council Recommendations / *Eraikinen energia eraginkortasunaren inguruko Europako zuzentarau eta gomendioen laburpen kronologikoa*

- 76/492/EEC (*CR 76/492/EEC, 1976*).

An energy policy whose objective was focussed on the "reduction of the rate of growth of internal consumption by

Energia-politika bat, helburutzat hau duena: "barne-kontsumoaren igoera-tasa murriztea energia zentzuz measures for using energy rationally and economically without jeopardizing social and economic growth objectives". For that, this standard promoted the use of thermal insulation of buildings.

erabiltzeko eta energia aurrezteko neurrien bidez, eta hazkuntza sozial eta ekonomikoko helburuak arriskuan jarri gabe". Hori dela eta, irizpide horrek eraikinetan isolamendu termikoa erabiltzea sustatu zuen.

- 76/493/EEC (*CR 76/493/EEC, 1976*).

Council recommendation on the rational use of energy in the heating systems of existing buildings. This document proposed aspects such as the automatic programming and regulating device which will produce the desired temperature curve, fitting of separate automatic cut-in devices, heating systems individual regulations, maintenance and inspection of heating systems or the improvement of the improving the efficiency of hot-water systems in residential accommodation.

Kontseiluaren gomendioa, eraikinetako berokuntza-sistemetan energia arrazoizko eran erabiltzeari buruzkoa. Dokumentu horrek hainbat alderdi proposatzen zituen, besteak beste: programatzeko eta erregulatzeko gailu automatiko bat, nahi den tenperatura-kurba ezarriko duena; automatikoki konektatzeko gailu bereizien instalazioa; norberak erregulatzeko berokuntza-sistemak; berokuntza-sistemen mantentze-lanak, eta ikuskapena edo etxebizitzetako ur beroko sistemen eraginkortasuna hobetzea.

- 77/712/EEC (*CR 77/712/EEC, 1977*).

Council recommendation on the regulating of space heating (system with an automatic programming and regulation device, indoor temperature limits when the heat generators are operating, the production of domestic hot water (temperature of hot water at the entry to the common circuit does not exceed 60°C) and the metering of heat in new buildings (each dwelling heated by a collective installation is fitted with the means of metering).

Kontseiluaren gomendioa eraikin berrietan hauek erregulatzeko: berokuntza (automatikoki programatzeko eta erregulatzeko gailua duen sistema, barruko tenperatura mugatu egiten da bero-sorgailuak martxan daudenean), ur bero sanitarioaren ekoizpena (ur beroaren tenperaturak ez du 60°C-tik gorakoa izan behar zirkuitu komunean sartzerakoan) eta beroaren kontrola (instalazio kolektibo baten bidez berotutako etxebizitza bakoitzean *neurketa-gailuak instalatuta izatea).*

- 79/167/ECSC, EEC, Euratom (*CR 79/167/ECSC, 1979*).

Council recommendation of 5 February 1979 on the reduction of energy requirements for buildings in the Community. To pursue, it recommended to member states to develop policies to save energy by reducing energy requirements through the improvement of the thermal efficiency of buildings. These policies shall be decided in the context of a programme extending over at least four years, which takes account of variations in social, economic and climatic conditions.

1979ko otsailaren 5eko Kontseiluaren gomendioa, Komunitateko eraikinen energia-eskaera murrizteari buruzkoa. Estatu kideei gomendatu zaie energia aurrezteko politikak garatzea; horretarako, eraikinen eraginkortasun termikoa hobetuz energia-eskaerak murriztu behar dira. Politika horiek gutxienez lau urteko iraupena izango duen programa baten testuinguruan erabakiko dira, eta kondizio sozialen, ekonomikoen eta klimatikoen aldaketak kontuan hartuko dira.

- Directive 93/76/EEC - SAVE (*Directive 93/76/EEC, 1993*).

The purpose of this Directive was the attainment by Member States of the objective of limiting carbon dioxide emissions by improving energy efficiency, notably by means of drawing up and implementing programmes in the following fields: energy certification of buildings; financing for energy efficiency investments in the public sector; thermal insulation of new buildings; regular inspection of boilers; and energy audits of undertakings with high energy consumption. Programmes could include laws, regulations, economic and administrative instruments, information, education and voluntary agreements whose impact could be objectively assessed.

Zuzentarau horren helburua energia eraginkortasuna hobetuz estatu kideek karbono dioxidoen emisioak mugatu zitzaten lortzea zen, batez ere arlo hauetako programak diseinatuz eta ezarriz: eraikinen ziurtagiri energetikoa, sektore publikoan energia eraginkortasunean inbertsioak garatzeko finantziazioa, eraikin berrien isolamendu termikoa, galderen ikuskatze erregularra eta energia kontsumo handia duten eragileen energia ikuskapenak. Programetan sartuko lirateke legeak, arauak, tresna ekonomiko eta administratiboak, informazioa, hezkuntza eta eragina objektiboki ebaluatzeko aukera ematen duten borondatezko hitzarmenak.

- Directive 2002/91/EC (*Directive 2002/91/EC, 2002*).

The Energy Performance of Buildings Directive (EPBD) was developed within the context of promoting clean energy and CO_2 emission reductions to generate a resource efficient economy which was more secure and less dependent upon external primary energy sources. All the EU countries were required to improve their energy regulations and to introduce energy certification schemes for buildings.

Eraikinen Energia Eraginkortasunari buruzko Zuzentaraua energia garbia eta CO_2-emisioak murriztea sustatzeko testuinguru batean garatu zen, baliabideak eraginkortasunez erabiltzen dituen ekonomia bat sortzeko, seguruagoa izango dena eta kanpoko energia-iturri primarioekiko mendekotasun txikiagoa izango duena. EB-eko herrialde guztiei eskatu zitzaien energia-araudiak hobetzeko eta eraikinen energia-ziurtapenak ezartzeko.

- Directive 2005/32/EC (*Directive 2005/32/EC, 2005*).

This Ecodesign Directive establishes a framework for the setting of Community ecodesign requirements for energy-using products. It contributes to sustainable development by increasing energy efficiency and the level of protection of the environment, while at the same time increasing the security of the energy supply.

Ekodiseinuari buruzko Zuzentarau horrek esparru bat ezartzen du energia erabiltzen duten produktuei ekodiseinu-eskakizunak ezartzeko. Garapen jasangarria bultzatzen du energia-eraginkortasuna eta ingurumenaren babes-maila handituz, eta aldi berean energia-hornikuntzaren segurtasuna handituz.

- Directive 2006/32/EC (*Directive 2006/32/EC, 2006)*

The purpose of this Directive was to enhance the cost-effective improvement of energy end-use efficiency in the Member States providing the necessary indicative targets as well as financial and legal frameworks to remove existing market barriers that impede the efficient end use of energy; and creating the conditions for the development of a market for energy services and for the delivery of other energy efficiency

Zuzentarau horren helburua zen energiaren azken erabileraren eraginkortasuna errentagarriagoa egitea estatu kideetan; horretarako, energiaren azken erabilera eraginkorra eragozten duten merkatu-oztopoak kentzeko behar diren helburu adierazgarriak eta esparru finantzario eta legalak ezarriko ziren, eta baldintzak sortuko ziren energia-zerbitzuen merkatu bat garatzeko eta azken erabiltzaileentzako energia-

improvement measures to final consumers.

eraginkortasuna hobetzeko beste neurri batzuk finkatzeko.

- COM(2006)545. (*CEC, 2006*).

The purpose of this Action Plan for energy efficiency was to mobilise the general public, policy-makers and market actors, and to transform the internal energy market in a way that provides EU citizens with the most energy-efficient infrastructure, products and energy systems. The objective of the Action Plan is to control and reduce energy demand and to take targeted action on consumption and supply in order to save 20% of annual consumption of primary energy by 2020.

Ekintza Plan horrek energia-eraginkortasunerako duen helburua da publiko orokorra, politika-arduradunak eta merkatuko eragileak mobilizatzea, eta, halaber, energiaren barne-merkatua aldatzea, EBko herritarrei energia-eraginkortasun handieneko azpiegiturak, produktuak eta energia-sistemak eskaintzeko. Ekintza Planaren helburua da energia-eskaera kontrolatzea eta murriztea, eta selektiboki jardutea kontsumoari eta hornikuntzari dagokienez, 2020rako % 20 murrizteko energia primarioaren urteko kontsumoa.

- Leipzig Charter (*Leipzig, 2007*).

Since the signing of the Leipzig Charter of 2007, the energy rehabilitation is within the priorities of the European Union. This letter supports the sustainable development of cities through the energy efficiency improvement of existing buildings.

2007an Leipzigeko Gutuna sinatu zenetik, birgaitze energetikoa Europar Batasunaren lehentasunetako bat da. Gutun horrek hirien garapen jasangarria bultzatzen du, lehendik dauden eraikinen energia-eraginkortasuna hobetuz.

- COM(2008) 772 final (*CEC, 2008*).

EU leaders had stressed the need to increase energy efficiency as part of the '20-20-20' goals for 2020: save 20% of the EU's primary energy consumption through increased energy efficiency, a binding target of 20% reduction of greenhouse gas emissions and 20%

EBko buruek energia-eraginkortasuna handitzeko beharra azpimarratu dute 2020rako '20-20-20' helburuen barruan: EBren energia primarioaren kontsumoa % 20 aurreztea energia-eraginkortasuna handituz, berotegi-efektuko gasen emisioak % 20 murrizteko helburu lotesle bat finkatzea eta 2020rako % 20 renewable energies by 2020.

energia berriztagarriak izatea.

- Directive 2009/28/UE (*Directive 2009/28/EC, 2009*).

This Directive establishes a common framework for the promotion of energy from renewable sources. It sets mandatory national targets for the overall share of energy from renewable sources in gross final consumption of energy.

Zuzentarau horrek esparru komun bat ezartzen du energia berriztagarrietatik eratorritako energia sustatzeko. Helburu lotesle nazionalak jarri dira, ezartzeko kontsumitzen den energia-kantitate osotik zer portzentajek izan behar duen energia berriztagarrietatik sortua.

- Directive 2010/31/UE (*Directive 2010/31/UE, 2010*)

2002/91/EC was not transposed fully in many Member States and as a result the European Commission proposed a new version of the EPBD (2010), which urged member states to ensure all new public buildings will be “nearly zero-energy buildings” by the end of 2018 (all new private sector buildings from 2020), benchmark national energy performance requirements against cost-optimal levels, make energy performance certificates mandatory for the rental-sale and elaborate national plans that encourage owners to make energy efficiency improvements in the existing housing stock.

2002/91EE Zuzentaraua ez zen osorik ezarri estatu kide askotan, eta, horren ondorioz, Europako Batzordeak Eraikinen Eraginkortasun Energetikoaren (EEE) inguruko zuzentarauaren (2010) beste bertsio bat proposatu zuen. Bertsio horretan, estatu kideei hau eskatzen zaie: ziurta dezatela eraikin publiko berri guztiak "ia zero energiako eraikinak" izango direla 2018. urtearen amaierako; energia-eraginkortasuneko eskakizun nazionalak errentagarritasun-maila optimoekin alderatu ditzatela; energia-eraginkortasunari buruzko ziurtagiriak nahitaezko bihur ditzatela alokairuko eta salmentako etxebizitzetan; eta, azkenik, plan nazionalak egin ditzatela jabeak animatzeko lehendik dauden etxebizitzen energia-eraginkortasuna hobetzera.

- Directive 2010/30/UE (*Directive 2010/30/UE, 2010*)

This Directive establishes a framework for the harmonisation of national measures on end-user information,

Zuzentarauak azken erabiltzailea informatzeko neurri nazionalak harmonizatzeko esparru bat ezartzen particularly by means of labelling and standard product information, on the consumption of energy and where relevant of other essential resources during use, and supplementary information concerning energy-related products, thereby allowing end-users to choose more efficient products.

du, batez ere produktuen energia-kontsumoari eta, dagokionean, erabiltzean kontsumitzen diren bestelako funtsezko baliabideen kontsumoari buruzko etiketa eta informazio estandarraren bidez, eta energiarekin lotutako produktuei buruzko informazio osagarria emanez, azken erabiltzaileek produktu eraginkorragoak hautatzeko aukera izan dezaten.

- REGULATION (EU) No 305/2011 (*Regulation 305/2011, 2011*)

This Regulation lays down conditions for the placing or making available on the market of construction products by establishing harmonised rules on how to express the performance of construction products in relation to their essential characteristics and on the use of CE marking on those products.

Araudi horrek baldintzak ezartzen ditu eraikuntza-produktuak merkatuan sartzeko edo merkaturatzeko. Horretarako, arau harmonizatuak ezartzen ditu, eraikuntza-proiektuek beren oinarrizko ezaugarriei dagokienez duten errendimendua nola adierazi behar den eta produktu horietan CE marka nola erabili behar den finkatzeko.

- REGULATION (EU) No 244/2012 (*Regulation 244/2012, 2012)*

This Regulation establishes a comparative methodology framework to be used by Member States for calculating cost-optimal levels of minimum energy performance requirements for new and existing buildings and building elements. The methodology framework specifies rules for comparing energy efficiency measures, measures incorporating renewable energy sources and packages and variants of such measures, based on the primary energy

Araudi horrek esparru metodologiko konparatibo bat ezartzen du, estatu kideek erabil dezaten, eraikin eta eraikuntza-elementu berriek eta lehendik daudenek gutxienez bete beharreko energia-eraginkortasuneko eskakizunen errentagarritasun-maila optimoak kalkulatzeko. Metodologia-esparruak arauak zehazten ditu energia-eraginkortasuneko neurriak, energia-iturri berriztagarriak barne hartzen dituzten neurriak eta neurri horien paketeak eta aldaerak elkarrekin performance and the cost attributed to their implementation. It also lays down how to apply these rules to selected reference buildings with the aim of identifying cost-optimal levels of minimum energy performance requirements. In addition, this regulation defines that “It is the responsibility of Member States to set minimum energy performance requirements for buildings and building elements. The requirements must be set with a view to achieving cost-optimal levels”.

konparatzeko, energia primarioaren errendimenduan eta haiek ezartzeak izango lukeen kostuan oinarrituta. Halaber, ezartzen du arau horiek nola aplikatu behar zaizkien hautatutako erreferentzia-eraikinei, energia-eraginkortasuneko gutxieneko eskakizunen errentagarritasun-maila optimoa identifikatzeko. Horrez gainera, zehazten du "estatu kideen erantzukizuna dela eraikinen eta eraikuntza-elementuen energia-eraginkortasuneko gutxieneko eskakizunak ezartzea. Errentagarritasun maila optimoak lortzeko ezarri behar dira eskakizunak".

- Directive 2012/27/UE (*Directive 2012/27/EU, 2012*)

In 2011, the European Commission recognized the need to redouble efforts to deliver energy efficiency, as it seemed that its 2020 target would not be reached, and it launched a review process that resulted in the passing of the new Energy Efficiency Directive (EED) in October of 2012. This Directive establishes a common framework of measures for the promotion of energy efficiency within the Union in order to ensure the achievement of the Union’s 2020 20 % headline target on energy efficiency and to pave the way for further energy efficiency improvements beyond that date. This new EED define especially new parameters related with the building refurbishment: A mandatory reform of 3% of the surface area of

2011n, Europako Batzordeak onartu zuen ahalegin handiagoa egin behar zela energia-eraginkortasuna hobetzeko, 2020rako ezarritako helburua ez zela beteko baitzirudien, eta berrikuste-prozesu bat jarri zuen martxan. Prozesu haren ondorioz, Energia Eraginkortasunari buruzko Zuzentarau berria onartu zen 2012ko urrian. Zuzentarau horrek EBn energia-eraginkortasuna sustatzeko neurrien esparru komun bat ezartzen du, EBk 2020rako energia-eraginkortasunari buruz duen % 20ko helburu nagusia lortzea ziurtatzeko eta data horretatik aurrera energia-eraginkortasuna hobetzeko bidea urratzeko. EED berri horrek eraikinen birgaitze-lanei buruzko parametro berriak ezartzen ditu bereziki:

public buildings and the obligation for each EU Member State to develop a long-term “road map” for the Buildings sector to encourage investment in the deep renovation of buildings.

Eraikin publikoen azaleraren % 3 nahitaez eraberritzea eta EBko estatu kide bakoitzak eraikuntza-sektoreari buruzko epe luzeko "bide-orri" bat egitea, eraikinen birgaitze sakona egiteko inbertsioak sustatzeko.

2.4. Evaluation methodologies / *Ebaluazio metodologiak*

On 16 December 2002, the European Union adopted the Energy Performance of Buildings Directive (EPBD), (*Directive 2002/91/EC, 2002*) which was one of the main EU policy instrument to improve the energy performance of buildings. Among other measures, the article 7 introduced a framework for Energy Performance Certification (EPC), allowing assessing the energy performance of the new and refurbished buildings in different European Member States based on a common methodology in a harmonized and standardized form. In addition, this directive determinates aspects related to the minimum standards on the energy performance of new buildings and large existing buildings that are subject to major renovation and systems for the energy certification of new and existing buildings. Following the requirements of the first EPBD, all Member States had to introduce an effective certification scheme for:

- All buildings which are newly constructed or undergo major

*2002ko abenduaren 16an, Europar Batasunak Eraikinen Energia Eraginkortasunari buruzko Zuzentaraua (EEE) onartu zuen (*Directive 2002/91/EC, 2002*), zeina eraikinen energia-eraginkortasuna hobetzeko EBren politika-instrumentu nagusietako bat baitzen. Beste neurri batzuen artean, 7. artikuluak Energia Portaera Ziurtagiriei (EPZ) buruzko esparru bat ezarri zuen, eta haren bidez, Europako zenbait estatu kideetako eraikin berrien eta birgaituen energia-eraginkortasuna ebaluatu daiteke, metodologia komun batean oinarritutako inprimaki harmonizatu eta normalizatu baten bidez. Horrez gainera, eraikin berriek eta birgaitze sakona behar duten eraikin handiek energia-eraginkortasunari dagokionez bete beharreko gutxieneko eskakizunei loturiko alderdiak ezartzen ditu zuzentarau horrek (EPBD), bai eta eraikin berrien eta lehendik daudenen energia-ziurtapenak egiteko sistemak ere:*

- *Eraikin berri edo birgaitze handiak jasango dituzten eraikin guztiak.*

renovation;

- All buildings or building units sold or rented out to a new tenant; and
- All buildings where a total useful floor area over 1,000 m^2 is occupied by a public authority and frequently visited by the public.

Although the objective of the certificates shall be limited to the provision of information, where it shall include reference values such as current legal standards and benchmarks in order to make it possible for consumers to compare and assess the energy performance of the building, the ultimate goal of EPCs was to create a demand-driven market for energy efficiency in the building sector, thereby helping to improve the energy efficiency of the building stock in the country.

Energy performance certification provides a means of rating individual buildings how efficient (or inefficient) they are in relation to the amount of energy needed to provide users with expected degrees of comfort and functionality. The degree of efficiency depends on many factors including: local climate; the design of the building; construction methods and materials; systems installed to provide heating, ventilation, air condition or hot sanitary water; and the appliances and equipment needed to support the functions of the building and its users. Energy certification of buildings typically

- *Saldu edo alokatuko diren eraikin guztiak.*
- *1,000 m^2 baino gehiagoko azalera erabilgarria duten eraikin publikoak eta maiztasunez publikoarengandik bisitatuak direnak.*

Ziurtagirien helburua informazioa ematera mugatuko da, eta informazio horren barruan erreferentzia-balioak emango dira —adibidez, uneko lege-arauak eta erreferentzia-puntuak—, kontsumitzaileek eraikinaren energia-eraginkortasuna konparatu eta ebaluatu ahal izateko. Baina, hala eta guztiz ere, energia-portaeren ziurtagirien (EPZ) helburu nagusia zen eskaeraren araberako merkatu bat sortzea energia-eraginkortasunerako eraikuntza-sektorean, eta, ondorioz, herrialdeko eraikinen energia-eraginkortasuna hobetzen laguntzea.

Energia-eraginkortasunaren ziurtapenak aukera ematen du eraikin bakoitza zer eraginkorra (edo ezeraginkor) den ebaluatzeko, erabiltzaileek espero dituzten erosotasun- eta funtzionalitate-mailak izateko behar duen energia-kantitateari dagokionez. Eraginkortasun-maila faktore askoren mende dago. Besteak beste, hauen mende: klima lokala; eraikinaren diseinua; eraikitze-metodoak eta materialak; berokuntza- eta aireztatze-sistemak, aire girotuarenak edo ur bero sanitarioarenak; eta eraikinaren eta haren erabiltzaileen funtzioei involves three main steps:

- The assessment of the energy performance of a building by a competent assessor using a nominated methodology.
- The issuance of a certificate rating the building's energy performance which includes, in some cases, information on possible improvements likely to yield energy savings.
- The communication of this information to stakeholders through publication of the certificate.

In the case of existing buildings, certification is used to compare similar buildings and to assess the degree to which an older building falls short of codes that have been introduced since the time of its construction. As much of the existing building stock was built before energy efficiency became a focus of government policy, certification of existing buildings can do more than provide ratings: it can identify measures to improve energy performance (*Arkesteijn & Dijk, 2010*). An energy performance assessment of the buildings generally includes, as a minimum, an analysis of:

- The form, area and other details of the building.
- The thermal, solar and daylight properties of the building envelope and its air permeability.
- Space heating installation and hot water supply, including their efficiency

erantzuteko behar diren tresnak eta ekipamendua. Eraikinen energia-ziurtapena egiteko, normalean hiru urrats egin behar izaten dira:

- *Gaitasuna duen ebaluatzaile batek metodologia batean oinarrituz egindako eraikinaren energia portaeraren analisia*
- *Eraikinaren energia portaeraren ziurtagiri baten igortzea. Zenbait kasuetan energia aurrezteko hobekuntzen informazioa zehazten da.*
- *Ziurtagiri baten bidez aktore desberdinei informazio hau komunikatzea.*

Lehendik dauden eraikinen kasuan, antzeko eraikinak konparatzeko eta eraikin zaharrago batek hura eraikiz geroztik sartu diren arauak zenbateraino ez dituen betetzen ebaluatzeko erabiltzen da. Lehendik dauden eraikin asko energia-eraginkortasuna gobernuaren politikaren puntu garrantzitsu bihurtu aurretik eraiki zirenez, lehendik dauden eraikinen ziurtapenak, sailkapenak egiteaz gain, beste zerbait ere egin dezake: energia-eraginkortasuna hobetzeko neurriak identifika ditzake (Arkesteijn & Dijk, 2010). Eraikinen energia-eraginkortasuneko ebaluazio batean, gutxienez, hauen analisia sartzen da:

- *Forma, azalera eta eraikinaren beste zenbait xehetasun.*
- *Eraikinaren azalaren ezaugarri termiko, eguzkitzapen, argiztapen*

and controls.

- Ventilation, air-conditioning systems and controls, and fixed lighting.
- Fuel and renewable energy sources.
- Other elements, such as lighting systems and appliances.

This information is input into an authorised calculation model that assesses the building's energy consumption under local climatic conditions providing the final certificate. An energy performance calculation method is central to certification. Common standards have been developed to support harmonisation in Europe (through the European Committee for Standardisation -CEN) and in North America through the Residential Energy Services Network (RESNET) programme. These programmes also reflect international standards contained in the International Energy Conservation Code (IECC), those of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and those developed by the International Organisation for Standardisation (ISO). All of these standardisation efforts seek to provide guidance on comparability and transparency of certification schemes.

Assessment methodologies generally use software tools to calculate energy performance and ratings, which will often be based on annual energy use in

natural eta aire iragazkortasunaren inguruko ezaugarriak.

- *Berokuntza eta ur bero hornidura instalazioen eraginkortasuna eta kontrolak.*
- *Aireztapena, aire girotu sistemak eta kontrolak eta argiztapena.*
- *Erregaien eta energia berriztagarrien iturria.*
- *Argiztapen sistema edo etxe tresnak bezalako beste elementuak.*

Informazio hori kalkulu-eredu baimendu batean kargatzen da, eta eraikinak tokiko klima-kondizioetan duen energia-kontsumoa ebaluatzen da; horrela lortzen da azken ziurtagiria. Energia-eraginkortasuna kalkulatzeko metodo bat izatea ezinbestekoa da ziurtapena egiteko. Arau komunak garatu dira Europan (Europako Normalizazio Batzordearen bidez) eta Ipar Amerikan (Etxeko Energia Zerbitzuen Sarea programaren bidez) bateratzea bultzatzeko. Programa horiek Energia Kontserbatzeko Kodean jasota dauden nazioarteko arauak ere biltzen dituzte, bai eta Beroaren, Hotzaren eta Aire Girotuaren Ingeniarien Estatu Batuetako Sozietatearen (ASHRAE) arauak eta Normalizaziorako Nazioarteko Erakundeak (ISO) garatutakoak. Estandarizazioa sustatzeko ahalegin horien guztien xedea da ziurtapen-sistemen konparagarritasunari eta gardentasunari buruzko orientazioa ematea.

specific terms, such as the number of kilowatt hours used per square meter (kWh/(m^2·year)). They may also measure related CO_2 emissions, measured in kilograms of CO_2 per square meter (kgCO_2/(m^2·year)). However, along with the results of the final energy consumption or CO_2 emissions, other countries display their results using the impact indicator of primary energy.

Ebaluazio-metodologiek normalean software-tresnak erabiltzen dituzte energia-eraginkortasuna eta -kalifikazioak kalkulatzeko, eta horiek askotan neurri zehatz batzuetan adierazitako urteko energia-kontsumoan oinarrituta egoten dira; adibidez, metro karratu bakoitzeko orduko erabilitako kilowattak (kWh/(m^2·year)). Kontsumo horiei dagozkien CO_2-emisioak ere neurtu ditzakete, metro karratu bakoitzeko CO_2 kilotan neurtuta (kgCO_2/(m^2·year)). Bestalde, guztizko energia-kontsumoaren edo CO_2-emisioen emaitzekin batera, beste herrialde batzuek energia primarioaren inpaktu-adierazlea erabiltzen dute emaitzak bistaratzeko.

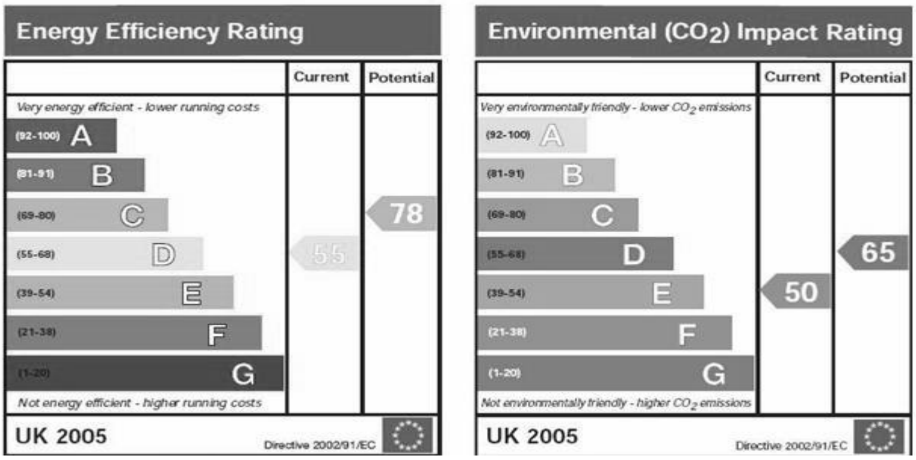


Figure / Irudia 13 Results obtained by the UK Energy Performance Certification system / *Erresuma Batuetako Energia Portaera Ziurtagi sistemaren bidez lorturiko emaitzak.*

In order to improve the quality, usability and public acceptance of EPCs, in 2010 the EPBD recast (*Directive 2010/31/EU, 2010*) added a set of new requirements (Art. 11) and broadened the scope of the directive by demanding, for

EPZ-en kalitatea, erabilgarritasuna eta onarpen publikoa hobetzeko, 2010ean EEE zuzentarau bateratuak recast (Directive 2010/31/EU, 2010) eskakizun sorta berri bat (11.art) gehitu zuen eta Zuzentarauaren irismena zabaldu zuen example, that all existing buildings undergoing major renovation should meet certain energy efficiency criteria (the original directive set this demand only for buildings larger than 1 000 m²). It also stipulates that certification must be based on life-cycle analyses. The recast calls on the public sector to be a leading example in investing in energy efficiency in buildings: it states that, by 2018, all existing public buildings over 500 m² must be certified and display certificates (from 2015 this demand will cover all public buildings of more than 250 m²). Among the recommendations could highlight issues such as the introduction of additional information as the annual energy consumption for non-residential buildings, percentage of energy from renewable sources in the total energy consumption, heating / cooling primary energy consumption or the estimate for the range of payback periods or cost-benefits over its economic lifecycle.

Both the original directive and the recast aim to overcome some of the market barriers and failures for energy efficiency by ensuring that decision makers have access to information and by providing incentives to improve energy efficiency in both new and existing buildings.

However, together with the Energy Performance Certification system based on the Directives 2002/91/EC and

eskatuz, adibidez, birgaitze handia egiten zitzaien lehendikako eraikinek energia-eraginkortasunari buruzko irizpide jakin batzuk bete behar zituztela (hasierako zuzentarauak baldintza hori 1.000 m^2 baino handiagoko eraikinentzat bakarrik ezartzen zuen). Horrez gainera, ezartzen du ziurtapenak bizi-zikloaren analisian oinarritu behar duela. Testu bateratuak sektore publikoari eskatzen dio eredu izan dadila eraikinen energia-eraginkortasunean inbertitzen. Adierazten du, 2018rako, lehendik dauden 500 m^2 baino gehiagoko eraikin publiko guztiek izan behar dituztela ziurtagiriak eta ikusgai jarri behar dituztela (2015etik aurrera, eskaera hori 250 m^2-tik gorako eraikin publiko guztiei aplikatuko zaie). Gomendioen artean azpimarratzekoa da, adibidez, informazio gehigarria sartzea; esaterako, etxebizitzak ez diren eraikinen urteko energia-kontsumoa, energia-kontsumo osotik zer ehuneko datorren energia-iturri berriztagarrietatik, berotzeko edo hozteko kontsumitutako energia primarioa eta inbertsioa berreskuratzeko epeen kalkulu bat edo bizi-ziklo erabilgarrian izango dituen kostu-onuren kalkulu bat. Bai jatorrizko zuzentarauak eta bai zuzentarau berridatziak energia-eraginkortasuneko merkatuaren oztopo eta hutsune batzuk gainditzea dute helburu; horretarako, ziurtatzen dute erabaki-hartzaileek informazioa eskuratu dezaketela, eta

2010/31/EU and with the purpose of promoting improvement of the energy efficiency of the building stock and evaluating aspects such as the cost-optimal, new systems or evaluation methodologies have been developed and implemented in recent years, the most important of which are two work methodologies.

pizgarriak ematen dituzte eraikin berrien nahiz lehendik daudenen energia-eraginkortasuna hobetzeko.

Bestalde, 2002/91/EE eta 2010/31/EE zuzentarauetan oinarritutako EPZ sistemarekin batera, eta eraikinen energia-eraginkortasuna hobetzea sustatzeko eta zenbait alderdi —esate baterako, errendimendua— ebaluatzeko asmoz, sistema edo ebaluazio-metodologia berriak garatu eta ezarri dira azken urteotan, non garrantzitsuenak bi lan-metodologia diren.

0- Energy Performance Certification
Energia portaera ziurtagiria

1- Multi-Criterial Voluntary Sustainability Evaluation systems
Borondatezko Irizpide Anitzeko Jasangarritasun Ebaluazioa

2- Life Cycle methodology
Bizi ziklo analisia

On the one hand, there are the Multi-Criteria Voluntary Sustainability Evaluation systems, whose main focus is on evaluating most of the aspects related to the concept of "green building" and increasing the awareness among customers by specifying the benefits of green building. On the other hand, there is the methodology of life cycle thinking, which evaluates all stages of the life cycle of a system, process or architectural performance, evaluating and valuing every decision taken at each stage of the project.

Alde batetik, Borondatezko Irizpide Anitzeko Jasangarritasun Ebaluazioaren (BIAJE) sistemak daude: funtsean "eraikin berdea" kontzeptuarekin lotutako alderdi gehienak ebaluatzen dituzte eta, eraikin berdearen onurak zehaztuz, bezeroen artean kontzientziazioa handitzen dute. Bestetik, bizi-zikloari buruzko metodologia dago. Horrek sistema, prozesu edo arkitektura-adierazpenen bizi-zikloaren fase guztiak ebaluatzen ditu, proiektuaren fase bakoitzean hartu diren erabaki guztiak ebaluatuz eta aintzat hartuz.

2.4.1. Multi-Criterial Voluntary Sustainability Evaluation systems / *Borondatezko Irizpide Anitzeko Jasangarritasun Ebaluazioa*

From 1990, with the aim of boosting the term "Green building" or sustainable building, different work teams began to define various MCVSE systems allowing to the end user to evaluate the overall performance (environmental, energy and social) of their building.

The main distinguishing feature of this type of evaluation systems, in comparison with the EPC tools, is their evaluation entirety. The reason for this being that, along with the assessment of the energy, they analyse aspects such as the management, sustainable site, management, water efficiency, waste, pollution, materials, resources, indoor environmental quality, etc. That is, they allow for the analysis and improvement of most part of the parameters of an energy rehabilitation performance.

Due to the high competition in the construction sector, to the need for new benchmarking systems to set a building apart from others and from the significance of environmental seals from MCVSE systems, new MCVSE systems are increasingly developing and there is an ever growing number of technicians and investors who choose to apply this type of voluntary evaluation methodologies in their buildings (see figure 14).

1990az geroztik, eraikin berdea terminoa edo eraikuntza jasangarriari bultzada emateko asmoz, lantalde batzuk zenbait BIAJE sistema zehazten hasi ziren azken erabiltzaileari aukera emanez beren eraikinaren errendimendu orokorra (ingurumen, ekonomiko eta soziala) ebaluatzeko.

Horrelako ebaluazio-sistemen ezaugarri bereizgarri nagusia da, EPZen tresnekin alderatuta, haien ebaluazioa osatuagoa dela. Izan ere, energia ebaluatzeaz gain, beste hainbat alderdi aztertzen dituzte; esaterako, kudeaketa, kokaleku jasangarria, ur-kudeaketaren eraginkortasuna, hondakinak, poluzioa, materialak, baliabideak, barruko giroaren kalitatea, etab. Hau da, aukera ematen du birgaitze energetikoko lan baten parametro gehienak aztertzeko eta hobetzeko.

Eraikuntza-sektorean dagoen lehia handiagatik, eraikin bat besteetatik bereizteko erreferentzialtasun-sistema berrien beharragatik eta, BIAJE sistemen ingurumen-zigiluek duten garrantziagatik, BIAJE sistema berriak ari dira garatzen eta gero eta teknikari eta inbertitzaile gehiagok aukeratzen dute (ikus 14. irudia) horrelako borondatezko ebaluazio-metodologiak aplikatzea beren eraikinetan.

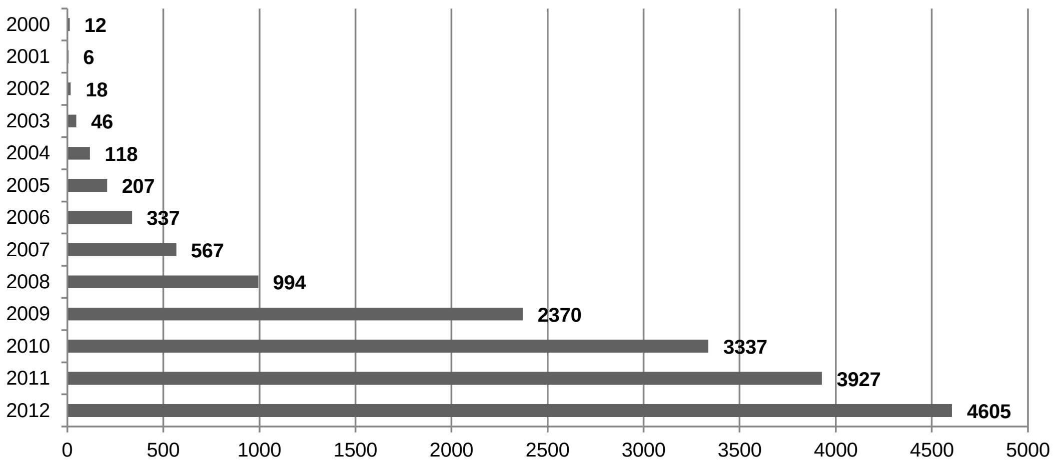


Figure / Irudia 14 LEED-certified projects over time / *LEED ziurtagiria duten proiektuak denboran zehar*. Source / *Iturria*: (LEED)

This new demand from the construction market has led to the existence of various MCVSE systems (see figure 15) allowing for the evaluation of buildings' sustainability and rehabilitations performed in them (for more information, see annex 7.1).

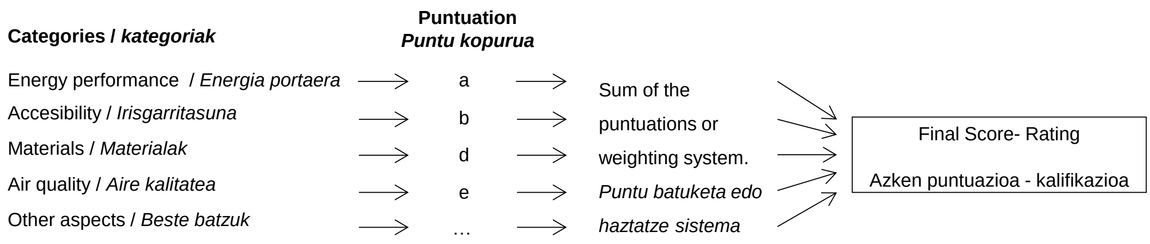
Eraikuntza-merkatuaren eskaera berri horren ondorioz, BIAJE sistema ugari daude (ikus 15. irudia), eraikinen jasangarritasuna eta birgaitze-lanak ebaluatzeko aukera ahalbideratuz (informazio gehiago 7.1 eranskinean).

Figure / Irudia 15 Current different Multi-Criterial Voluntary Sustainability Evaluation (MCVSE) systems / *Gaur egungo zenbait Borondatezko Irizpide Anitzeko Jasangarritasun Ebaluazioa (BIAJE)sistemak*

Although as shown in the annex 7.1, each MCVSE system considers different parameters, the general structure and working philosophy of all turns out to be similar. Using different calculation systems, each MCVSE determines a score range for each evaluated

7.1 eranskinean erakutsi bezala BIAJE sistema bakoitzak parametro desberdinak kontuan hartzen dituen arren, antzekoa da horien guztien egitura orokorra eta lan egiteko filosofia. Kalkulu-sistema desberdinak erabiliz, BIAJE bakoitzak puntuazio-tarte bat parameter and once obtained that score, by the sum of points or by a weighting system, the end user gets the final score or rating for the refurbished building.

zehazten du ebaluatutako parametro bakoitzarentzat, eta behin puntuazio hori lortuta —puntuak gehituta edo haztapen-sistema baten ondorioz—, azken erabiltzaileak eraikin birgaituaren azken puntuazioa edo sailkapena lortzen du.



However, this increase in MCVSE systems is analysed by more and more research works based primarily on analysing one of the critical points of such systems MCVSE: the lack of standardization of a comprehensive set of criteria, and also of the metric measurement. In the study of Zeinal et al. (*Zeinal & Huber, 2012*), a brief history, introduction, certification process, certification types, criteria, rating system, advantages and disadvantages of DGNB, LEED and BREEAM are reviewed. Martin Yuce (*Yuce, 2012*) carried out a comparative analyse between LEED, BREEAM, and DGNB green building certification systems. This analysis demonstrated the necessary further improvement of the three systems since important categories and/or criteria are missing. Due to the differences between BREEAM and LEED building

Bestalde, gero eta ikerketa-lan gehiagok aztertzen dute BIAJE sistemen gorakada hori, sistema horien alderdi kritikoetako baten azterketan oinarrituta, batez ere: irizpide-sorta oso baten eta neurketa metrikoaren normalizazio falta. Zeinal-en azterketak (Zeinal & Huber, 2012) hauek jasotzen ditu: DGNB, LEED eta BREEAMen historia labur bat, sarrera, ziurtapen-prozesua, ziurtagiri-motak, irizpideak, ebaluazio-sistema eta abantailak eta desabantailak. Martin-ek eraikin berdeen LEED, BREEAM eta DGNB ziurtapen-sistemen arteko azterketa konparatiboa egin zuen (Yuce, 2012). Azterketa horrek erakutsi zuen hiru sistemak hobetu beharra zegoela, kategoria eta/edo irizpide garrantzitsu batzuk falta baitziren. BREEAM eta LEED ziurtapen-sistemen arteko desberdintasunak direla eta, Schwartz-ek erakutsi zuen (Scwartz & Raslan, 2013) azterketan eredutzat hartutako eraikinari certification systems, Schwartz (*Scwartz & Raslan, 2013*) shows that the case study building was awarded a considerably different rating level in each. The study realized by Lee (*Lee, 2013*) shows a comprehensive review and comparison of the issues and metrics of five representative qualitative evaluation systems: BREEAM, LEED, CASBEE, BEAM Plus and the Chinese scheme ESGB. Comparison of these five schemes shows that BREEAM and LEED are the most comprehensive. The aim of the study realized by Seinre (*Seinre et al, 2014*) was to classify Estonian best practice buildings and regulations against LEED and BREEAM sustainable building schemes. It compares each category and score, showing what would be the influence of applying different certification systems. Finally, the study of Reith (*Reith & Orova, 2015*) compares five assessment systems: CASBEE-UD, BREEAM Communities (2009 and 2012 versions), LEED-ND and DGNB-UD.

sailkapen-maila oso desberdina ematen zitzaiola sistema bakoitzean. Lee-k egindako azterketak (Lee, 2013) bost ebaluazio-sistema adierazgarri eta kualitatibo hauen arazoen eta neurketen berrikuspen eta konparaketa oso bat eskaintzen du: BREEAM, LEED, CASBEE, BEAM Plus eta ESGB eskema txinatarra. Bost eskema horien arteko konparaketak erakusten du BREEAM eta LEED direla osoenak. Seinre-k egindako azterketaren helburua (Seinre et al, 2014) zen Estoniako eraikinetako jardunbide egokiak eta araudiak LEED eta BREEAM eraikin jasangarrien eskemekin konparatzea. Kategoria eta puntuazio guztiak konparatzen ditu, erakutsiz nola eragingo lukeen ziurtapen-sistema desberdinak aplikatzeak. Azkenik, Reith-en azterketak (Reith & Orova, 2015) bost ebaluazio-sistema konparatzen ditu: CASBEE-UD, BREEAM Communities (2009 eta 2012ko bertsioak), LEED-ND eta DGNB-UD

As shown in previous studies, this lack of standardization of the assessment criteria may result in different outcomes with regards to the same energy rehabilitation performance, depending on the MCVSE system applied.

Aurreko azterketek erakutsi bezala, ebaluazio-irizpideen normalizazio falta horrek birgaitze energetikoko lan berak emaitza desberdinak izatea ekar dezake, aplikatzen den BIAJE sistemaren arabera.

In order to delve into this lack of standardization of the assessment criteria in this type of evaluation systems, this section focuses on

Horrelako ebaluazio-sistemetako ebaluazio-irizpideen normalizazio falta hori sakonago aztertzeko, atal honek nazioarteko bi ebaluazio-sistema analysing the operation of the weighting of two international qualitative evaluation systems (LEED and BREEAM) and make-critical reflection about their objectivity and criterion. Refine that this work will focus on analysing only the points related to paragraphs Energy & Atmosphere, Materials & Resources and Indoor Environmental Quality, which are directly related to an energy refurbishment strategy. As a first step of analysis, in order to get an overview of the functioning of these systems, in the same table 5 are grouped the items or requirements related to each other.

kualitatiboren (LEED eta BREEAM) haztapen-jarduera aztertzen du, eta gogoeta kritiko bat egiten du haien objektibotasunari eta irizpideari buruz. Zehaztu behar da lan honek "Energia eta atmosfera", "Materialak eta baliabideak" eta "Barruko giro-tenperatura" paragrafoei buruzko puntuak baino ez dituela aztertuko, horiek lotura zuzena baitute birgaitze energetikoko estrategia batekin. Azterketaren lehen urrats gisa, sistema horien funtzionamenduaren ikuspegi orokorra zein den ikusteko 5. taulan bertan multzokatuta daude bakoitzari lotutako elementuak eta eskakizunak.

Table / Taula 5 Different issues considered in LEED and BREEAM assessment systems and their score.

BREEAM		LEED	
Health & Wellbeing		**Indoor Environmental Quality**	
Visual Comfort	1	Daylight and Views – Daylight	1
Exterior views	1	Daylight and Views – Views	1
Glare control	1		
High frequency lighting	1		
Levels of external and internal lighting	1		
Areas and lighting controls	1	Controllability of Systems – Lighting	1
Indoor air quality	1	Minimum Indoor Air Quality	1
Volatile organic compounds	1	Low-Emitting Materials	1-6
Thermal comfort	2	Thermal Comfort (TC)	1+1
Thermal zoning	1	Controllability of TC Systems	1
Energy		**Energy & Atmosphere**	
Optimize Energy Performance	15	Optimize Energy Performance	1-19
Energy monitoring	2	Measurement and Verification	3
External lighting	1		
Low and zero carbon technologies	3	On-site Renewable Energy	1-7
Energy Efficient (cold storage and transportation system)	2-5		
Materials		**Material & Resources**	
Life cycle impacts	4	Building Reuse	1-3
Boundary protection	1	Recycled Content	1-5
Structure protection	1		
Responsible sourcing of materials	3		
Designing for robustness	1		

Each evaluation system looks at different points and issues related to the building performance, and assigns different scores to the criteria. Therefore, it is observed that there is no general agreement regarding indicators to be used, and the way those are given a certain value and weighted and aggregated through the score system. It is disconcerting that the weighting of points for each label is different. For example, example, while in BREEAM optimizing building energy efficiency could earn a maximum of 15 points, LEED assigns up to 19 points in this particular criteria .Why not 17 or 24 points? Theoretically, behind these scores should have a foundation based on a life cycle analysis and their respective impacts, however, these values make clear that these systems of "eco-labelling" lack of scientific rigor it is not known how and what is parsed for each of the points.

It is also remarkable to observe that many of the scoring requirements are interrelated, both within the same category and also between the different categories, which can also create problems of "double counting", and create confusion about the weighting system used. The following figure 16 shows the different scores for the categories of indoor comfort, energy and materials (LEED scores are shown in this example).

Ebaluazio-sistema bakoitzak eraikinen eraginkortasunarekin lotutako puntu eta gai desberdinei erreparatzen die, eta puntuazio desberdinak ematen dizkie irizpideei. Beraz, ikusi da ez dagoela adostasun orokorrik erabili beharreko adierazleei dagokienez eta haiei balioa emateko eta puntuazio-sistemaren bidez neurtzeko eta gehitzeko moduei dagokienez. Harrigarria da adierazle bakoitzaren puntu-haztapena desberdina izatea. Adibidez, BREEAMen, eraikinen energia-eraginkortasuna optimizatzeari gehienez 15 puntu ematen zaizkio. LEEDek, berriz, 19 puntu ematen ditu horrelakoetan. Zergatik ez 17 edo 24 puntu? Teorian, puntuazio horien atzean bizi-zikloaren eta haien inpaktuen azterketa batek egon beharko luke, baina balio horiek garbi uzten dute "eko-sailkapeneko" sistema horiek zorroztasun zientifikoa falta dutela eta ez dakigula nola eta zer aztertzen den puntu bakoitzean.

Horrez gain, azpimarratzekoa da puntuazio-eskakizun asko elkarrekin erlazionatuta daudela, bai kategoria beraren barruan, bai kategoria desberdinen artean, eta horrek "kontaketa bikoitzeko" arazoak ere sor ditzake, eta nahastea eragin erabilitako haztapen-sistemari buruz. 16. irudiak erakusten ditu barruko erosotasuna, energia eta materialak kategorientzako puntuazio desberdinak.

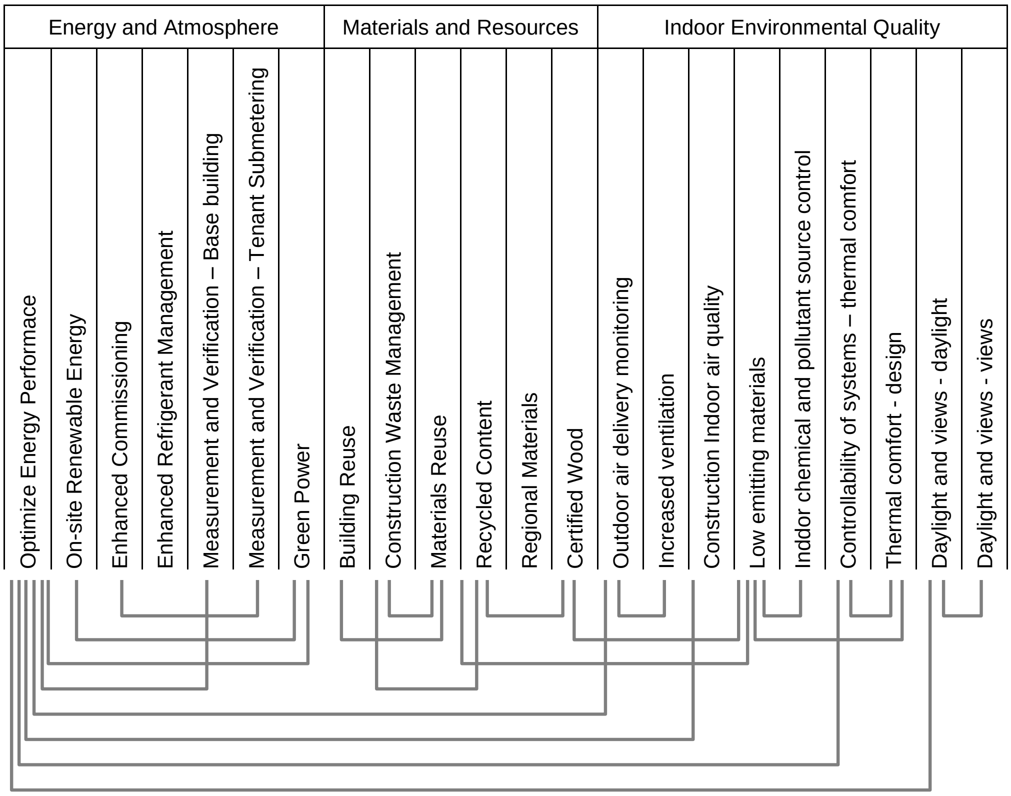


Figure / Irudia 16 Double Counting. Relationship between different credits in LEED / *Puntuazio bikoitza. Kreditu desberdinen arteko erlazioa LEED-en*.

Reviewing this network of relationships, a number of questions arise about the methodology used for weighting and providing score for each credit. While optimization of the energy performance of the building is one of the most important issues within the assessment systems, issues such as natural lighting or thermal comfort, which are also linked to the overall energy performance of the buildings, are assessed separately. It is not very clear how these issues are weighted against the energy performance, particularly as their assessment methods are mainly qualitative, while in reality they have an impact on the energy performance that

Erlazioen sare hori berrikustean, zalantzak sortzen dira alderdi bakoitza neurtzeko eta puntuatzeko erabilitako metodologiari buruz. Ebaluazio-sistemetan, eraikinen energia-eraginkortasuna optimizatzea alderdirik garrantzitsuenetako bat bada ere, argiztapen naturala edo erosotasun termikoa —hauek ere eraikinen energia-eraginkortasun orokorrari lotuta daude— bereizita ebaluatzen dira. Ez dago oso argi alderdi horiek nola neurtzen diren energia-eraginkortasunari dagokionez, batez ere haien ebaluazio-metodologiak batik bat kualitatiboak direlako, eta litekeena delako energia-eraginkortasunean duten inpaktua might be already quantified in the energy related credits. Other issues such as measurement and verification, can be a very important criterion for some buildings, for example in those buildings built with very demanding targets where, but might not be as important if original targets of performance are low level. In this system, however, they are given equal importance independently of the building characteristics. Another example is the consideration of renewable energies, or green power purchasing, as they are assessed in a qualitative manner (eg. % of energy), and their potential environmental impact in relation to the optimization energy performance is not assessed through a common indicator as could be the total non-renewable primary energy.

The following figure 17 intends o relate the different criteria of a particular qualitative evaluation system (LEED), to some other global indicators. Different overlapping issues and potential double counting can be observed throughout this figure.

There are various indicators, some of them which are quantitative and some qualitative, which in practice relate to the same indicator, and in many cases are overlapping. In practice, there is a weighting and aggregation of different criteria, through a scoring system that assign a number of points to each

dagoeneko kuantifikatuta egotea energiarekin lotutako alderdietan. Beste alderdi batzuk, hala nola neurketa eta egiaztapena, oso irizpide garrantzitsuak izan daitezke eraikin batzuetarako —adibidez, oso helburu handiekin eraikitako eraikinetarako—, baina litekeena da hain garrantzitsuak ez izatea eraikinaren hasierako eraginkortasun-helburuak txikiak badira. Sistema honetan, ordea, garrantzi bera ematen zaie, eraikinaren ezaugarriak edozein direlarik ere. Beste adibide bat da energia berriztagarriak edo energia berdea erostea zenbateraino hartzen diren kontuan, modu kualitatiboan ebaluatzen baitira, eta energia-eraginkortasuna optimizatzeari dagokionez ingurumenean izan dezaketen inpaktua ez da ebaluatzen adierazle komun baten bidez; adibidez, energia primario ez-berriztagarrien totalaren bidez.

17. irudiaren asmoa da ebaluazio-sistema kualitatibo jakin baten irizpideak beste adierazle orokor batzuekin erlazionatzea. Gainjartzen diren alderdi batzuk eta kontaketa bikoitz posible batzuk ikus daitezke irudian.

Hainbat adierazle daude, batzuk kuantitatiboak eta beste batzuk kualitatiboak. Praktikan adierazle berarekin lotuta daude, baina kasu askotan gainjarri egiten dira. Praktikan, irizpide desberdinak haztatu eta gehitu dira, irizpide bakoitzari puntu-kopuru criterion. However, in many cases various criteria relate to the same ‘midpoint´ indicator, and there is no clear and transparent information about the significance and importance of the different criteria in relation to that indicator.

jakin bat esleitzen dion puntuazio-sistema baten bidez. Askotan, ordea, irizpide bat baino gehiago daude "erdiguneko" adierazle bati lotuta, eta ez dago informazio garbirik eta gardenik adierazle horrekin lotutako irizpide horien esanahiaz eta garrantziaz.

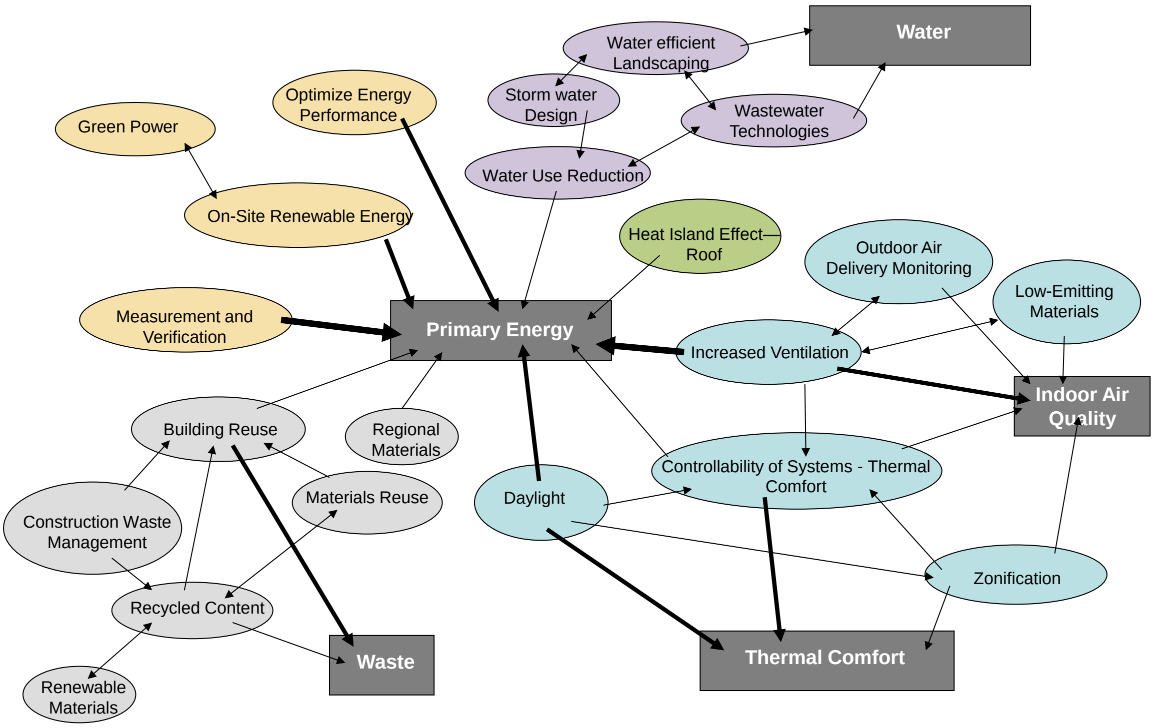
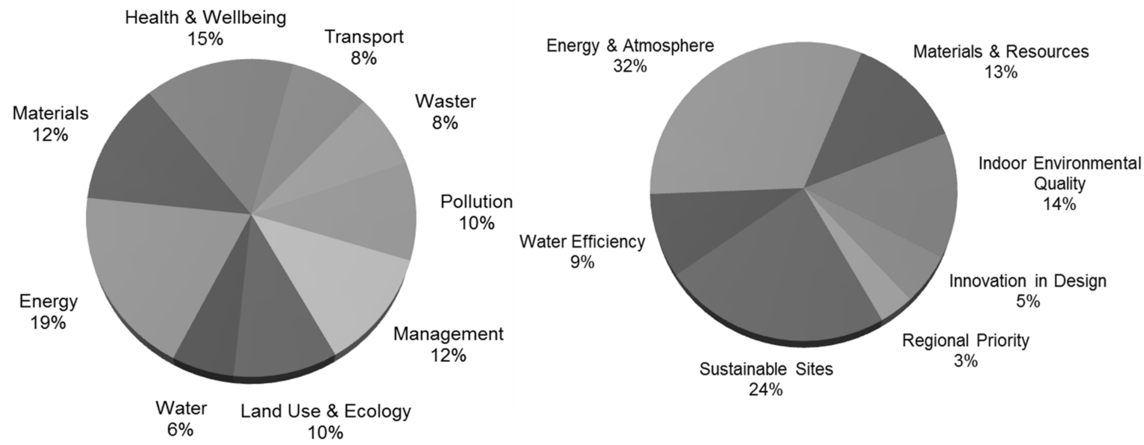


Figure / Irudia 17 Relation between LEEDs assessment issues and other general indicators / *LEED-eko ebaluazio gai eta beste adierazle batzuen arteko erlazioa.*

Finally, as it can be observed in the figure 18, the final weighting system between categories also differs between assessment systems. Because of this difference, the result obtained by the different systems can vary significantly, making more difficult the last stag o the decision making or prioritization of actions.

Azkenik, 18. irudian ikus daitekeen bezala, kategorien arteko azken haztapen-sistema ere desberdina da ebaluazio-sistema batetik bestera. Desberdintasun horregatik, sistema desberdinen bidez lortutako emaitzak oso desberdinak izan daitezke, eta horrek are gehiago zailtzen du erabakiak hartzeko azken fasea edo ekintzen lehentasunak ezartzea.



BREEAM 2011 **LEED 2009**

Figure / Irudia 18 Weighting for different categories in BREEAM and LEED assessment systems / *BREEAM eta LEED ebaluazio sistemen kategoria desberdinen ehunekoak.*

2.4.2. Life Cycle methodology / *Bizi ziklo analisia*

Energy consumption during operation of a building is a substantial element of environmental or economic assessments, which far outweighs the impact of the other life cycle stages in a conventional building. Therefore, current EPC are based only on evaluating that stage of the building.

However, based on the new energy performance limitations determinate by the Directive 2010/31/EU (art 9: Nearly zero-energy buildings), the figure 19 shows that the buildings become more energy efficient and the impact of the operational stages is reduced, increasing the relevance of the environmental and economic impact of the other life cycle stages.

Eraikin batek erabileran kontsumitzen duen energia ingurumen-ebaluazioetako edo ekonomikoetako oinarrizko elementu bat da, eta eraikin konbentzional baten bizi-zikloko beste etapen inpaktua baino askoz garrantzitsuagoa. Horregatik, gaur uneko EPZ sistemak eraikinaren fase horren ebaluazioan baino ez da oinarritzen.

Baina, 2010/31/EE Zuzentarauak zehaztutako energia-eraginkortasunari buruzko muga berrietan oinarrituta, 19. irudiak erakusten du eraikinak gero eta eraginkorragoak direla energetikoki eta funtzionamendu-faseen inpaktua txikitu egin dela, eta bizi-zikloaren beste etapen ingurumen eta ekonomia inpaktuaren garrantzia handitu egin dela.

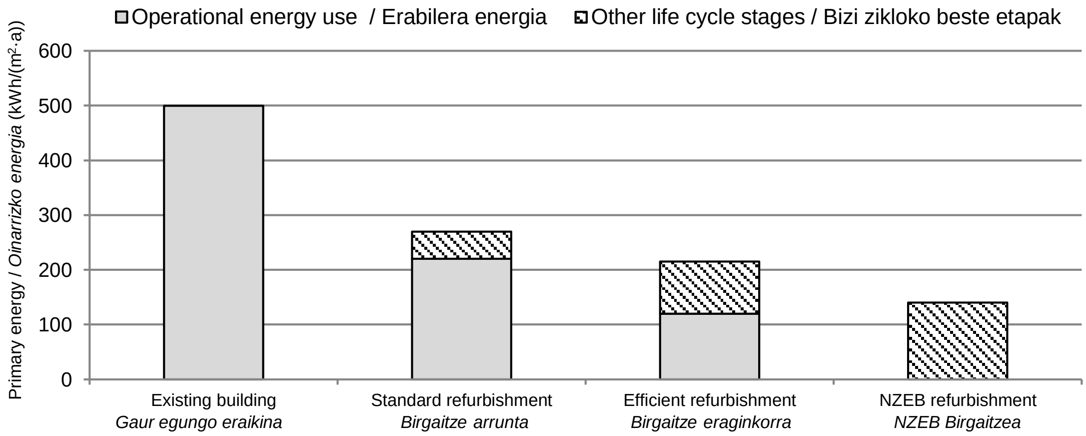


Figure / Irudia 19 Energetic behaviour progress from the current buildings to refurbished Nearly Zero Energy Buildings (NZEB) / *Gaur egungo eraikinetatik birgaitutako ia zero energiako eraikinetarako energia portaeraren bilakaera.*

The process from conventional buildings to nearly zero-energy buildings (new or renovated) makes manifest the concern about the need to adapt the scope of the current assessment methodology of the different Performance Energy Certification systems. In fact, it has been already beginning to propose the need to integrate the lifecycle methodology in their studies (Directive 2010/31/EU, Art. 11).

In addition, according to the European Commission (*CEC, 2014a; CEC, 2014b*), the Life Cycle Assessment (LCA) methodology could be the best framework available to assess the potential environmental and economic impacts of any activity, product or service without geographical, functional or time limits, since it quantifies the impact of the inputs and outputs along its whole life cycle, including the extraction of raw materials, production process, use and end of life stages.

Eraikin konbentzionaletatik ia zero energiako eraikinetara (berri edo birgaitu) igarotzeko prozesuak agerian uzten du energia-eraginkortasunari buruzko ziurtapen-sistema desberdinen uneko ebaluazio-sistemaren irismena egokitzeko dagoen beharrari buruzko kezka. Hain zuzen, dagoeneko hasi dira proposatzen (2010/31/EU zuzentaraua, 11. art) bizi-zikloaren metodologia sartu behar dela haien azterketetan.

Horrez gainera, Europar Batzordearen arabera (CEC, 2014a; CEC, 2014b), bizi-zikloaren analisiaren (BZA) metodologia eskura dagoen tresnarik onena izan liteke edozein jarduera, produktu edo zerbitzuk izan dezakeen ingurumen- eta ekonomia-inpaktua muga geografikorik, funtzionalik edo tenporalik gabe ebaluatzeko, sarrerako eta irteerako elementuek bizi-ziklo osoan duten inpaktua kuantifikatzen baitu, lehengaien erauzketa, ekoizpen-prozesua, erabilera eta deuseztatze

The application of this methodology in the building sector and especially in the energy refurbishment sector could lead countless opportunities for the sector. In that way, it facilitates decision-making, identifies opportunities to improve the environmental and economic impacts during all stages, establishes priority for eco-rehabilitation or defines new energy certification systems that avoid a partial evaluation stage.

etapak barne.

Metodologia hau eraikuntza-sektorean eta bereziki birgaitze energetikoaren sektorean aplikatzeak aukera ugari ekarriko lituzke sektorearentzat. Izan ere, erabakiak hartzea errazten du, fase guztietan ingurumen- eta ekonomia-inpaktuak hobetzeko aukerak identifikatzen ditu, lehentasunak ezartzen ditu birgaitze-lan ekologikoak egiteko eta ebaluazio partzial baten fase bat saihesten duten energia-egiaztapeneko sistema berriak definitzen ditu.

Figure / Irudia 20 Scheme of the Life Cycle concept in the construction sector / *Eraikuntza sektorean Bizi Zikloaren kontzeptuaren eskema*. Source / Iturria: EeB Guide

Life Cycle methodology is a technique for assessing the environmental, economic or social performance of an evaluated element, system or refurbishment project through all stages of its life cycle: extraction raw materials, packing, distribution, use, maintenance, recycling, reuse, recovery and final disposal. The general methodology is based on compiling an inventory of

Ebaluatutako elementu, sistema edo birgaitze-proiektu batek bere bizi-ziklo osoan zehar —lehengaien erauzketa, paketatzea, banaketa, erabilera, mantenua, birziklatzea, berrerabiltzea, berreskuratzea eta azken ezabatzea— eragiten duen ingurumen-, ekonomia- eta gizarte-inpaktua ebaluatzeko teknika bat da bizi-zikloaren metodologia. Metodologia orokorrak hiru oinarri ditu:

relevant inputs and outputs of a product system; evaluating the potential impacts associated with those inputs and outputs; and interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

The life cycle methodology assesses the three pillars of sustainability, where according to the purpose of each studio, the technician adjusts its inventory and interpretation of impacts.

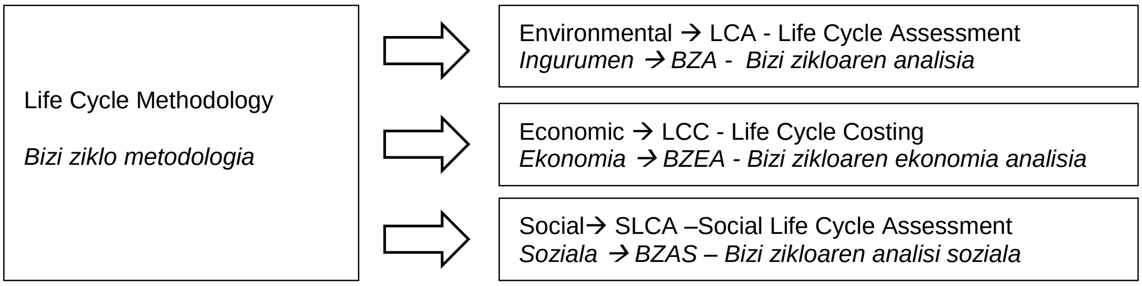
A Life Cycle Assessment (LCA) assist in identifying opportunities to improve the environmental aspects of products at various points in their life cycle; decision-making in industry, governmental or non-governmental organizations; selection of relevant indicators of environmental performance, including measurement techniques; and marketing (e.g. an environmental claim, ecolabelling scheme or environmental product declaration). Regarding a Life Cycle Costing (LCC), the economic evaluation assists selecting the improvement action (refurbishment strategies in this case) that ensures the facility will provide the lowest overall cost of ownership consistent with its quality and function. LCC is especially useful when project alternatives that fulfil the same performance requirements, but differ with respect to initial costs and operating costs, have to be compared in

produktu-sistema baten sarrerako eta irteerako elementu garrantzitsuen inbentario bat egitea; sarrerako eta irteerako elementu horiekin lotutako inpaktu potentzialak ebaluatzea, eta inbentario-azterketaren eta inpaktu-ebaluazioko faseen emaitzak azterketaren helburuekin lotuta interpretatzea.

Bizi-zikloaren metodologiak jasangarritasunaren hiru oinarri ebaluatzen ditu; azterketa bakoitzaren arabera, teknikariek metodologiaren inbentarioa eta inpaktuen interpretazioa egokitzen dituzte.

BZA batek produktuen ingurumen-alderdiak haien bizi-zikloaren zenbait puntutan hobetzeko aukerak identifikatzen laguntzen du; erabakiak hartzen laguntzen die industriako, gobernuko eta gobernuz kanpoko erakundeei; ingurumen-inpaktuaren adierazle garrantzitsuak hautatzen laguntzen du, neurtzeko teknikak eta marketina barne. Bizi-zikloaren ekonomia analisi (BZEA) bati dagokionez, ebaluazio ekonomikoak lagundu egiten du hobetze-ekintza bat hautatzen, eraikinak bere kalitatearekin eta funtzioaren arabera, jabearentzat kostu total txikiena eragingo duela ziurtatzeko. Bizi-zikloaren ekonomia-analisia batez ere baliagarria da eraginkortasun-eskakizun berak betetzen dituzten baina hasierako kostuei eta funtzionamendu-kostuei order to select the one that maximizes net savings. Finally, Social Life Cycle Assessment (SLCA) is a method that can be used to assess the social and sociological aspects of products, their actual and potential positive as well as negative impacts along the life cycle. It provides an adequate technical framework from which a larger group of stakeholders can engage to move towards social responsibility when assessing the life cycle of goods and services.

dagokienez desberdintasunak dituzten proiektu-alternatibak konparatu behar direnean, aurrezki garbiak maximizatzen dituen hura hautatzeko. Azkenik, bizi-zikloaren analisia produktuen alderdi sozialak (BZAS) ebaluatzeko erabil daiteke, gaur egun eragiten dituzten nahiz bizi-ziklo osoan zehar eragin ditzaketen inpaktu positiboak nahiz negatiboak ebaluatzeko. Esparru tekniko egokia eskaintzen du interes-talde handiago batek erantzukizun sozial handiagoa hartzeko ondasunen eta zerbitzuen bizi-zikloa ebaluatzean.



Origin – standards / *Jatorria - zuzentarauak*

The first studies on Life Cycle methodologies date back to the beginning of the seventies (*Boustead, 1972; Boustead & Hancock, 1979*), emphasising on the analysis of energy consumption efficiency and its sources, raw materials consumption and, to a lesser extent, on the final disposal of the generated waste.

Bizi-zikloaren metodologiako lehen azterketak hirurogeita hamarreko hamarkadaren hasierakoak dira (Boustead, 1972; Boustead & Hancock, 1979), eta energia-kontsumoaren eraginkortasunaren eta haren jatorrien analisian, lehengaien kontsumoan eta, hein txikiagoan, sortutako hondakinen azken ezabatzean jartzen zuten arreta.

Regarding the construction sector, Bekked (*Bekker, 1982*) published one of the first works with life cycle perspective. This paper dealt with the

Eraikuntzaren sektoreari dagokionez, Bekked-ek bizi-zikloaren ikuspegiarekin egin ziren lehen lanetako bat argitaratu zuen (Bekker, 1982). Lan horrek problem of limited natural and non-renewable resources and their impact on the construction sector. A demonstration was given of how quantitative influences could be determined by means of an appropriate life-cycle approach. An input/output flow diagram and a simple formula were presented and discussed in order to obtain more knowledge of the problem being investigated. Besides the theoretical work, the paper also covered some of the practical implications and methods of reducing the consumption of limited resources and environmental losses in the field of construction.

However, it was not until the 90s (*Boustead, 1996)* that the Life Cycle Assessment methodology was sufficiently developed, its application still being quite limited. Precisely, it was in 1993 when the Society of Environmental Toxicology and Chemistry (SETAC) established the first official LCA definition, by which the LCA is “a process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and materials used and releases to the environment; and to identify and evaluate opportunities to affect environmental improvements” (*SETAC, 1993*).

baliabide natural eta baliabide ez-berriztagarri mugatuen arazoa eta haiek eraikuntzaren sektorean duten eragina aztertzen zuen. Erakustaldi bat egin zen, erakusteko nola bizi-zikloaren ikuspegi egoki baten bidez eragin kuantitatiboak zehatz litezkeen. Sarreren eta irteeren fluxu-diagrama bat eta formula soil bat aurkeztu ziren eta eztabaidatu, ikergai zen arazoa gehiago ezagutzeko. Lan teorikoaz gain, eraikuntzaren alorrean baliabide mugatuen kontsumoa eta ingurumen-galerak murrizteko esku-hartze praktiko eta metodo batzuk ere aztertu zituen lan horrek.

Baina 90eko hamarkadara arte BZA metodologia ez zegoen nahikoa garatua (Boustead, 1996), eta oraindik aplikazio nahiko mugatua zuen. Hain juxtu, 1993an eman zion lehenengo definizio ofiziala SETACek. Haren arabera BZA hau da: "erabilitako energia eta materialak eta ingurumenera isuritako hondakinak identifikatuz eta kuantifikatuz produktu, prozesu edo jarduera bati lotutako ingurumen-kargak ebaluatzeko prozesua, erabilitako energia eta material horien eta ingurumen-emisioen inpaktua ebaluatzen dituena, eta ingurumen-hobekuntzak eragiteko aukerak identifikatzen eta ebaluatzen dituena" (SETAC, 1993).

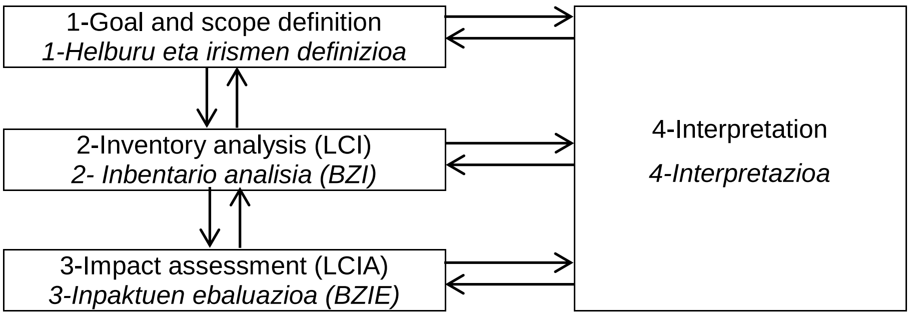
1996an, SETACek "Towards a Methodology for Life Cycle Impact

In 1996, SETAC developed the "Towards a Methodology for Life Cycle Impact Assessment" document (*Udo de Haes, 1996*), which served as the basis for the development of the first LCA standards: ISO 14040:1997 (*ISO, International Standardisation Organisation, 1997*) and 14044:1998 (*ISO, International Standardisation Organisation, 1998*).

ISO 14040 describes the principles and framework and ISO 14044 specified requirements and provides guidelines for Life Cycle Assessment (LCA) including: definition of the goal and scope of the LCA, the Life Cycle Inventory analysis (LCI) phase, the Life Cycle Impact Assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements. However, these standards did not describe the LCA technique detail, nor did it specify methodologies for the individual phases of the LCA.

Assessment" (Bizi-zikloaren inpaktua ebaluatzeko metodologia baterantz) dokumentua sortu zuen (Udo de Haes, 1996), zeina oinarri gisa baliatu baitzen lehen BZA arauak garatzeko: ISO 14040:1997 (ISO, International Standardisation Organisation, 1997) eta 14044:1998 (ISO, International Standardisation Organisation, 1998).

ISO 14040 arauak printzipioak eta esparrua deskribatzen ditu, eta ISO 14044 arauak eskakizunak zehazten ditu eta bizi zikloaren analisia (BZA) egiteko gidalerroak ematen ditu, hauek barne: BZAren helburuaren eta irismenaren definizioa, bizi-zikloaren inbentarioaren (BZI) analisiaren fasea, bizi-zikloaren inpaktuen ebaluazioaren (BZIE) fasea, bizi-zikloa interpretatzeko fasea, BZAren faseen arteko erlazioa, eta balio-aukerak eta hautazko elementuak erabiltzeko baldintzak. Arau horiek, ordez, ez zuten xehetasunez deskribatzen BZA teknika, eta BZAren fase indibidualetako metodologiak ere ez zituzten zehazten.



Based on these first standards, the intense standardization work undertaken by the European Committee for Standardization (CEN), and specifically by its Technical Committee TC/350 (*CEN TC 350*), have made that currently exists the new standard EN 15978 (*EN 15978, 2011*) specially for the construction sector (new and existing buildings), allowing the definition of the different phases of a building life cycle, defining the number of indicators, providing calculation rules for the assessment of the environmental performance of buildings and determining the methods used to declare the environmental results of the analysis. In addition, CEN/TC 350 had prepared the standard EN 15804 (*EN 15804, 2012*), which provides core product category rules of the environmental assessment for all construction products and services. This European Standard provides the means for developing a Type III environmental declaration or Environmental Product Declaration (EPD) of construction products, whose environmental impact results could be very useful to integrate in the product stage of the building LCA evaluation.

Regarding the building economical assessment, in 2012 was published the EN 15643-4 (*EN 15643-4, 2012*), an European framework level Standards which provides specific principles and

Lehen arau horietan oinarrituta, Europako Normalizazio Batzordeak (ENB) eta batik bat haren TC/350 Batzorde Teknikoak egindako normalizazio-lan handiari esker (CEN TC 350), EN 15978 arau berria dago bereziki eraikuntzaren sektorerako (EN 15978, 2011). Arau horrek eraikinaren (berri edo gaur egungo eraikin) bizi-zikloaren faseak definitzen ditu, adierazle-kopurua definitzen du, eraikinen ingurumen-eraginkortasuna ebaluatzeko kalkulu-arauak ematen ditu, eta analisiaren ingurumen-emaitzak jakinarazteko erabiltzen diren metodoak zehazten ditu. Horrez gainera, CEN/TC 350 batzordeak EN 15804 araua prestatu zuen (EN 15804, 2012), zeinak eraikuntza-produktu eta -zerbitzu guztien ingurumen-ebaluazioa egiteko produktu nagusien kategoriako arauak ematen dituen. Europako arau horrek III. motako ingurumen-adierazpen bat edo eraikintza Produktuen Ingurumen Adierazpen (PIA) bat egiteko baliabideak ematen ditu. Produktu horien ingurumen-inpaktuen emaitzak oso baliagarriak izan litezke eraikinen BZA ebaluazioren produktu-fasean sartzeko.

Eraikinen ebaluazio ekonomikoari dagokionez, 2012an, EN 15643-4 argitaratu zen (EN 15643-4, 2012); Europa mailako arau bat da, zeinak eraikinen errendimendu ekonomikoaren ebaluazioa haien bizi-ziklo osoan zehar requirements for the assessment of economic performance of buildings over their life cycle taking into account technical characteristics and functionality of a building. In order to adapt this frame-working level standard to the building level, CEN/TC 350 is developing the final version of the FprEN 16627 (*FprEN 16627, 2014*), an European Standard that specifies the calculation methods to assess the economic performance of a building during its life cycle, and gives the means for the reporting of the outcome of the assessment.

Finally, regarding the building social assessment, in 2012 was published the EN 15643-3 (*EN 16643-2, 2012*), a European framework level Standard which provides the specific principles and requirements for the assessment of social performance of buildings taking into account technical characteristics and functionality of a building. The social performance measures will be represented through indicators for categories such as accessibility, adaptability, health / comfort, maintenance, security, sourcing of materials and stakeholder involvement. In order to adapt this frame-working level standard to the building level, CEN/TC 350 is developing the draft prEN 16309 (*prEN 16309, 2014*), new European Standard that intended to support the decision making process

egiteko printzipioak eta eskakizunak zehazten dituen eraikinen ezaugarri teknikoak eta funtzionalitatea kontuan hartuz. Oinarrizko mailako arau hori eraikin-mailara egokitzeko, CEN/TC 350 batzordea FprEN 16627ren azken bertsioa egiten ari da (FprEN 16627, 2014): arau europar bat da, eraikin baten errendimendu ekonomikoa haren bizi-zikloan zehar ebaluatzeko kalkulu-metodoak zehazten ditu, eta ebaluazioaren emaitzaren berri emateko baliabideak ematen ditu.

Azkenik, eraikinen ebaluazio sozialari dagokionez, 2012an, EN 15643-3 argitaratu zen (EN 16643-2, 2012), Europa mailako arau bat: eraikinen alderdi sozialaren ebaluazioa egiteko printzipioak eta eskakizunak zehazten ditu; horretarako, eraikinen ezaugarri teknikoak eta funtzionalitatea kontuan hartzen dira. Alderdi sozialak adierazteko, zenbait kategoriatako adierazleak erabiliko dira; adibidez, irisgarritasuna, egokigarritasuna, osasuna, konforta, mantentzea, segurtasuna, materialen ekoizpena edo aktore desberdinen parte hartze kategoriakoak. Oinarrizko mailako arau hori eraikin-mailara egokitzeko, CEN/TC 350 batzordea prEN 16309ren zirriborroa egiten ari da (prEN 16309, 2014): arau europar berri bat da, zeinaren xedea baita lagungarria izatea eraikinen alderdi sozialen ebaluazioa haien bizi-zikloaren ikuspegian and documentation of the assessment of the social performance of a building based on a life cycle approach.

oinarrituz egiteko erabakiak hartzeko eta dokumentatzeko prozesuan.

Level / *Maila*	**Environmental *Ingurumen***	**Economic *Ekonomiko***	**Social *Sozial***
Framework / *Esparru*	EN 15643-2:2011	EN 15643-4:2012	EN 15643-3:2012
Building / *Eraikin*	EN 15978:2011	FprEN 16627:2014	prEN 16309:2014+A1
Product / *Produktu*	EN 15804:2012		

<u>Life Cycle evaluation tools for the construction sector / *Eraikuntza sektorerako bizi zikloan oinarritutako ebaluazio tresnak*</u>

This standardization of the different life-cycle calculating methodologies resulted in a considerable speed-up of the development process of research studies and publications and in a wide variety of tools or software that make it easier for the user to evaluate buildings or specific performances during their life-cycle. The general features of the main tools used to implement the life-cycle methodology in buildings are defined below (Evaluation scope: Environmental-ENV, Economic-ECO and Social-SOC).

Bizi-zikloa kalkulatzeko metodologia desberdinak normalizatzeak ikerketa-azterketen eta argitalpenen garapen prozesua nabarmen bizkortu zuen, eta tresna edo software ugari sortu ziren, erabiltzaileari erraztu egin ziotenak eraikinen edo errendimendu jakin batzuen ebaluazioa haien bizi-zikloan zehar egitea. Behean zehaztu ditugu eraikinetan bizi-zikloaren metodologia ezartzeko tresna nagusien ezaugarri orokorrak (Ebaluazio esparrua: ingurumen-ENV, ekonomikoa-ECO eta soziala-SOC).

- Athena (**ENV**)

Athena (*Stek et al, 2011; Richman et al 2014; Athena*) is a building LCA user-friendly application developed by the *“Athena Sustainable Materials Institute”* of Canada. The aim of the tool is to indicate implications of different material mixes and design options and consider trade-offs among the various

Athena (Stek et al, 2011; Richman et al 2014; Athena) eraikinen BZA egiteko aplikazio erabilerraz bat da, Kanadako Athena Material Jasangarrien Institutuak garatua. Tresnaren helburua da material nahasketen eta diseinu-aukeren ondorioak adieraztea eta zenbait ingurumen-efekturen arteko environmental effects.

konpentsazioak kontuan hartzea.

- Bees (**ENV+ECO**)

Developed by National Institute of Standards and Technology (NIST), Building for Environmental and Economic Sustainability (BEES®) provides product-to-product comparisons on the basis of environmental and economic performance *(Rajagolapan et al, 2012; BEES)*. Users are allowed to apply weighting factors selectively to environmental and economic impact and then weigh various environmental factors.

Arauen eta Teknologiaren Institutu Nazionalak garatu du, eta Ingurumen eta Ekonomia Jasangarritasunerako Eraikinak (BEES) produktu batzuk elkarren artean konparatzen ditu, ingurumen- eta ekonomia-errendimenduan oinarrituta (*Rajagolapan et al, 2012; BEES*)*. Erabiltzaileek haztapen-faktoreak aplika diezazkiokete ingurumen- eta ekonomia-inpaktuari, eta, hala, zenbait ingurumen-faktore hazta ditzakete.*

- Ecoeffect (**ENV+ECO**)

The EcoEffect method *(Myhr & Johansson, 2008; Assefaa et al, 2010; Ecoeffect)* has a holistic perspective of environmental issues with five parallel areas of focus: Energy, Material, Indoor Environment, Outdoor Environment and Life Cycle Costs. The method primarily target decision makers within the planning, designing and, management of the built environment.

EcoEffect metodoak (*Myhr & Johansson, 2008; Assefaa et al, 2010; Ecoeffect*) *ingurumen-gaien ikuspegi holistiko bat du. Bost arretagune paralelo ditu: energia, materiala, barruko giroa, kanpoko giroa eta bizi-zikloaren kostua. Metodoa, nagusiki, eraikitako ingurunearen plangintzaren, diseinuaren eta kudeaketaren arduradunei zuzentzen zaie.*

- Eco-Quantum (**ENV**)

Developed by IVAM, Eco-Quantum *(Klunder, 2014)* is a life cycle assessment tool for buildings used during the provisional design phase. This tool for provisional design provides architects with a clear picture of their building's sustainability from early in the design phase, thus helping them to improve its

Eco-Quantum (*Klunder, 2014*)*, IVAMek garatua, eraikinen bizi-zikloa ebaluatzeko tresna bat da, eta behin-behineko diseinu-fasean erabiltzen da. Behin-behineko diseinurako tresna horrek arkitektoei beren eraikinaren jasangarritasunaren irudi argi bat eskaintzen die diseinu-fasetik bertatik* environmental performance while it's still on the drawing board.

hasita. Hala, eraikinen ingurumen-eraginkortasuna hobetzeko aukera ematen zaie oraindik marrazketa-mahaian dagoen bitartean.

- Ecosoft (**ENV**)

ECOSOFT is a software developed by the IBO (Österreichisches Institut für Baubiologie und Bauökologie) for the ecological assessment of building components and buildings *(Ecosoft)*. Ecosoft includes the building material data base IBO and calculates processes related to material production, transport and energy.

ECOSOFT eraikinen eta eraikinetako osagaien ebaluazio ekologikoa egiteko softwarea da (*Ecosoft*)*, IBO institutuak garatua. Ecosoft-en, IBOren eraikuntzako materialen datu-basea sartzen da, eta materialen ekoizpenari, garraioari eta energiari lotutako prozesuak kalkulatzen ditu.*

- ELODIE (**ENV**)

Developed by CSTB (Centre scientifique et technique du bâtiment), Elodie is a program designed to provide for assessing a building's environmental performance throughout its life cycle *(Elodie)*. It is dedicated to all construction players who wish to integrate such environmental considerations into their analyses.

Elodie eraikinen ingurumen-eraginkortasuna haien bizi-zikloan zehar ebaluatzeko diseinatutako programa bat da (*Elodie*)*, CSTB zentroak garatua. Ingurumen-alderdi horiek beren analisietan sartu nahi dituzten eraikuntzako eragile guztiei zuzendua dago.*

- Envest 2 (**ENV+ECO**)

Developed by BRE (*Building Research Establishment*), Envest has been designed to simplify the process of designing environmentally friendly buildings *(Envest)*. It allows both environmental and financial trade-offs to be made explicit in the design process, allowing the client to optimize the concept of best value according to their

Envest softwarea ingurumenari kalterik egiten ez dioten eraikinak diseinatzeko prozesua errazteko diseinatu du BRE zentroak (*Envest*)*. Ingurumenari eta finantzei loturiko alderdien konpentsazioak diseinu-prozesuan argi adierazteko aukera ematen du, bezeroak aukera izan dezan beren lehentasunen arabera baliorik handiena* own priorities.

duen kontzeptua optimizatzeko.

- Equer (**ENV**)

Developed by the Center for Energy and Processes in Paris, EQUER (*Rossi et al, 2012; Equer*) performs simulations of a buildings life cycle, in order to provide designers with environmental indicators, allowing a project to be assessed from an environmental perspective.

EQUER tresna Parisko Energiaren eta Prozesuen Zentroak garatu du EQUER (Rossi et al, 2012; Equer), eta eraikinen bizi-zikloaren simulazioak egiten ditu, diseinatzaileei ingurumen-adierazleak emateko, eta aukera ematen die proiektu bat ingurumen-ikuspegitik ebaluatzeko.

- Greencalc+ (**ENV+ECO**)

GreenCalc is a tool to assess and compare the environmental sustainability of buildings (*Greencalc*).

GreenCalc eraikinen ingurumen jasangarritasuna ebaluatu eta alderatzeko tresna bat da (Greencalc).

- Jomar (**ENV+ECO**)

The objective for JOMAR was to develop a model as a basis for calculation of environmental profile for whole building constructions, based upon data from databases and general LCA software, in addition to the model structure from the Nordic project on LCC assessment of buildings (*Rønning et al., 2007*).

JOMARen helburua zen eredu bat garatzea eraikin osoen eraikuntzarako ingurumen-profila kalkulatzeko oinarri gisa, datu-baseetako eta BZA software orokorretako datuetan oinarrituta, eraikinen bizi-zikloaren ekonomia-analisiari buruzko proiektu nordikoko egitura-ereduaz gain (Rønning et al., 2007).

- Legep (**ENV+ECO**)

LEGEP (Lebenszyklus Gebäude Planung) is an integral software for integral project design (*Kohler et al, 2005; Legep*). It assesses Life Cycle Assessment (LCA) and Life Cycle Cost (LCC) based on German standard DIN 276 (Kosten Plannung).

LEGEP proiektu integralak diseinatzeko software integral bat da (Kohler et al, 2005; Legep). Bizi zikloaren ingurumen Analisia (BZA) eta Bizi Zikloaren Ekonomia Analisia (BZEA) egiten ditu, DIN 276 arau alemaniarrean oinarrituta.

- LTE-OGIP (**ENV+ECO**)

LTE-OGIP is a software tool that enables to optimise resources (costs, energy, and environmental impact) based on the life cycle method (*LTE-OGIP*).

LTE-OGIP softwarearen bidez, baliabideak (kostua, energía eta ingurumen inpaktua) optimiza daitezke bizi-zikloaren metodoan oinarrituta (*LTE-OGIP*).

- SBS (**ENV**)

The Sustainable Building Specifier (*SBS*) is a software tool for the efficient creation of building Life Cycle Assessments (LCA). SBS can be used on the one hand for the purpose of labelling under the rules of the German Sustainability Council and on the other hand for European research projects.

Sustainable Building Specifier (*SBS*) *eraikinen Bizi Zikloaren ingurumen Analisia (BZA) eraginkortasunez egiteko softwarea da. SBS, alde batetik, Alemaniako Jasangarritasun Kontseiluaren arauen arabera sailkatzeko erabil daiteke, eta, bestetik, Europako ikerketa-proiektuetarako.*

- SOFIAS (**ENV+ECO**)

Tool developed to assist building professionals on the sustainable design of new buildings, with particular emphasis on reducing the environmental and economic impacts through the building life cycle assessment. SOFIAS (*Oregi et al, 2014*) is presently directly related to the Spanish energy labelling tool and proposes a new environmental rating tool with life cycle perspective in Spain.

Eraikuntzako profesionalei eraikin berrien diseinu jasangarria egiten laguntzeko tresna bat da, eta arreta berezia jartzen du ingurumen- eta ekonomia-inpaktuak murriztean eraikinen bizi-zikloaren analisiaren bidez. SOFIASek (*Oregi et al, 2014*)*, gaur egun, lotura zuzena du Espainiako energia-sailkapenak egiteko tresnarekin, eta bizi-zikloaren ikuspegia duen ingurumena sailkatzeko tresna berri bat proposatzen du Espainiarako.*

Life Cycle evaluation scope-system boundary / *Bizi ziklo ebaluazioaren irismena*

Over the last decade, various publications, scientific articles or research projects, together with new software, have evaluated buildings and energy rehabilitation strategies focusing on their life-cycle. These are works that

Joan den hamarkadan, argitalpen, artikulu zientifiko edo ikerketa-proiektu ugarik, software berri batzuekin batera, eraikin eta birgaitze energetikoko estrategia ugari ebaluatu zituzten haien bizi-zikloari erreparatuta. Lan horiek eta are different from current Energy Performance Certification and Multi Criteria Voluntary Sustainability Evaluation systems because of the scope of their study (see figure 21), allowing for evaluating the impact of each stage of the building or energy rehabilitation's life-cycle:

- **Product Stage (A1-A3)**: this stage covers the 'cradle to gate' processes for the materials and services used in the construction.
- **Construction Process Stage (A4-A5)**: this stage covers the unit processes from the factory gate of the different construction products to the practical completion of the construction work.
- **Use Stage (B1-B7)**: This stage covers the period from the practical completion of the construction work to the point of time when the building is deconstructed - demolished.
- **End of life Stage (C1-C4)**: This stage of a building starts when the building is decommissioned and is not intended to have any further use. At this point the building's demolition/deconstruction may be considered as a multi output process that provides a source of materials, products and building elements that are to be discarded, recovered, recycled or reused
- **Benefits and loads beyond the system boundary (D)**: Information

gaur egungo energia-portaeraren ziurtagiriak eta BIAJE sistemak desberdinak dira, azterketek irismen desberdina dutelako (ikus 21. irudia). Azken horiek aukera ematen dute eraikinaren edo birgaitze energetikoaren bizi-zikloaren fase bakoitzaren inpaktua ebaluatzeko:

- ***Ekoizpen etapa (A1-A3)**: etapa honek eraikuntzan erabiltzen diren material eta zerbitzuen "sorlekutik aterarteko" prozesu hartzen du kontuan.*
- ***Eraikuntza prozesu etapa (A4-A5)**: etapa honek unitate-prozesuak hartzen ditu kontuan, zenbait eraikuntza-produkturen fabrikako atetik hasi eta eraikuntza-lana erabat amaitu arte.*
- ***Erabilera etapa (B1-B7)**: etapa honek eraikuntza-lana erabat amaitu denetik eraikina deseraikitzen edo eraisten den arteko aldia hartzen du kontuan.*
- ***Deuseztatze etapa (C1-C4)**: eraikinaren etapa hau hasten da eraikina ixten denean eta ez denean aurreikusten beste erabilerarik izatea. Puntu honetan, eraikinen eraispena aukera askoko prozesutzat jo daiteke, baztertu, berreskuratu, birziklatu edo berrerabil daitezkeen materialen, produktuen eta eraikin-elementuen iturria baita.*
- ***Sistemaren mugetatik at dauden onura eta kargak (D)**: D informazio-moduluaren helburua da gardentasunez azaltzea zer onura edo kalte dakarzkion*

module D aims at transparency for the environmental benefits or loads resulting from reusable products, recyclable materials and/or useful energy carriers leaving a product system e.g. as secondary materials or fuels.

ingurumenari produktu berrerabilgarriak, material birziklagarriak eta/edo energia-eramaile baliagarriak produktu-sistema batetik kanpo uzteak, adibidez, bigarren mailako material edo erregai gisa.

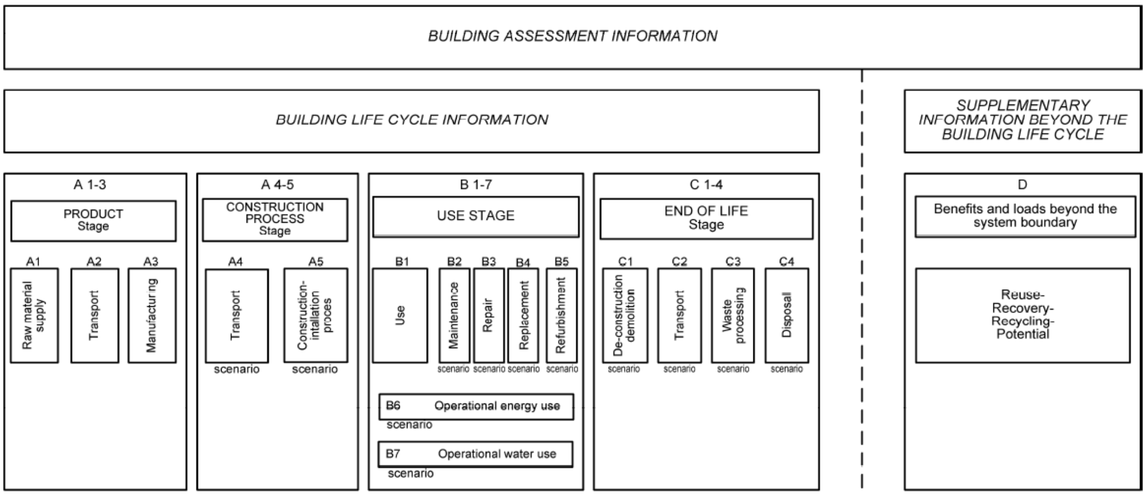


Figure / Irudia 21 Different stages of the building according to EN 15978 standard / *15978 estandarrean oinarrituriko eraikin baten etapa desberdinak*

However, despite the standardization efforts and the standardization related to the life cycle scope, there are very few studies or LCA-LCC tools that assess all the described life cycle stages, and instead most studies and tools have focused on just some of the stages, *i.e.*, product phase (A1-A3) and operational energy use stage (B6).

Why don't all studies/tools evaluate all the stages of the life-cycle when evaluating the environmental and/or economic impact of a building or energy rehabilitation performance of a building?

Baina, nahiz eta normalizazio-ahaleginak egin eta bizi-zikloaren irismenari lotutako normalizazioa egitea lortu, deskribatu ditugun bizi-zikloaren fase guztiak ebaluatzen dituzten azterketa edo BZA-BZEA analisia egiteko tresna gutxi daude. Aitzitik, azterketa eta tresna gehienak faseetako batzuetan bakarrik oinarritzen dira, hala nola produktu-fasean eta energiaren erabilera operatiboko fasean.

Zergatik azterketa eta tresna guztiek ez dituzte bizi-zikloaren fase guztiak ebaluatzen eraikin berri edi birgaitze baten ingurumen- eta/edo ekonomia-inpaktua ebaluatzen dutenean?

Table / Taula 6 Building Life Cycle Stages in relation to existing studies analysed / *Gaur egungo ikerketa lanen eraikinen bizi zikloaren etapak*. More information about each study in annex 7.2. / I*kerketa lan bakoitzaren inguruko informazio gehiago* 7.2 *eranskinean.*

	A1-3	A4	A5	B2	B4	B6	C1-4
Junnilla, 2004	X	X	X	X		X	X
Citherlet & Defaux, 2007	X	X	X	X	X	X	X
Nemry et al., 2008	X	X				X	X
Zabalza et al., 2009	X					X	
Utama & Gheewala, 2009	X	X	X		X	X	
Kofoworola & Gheewala, 2009	X	X	X	X		X	X
Blom et al., 2010	X	X		X	X	X	X
Blengini & Di Carlo, 2010	X	X	X	X	X	X	X
Gustavsoon & Joelsson, 2010	X	X				X	
Hernandez & Kenny, 2010	X				X	X	
Ortiz et al., 2010	X	X	X	X		X	X
Dodoo et al., 2010	X	X	X			X	X
Malmqvist et al., 2011	X					X	
Tae et al., 2011	X	X	X	X		X	X
Wallhagen et al., 2011	X					X	
Rossi et al., 2012	X	X				X	
Sharma et al., 2012	X	X		X		X	
Gazulla & Oregi, 2012	X					X	X
Iyer & Wong, 2012	X	X	X		X	X	X
Stephan et al., 2012	X	X	X	X	X	X	
Cuellar & Azapagic, 2012	X	X	X	X	X	X	X
Ramesh et al., 2012a	X	X			X	X	
Stephan et al., 2013	X	X	X	X	X	X	
Asdrubali et al., 2013	X	X	X		X	X	X
Allacker & De Troyer, 2013	X	X	X	X	X	X	X
Paulsen & Sposto, 2013	X	X	X	X	X	X	X
Vrijders & Wastiels, 2013	X	X	X	X	X	X	
De Angelis et al., 2013	X	X	X			X	X
Ostermeyer et al., 2013	X	X	X	X	X	X	
Mosteiro et al., 2014	X	X	X		X	X	X
Bull et al., 2014	X				X	X	X
Dodoo et al., 2014	X		X			X	X
Stephan & Stephan, 2014	X	X	X	X	X	X	
Russell-Smith et al., 2014	X	X	X		X	X	
Rodriguez & Freire, 2014	X	X	X	X	X	X	X
Bastos et al., 2014	X	X		X	X	X	
Devi & Palaniappan, 2014	X	X	X			X	X
Cellura et al., 2014	X	X	X		X	X	X
Assiego de Larriva et al., 2014	X	X			X	X	X
Cetiner & Edis, 2014	X	X	X	X	X	X	X
Oregi et al., 2015a	X	X	X		X	X	X

Table 6 shows that not all authors considered all the life cycle phases in their studies, being a general trend the omission of some life cycle modules. Only the Product Stage (A1-A3) and the operational energy use stage (B6) are the stages that have been assessed in all studies. For the other life cycle stages, the evaluation percentage is lower: transport (A4) 83%, construction process (A5) 66%, maintenance (B2) 46%, replacement (B4) 61% and end of life (C1-C4) 62%.

These omissions are due mainly to the lack of information, the difficulty of predicting future scenarios and the relatively low impact in comparison to the whole life cycle. The end of life stage was not addressed in LCA studies reported by Adalberth (*Adalberth et al., 2011*), Chen (*Chen et al., 2001),* Peuportier (*Peuportier, 2001*), Blengini (*Blengini, 2009*) and Ortiz (*Ortiz et al, 2009*). According to former experience the end-of life stage normally doesn't exceed 5% of the impacts from the use stage of an existing building. Other previous studies (*Cole, 1999; Crowther, 1999; Scheurer et al., 2003; Winistorfer et al., 2007; Dodoo et al., 2009; Arcelormittal; Wadel et al., 2011*) defined that the end of life stages impact is less than 1% for the life cycle energy use. Regarding the construction stage, case studies have shown that this stage normally accounts for less than 1% of the energy use during the building life span (*Sartori &*

6. taulan ikusten da egile guztiek ez zituztela aintzat hartu bizi-zikloaren fase guztiak beren azterketetan, eta joera orokorra dela bizi-zikloko modulu batzuk alde batera uztea. Produktu etapa (A1-A3) eta energiaren erabilera operatiboaren (B6) etapa bakarrik ebaluatu dira azterketa guztietan. Bizi-zikloaren beste faseen kasuan, ebaluazio-ehunekoa baxua da: garraioa (A4) % 83, eraikuntza-prozesua (A5) % 66, mantentzea (B2) % 46, ordezkapena (B4) % 61 eta deuseztatzea (C1-C4) % 62.

Fase horiek ez dira ebaluatu, askotan informazio faltagatik, etorkizuneko egoerak aurreikusteko zailtasunagatik eta bizi-ziklo osoarekin alderatuta nahiko inpaktu txikia dutelako. Adalberth (Adalberth et al., 2011), Chen (Chen et al., 2001), Peuportier (Peuportier, 2001), Blengini (Blengini, 2009) eta Ortizek (Ortiz et al, 2009) egindako BZA azterketetan ez dute bizitza-amaieraren fasea ebaluatu. Aurreko esperientzien arabera, bizitza-amaierako fasea normalean ez da izaten lehendik dagoen eraikin baten erabilera-fasearen inpaktuen % 5 baino gehiago. Lehendik egindako beste azterketa batzuen arabera (Cole, 1999; Crowther, 1999; Scheurer et al., 2003; Winistorfer et al., 2007; Dodoo et al., 2009; Arcelormittal; Wadel et al., 2011), bizitza-amaierako faseen inpaktua bizi-zikloko energia-erabileraren % 1 baino gutxiago da. Eraikuntza-faseari dagokionez, kasu-

Hestnes, 2007).

It is worth mentioning that due to various reasons such as the lack of information, the need for simplification and the purpose of each tool, not all the LCA-LCC assessment tools described in table 7 take the same system boundary into account.

azterketa batzuek erakutsi dute fase hori normalean erakinaren balio-bizitzan erabiltzen den energiaren % 1 baino gutxiago izaten dela (Sartori & Hestnes, 2007).

Aipatzekoa da zenbait arrazoi direla eta —informazio falta, sinplifikatzeko beharra eta tresna bakoitzaren helburua—, 7. taulan deskribatutako BZA-BZEA analisirako ebaluazio-tresna guztiek ez dutela sistema-muga bera hartzen kontuan.

Table / Taula 7 Building Life Cycle Stages in relation to existing LCA-LCC tools / *Gaur egungo BZA- BZAE tresna eta eraikinen bizi ziklo etapen arteko eralazioa*

	A1-3	A4	A5	B2	B4	B6	C1-4
Athena	X	X	X	X	X		X
Bees	X	X	X	X		X	X
Ecoeffect	X					X	X
Eco-quantum	X					X	X
Ecosoft	X					X	
ELODIE	X	X	X		X	X	X
Envest 2	X	X		X	X	X	X
Equer	X					X	X
Greencalc+	X					X	X
Jomar	X					X	
Legep	X	X	X	X	X	X	X
LTE-OGIP	X		X	X	X	X	X
SBS	X				X	X	X
SOFIAS	X	X	X		X	X	X

To these first simplifications of the Life Cycle methodology application we must add that, even in the year 2014, different applications created from European-national projects or international publications were still only evaluating impact reduction due to the different strategies for energy rehabilitation in the

Bizi-zikloaren metodologiaren aplikazioaren lehenengo sinplifikazio horiei buruz esan behar dugu 2014. urtean oraindik Europan edo nazio mailan egindako proiektuetan edo nazioaretko argitalpenek oraindik ere birgaitzearen ondorioz eraikinaren erabilera etaparen (B6 etapa) inpaktu-

operational energy use stage (B6 stage) of a building. That is, taking into account the same system boundary than Energy Performance Certification systems, focusing all efforts in evaluating its behaviour when the building is occupied and being used and keeping the impacts with regards to the other life-cycle stages away from the scope of the study. The following are some of the energy rehabilitation strategy evaluation projects, tools and publications which only focus on the building's use stage:

- TABULA research project (*TABULA*) aims to create a harmonised structure for European building typologies and to learn how to structure the variety of energy-related features of existing buildings. Through this project has been developed a software application called Tabula Web Tool, where users can perform different calculations of energy rehabilitation.
- Some studies (*Jaggs & Palmer, 2000; Rey, 2004; Alanne, 2004*) that proposed Multi Criteria-based approaches for the evaluation of retrofitting scenarios.
- EURIMA (European Insulation Manufacturers Association), has written different studies (*Eurima, 2005; Eurima, 2010; Eurima, 2012*) which analyses and compares the possible tracks for the renovation of the EU building stock, quantifying energy savings and avoided CO_2 emissions, financial impacts and employment effects.

murrizketa bakarrik ari zirela ebaluatzen. Hau da, Energia Portaera Ziurtagiri sistemek erabiltzen duten muga bera hartzen zuten kontuan, eraikinak okupatuta eta erabiltzen ari direnean duen eraginkortasuna ebaluatzean jarriz arreta guztia eta azterketatik kanpo utziz bizi-zikloaren beste etapekin lotutako inpaktuak. Hona hemen eraikinaren erabilera-fasea bakarrik kontuan hartzen duten birgaitze energetikoko estrategia ebaluatzeko proiektu, tresna eta argitalpen batzuk:

- *TABULA ikerketa-proiektuaren* (*TABULA*) *asmoa da egitura harmonizatu bat sortzea Europako eraikin-tipologientzat eta ikastea nola egituratzen diren lehendik dauden eraikinek energiarekin lotuta dituzten ezaugarriak. Proiektu horretan zehar Tabula Web Tool izeneko software-aplikazio bat garatu da, eta haren bitartez, erabiltzaileek birgaitze energetikoko kalkuluak egin ditzakete.*
- *Birgaitze egoerak ebaluatzeko irizpide anitzetan oinarritutako ikuspegiak proposatzen zituzten azterketak* (*Jaggs & Palmer, 2000; Rey, 2004; Alanne, 2004*).
- *EURIMAk zenbait azterketa idatzi ditu* (*Eurima, 2005; Eurima, 2010; Eurima, 2012*)*, non EBeko eraikinak birgaitzeko dauden bideak aztertzen eta konparatzen dituen, energia-aurrezkiak, saihestutako* CO_2*-emisioak, ondorio finantzarioak eta enpleguko efektuak*

- Diakaki investigated the feasibility of applying multi-objective optimization techniques (*Diakaki et al., 2008*) to the problem of improving energy efficiency in buildings.
- BPIE (Buildings Performance Institute Europe) has published the Europe's buildings under the microscope (*BPIE, 2011*) study, which analyses the critical role of refurbishment, when considering various pathways to achieve the 2050 building sector decarbonisation goals.
- Chantrelle developed a new tool, MultiOpt, for the multi-criteria optimization of renovation operations (*Chantrelle et al., 2011*), with regard to building envelopes, HVAC systems and control strategies.
- The Spanish Working Group for Rehabilitation "GTR" proposes a roadmap (*GTR, 2012*) which evaluates the transformation of residences built in Spain before 2001 into high efficiency, low-carbon/ low consumption residences by 2050.
- Asadi presented a multi-objective optimization model (*Asadi et al., 2012*) to quantitatively assess technology choices in a building retrofit project.

kuantifikatuz.

- *Diakakik helburu anitzeko optimizazio-teknikak eraikinen energia-eraginkortasuna hobetzeko arazoari aplikatzearen bideragarritasuna ikertu zuen* (*Diakaki et al., 2008*).
- *BPIEk Europe's buildings under the microscope study azterketa* (*BPIE, 2011*) *argitaratu zuen: birgaitze-lanek betetzen duten ezinbesteko funtzioa aztertzen du, 2050erako eraikuntza-sektorearen karbonogabetze-helburuak lortzeko zenbait bide aintzat hartuz.*
- *Chantrelle-k tresna berri bat garatu zuen (MultiOpt) berritze-eragiketak —fatxada, berokuntza-, BAH sistema eta kontrol-estrategiei dagokienez— irizpide anitzetan oinarrituta optimizatzeko* (*Chantrelle et al., 2011*).
- *Espainiako Birgaitzeetarako Lantaldeak (GTR) eraldaketa ebaluatzen duen bide-orri bat proposatzen du (GTR, 2012). Bertan, Espainian 2001 urte aurretik eraikitako etxebizitzek eraginkortasun altu eta kontsumo baxudun eraikinetaruntz izango duten aldaketa landuko da.*
- *Asadik helburu anitzeko optimizazio modelo kuantitatibo bat proposatzen du (Asadi et al., 2012)*, eraikin bat birgaitzeko teknologia desberdinen arteko aukerateko ebaluatuz

CHAPTER 3 – Reflection and thesis proposal

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3 ATALA – Hausnarketa eta tesiaren proposamena

3. Research questions and thesis proposal / *Ikerkuntza galderak eta tesiaren proposamena*

In accordance with what has been set out in previous chapters, the building industry of the twenty first century has two main features:

1. Buildings are one of the world's largest energy-consuming sectors, accounting for nearly 30% of final global energy consumption, reaching 40% in the European Union (*IEA, 2013*).

2. With new constructions adding at most 1% a year to the EU existing stock (*Power, 2008*), there is large potential for improving the energy performance of the other 99% of the building stock, making "energy refurbishment" a top priority in current EU and national policies.

The aforementioned high energy dependence and the age of the buildings –which is directly linked to their poor energy performance-, which have influenced the way documents such as the EU Energy Plan (*CEC, 2006*) and the Energy Performance of Buildings Directive recast (*Directive 2010/31/UE, 2010*) confirm that energy rehabilitation of existing buildings and the analysis of its impact of climate change policies must be one of the strategic lines of research worldwide.

In order to achieve the goals set out by various European and Spanish policies, going through the "European building

Aurreko ataletan ikus daitekeen bezala, bi dira XXI. mendeko eraikuntza sektorearen ezaugarri nagusiak:

1. Eraikuntza da munduan energia kontsumo handienetako bat duen sektorea, mundu mailako energia kontsumoaren ia %30a eta Europar Batasuneko %40aren arduradun izanik (IEA, 2013).

2. Kontuan harturik eraikin berriak urtean %1 gehitzen dutela EBeko gaur egungo eraikin bolumena (Power, 2008), beste eraikin bolumeneko %99a diren eraikinen energia portaera hobetzeko aukera izugarria dago, birgaitze energetikoa Europar Batasunaren eta nazio-politiken lehentasun bihurtuz.

Menpekotasun energetiko altuak eta eraikinen antzinatasunak (portaera energetiko eskasarekin zuzenean erlazionatuak) eragina izan dute Europar Batasunak hartu dituen erabaki ezberdinetan. Ondorioz, gaur egungo eraikinen birgaitze energetikoak eta hauek klima aldaketaren politiketan duten eraginaren analisiak mundu mailako ikerketa lerro estrategikoak izan behar direla baieztatzen dute EB-ko Energia Planak (CEC, 2006) edo eraikinen eraginkortasun *energetikoaren inguruko* zuzentarauak *(Directive 2010/31/UE, 2010)*.

Politika europar eta nazional ezberdinek energy legislations" (see 2.3 section) proved that the minimum requirements regarding the energy performance of existing buildings established by the new directives are increasing, even suggesting concepts such as nearly zero-energy buildings or the introduction of life-cycle methodologies when defining the cost-optimal strategy. The line of research that seeks to improve the energy performance of the existing building stock through energy rehabilitation has both direct and indirect positive effects in areas such as environmental (reduction of air pollution and emissions), energetic (security and peak loads reduction), social (fuel poverty reduction, health, comfort increase) and economic (cost saving, stimulus and poverty reduction). Therefore, in order to achieve such goals and benefits, it is essential to use the most appropriate evaluation methodologies so as to make decisions and prioritize the procedures of energy renovation of buildings in every scenario.

As shown in section 2.4, there are three groups of evaluation methodologies in today's market place and, although they share a common goal, that is to facilitate the process of analysis and decision-making of energy rehabilitation performances, each one of them applies different evaluation criteria.

The first group consists of the Energy

jarritako helburuetara iristeko asmoz, eraikinen portaera energetikoaren inguruan garaturiko zuzentarau europarren literaturaren azterketak (ikus 2.3 atala) erakusten du zuzentarau berriek portaera energetikoaren inguruan jarritako gutxieneko eskakizunak goraka doazela. Honen harian ikus daiteke batzuetan kontsumo ia zeroko eraikinak edo bizi zikloaren analisiaren metodologia bezalako kontzeptuak sartzen direla kostu hoberenaren estrategia definitzeko orduan. Birgaitze energetikoaren bidez gaur egungo eraikinen ezaugarri energetikoak hobetu nahi dituen lan ildoak ondorio onuragarri zuzen eta zeharkakoak izango ditu ingurumena (airearen kutsadura eta isurien gutxitzea), gizartea (erregaien urritasuna murriztea, osasuna, konforta hobetzea) eta ekonomia (kostua aurreztea eta pobrezia murriztea) bezalako aspektuetan. Hau guztia lortu eta jarritako helburu eta onuretara iristeko, ezinbestekoa da eraikinen birgaitze energetikoan lehentasuna eman behar zaien esku-hartzeak zein diren erabakitzeko ebaluazio metodologia egokienak erabiltzea.

2.4 atalean zehar erakutsi da gaur egun merkatuan ebaluazio metodologi 3 talde orokor daudela. Nahiz eta guztien helburua bera izan, hau da birgaitze energetikoetan erabakiak hartu eta analisi prozesua erraztea, bakoitzak

Performance Certification (EPC) systems, which analyse the energy and environmental performance of rehabilitated buildings in their operational stage in accordance with directives such as the 2002/91/EC and the 2010/31/EU.

The second group is made up of methodologies known as Multi-Criterial Voluntary Sustainability Evaluation (MCVSE) systems. These kinds of methodologies have many strengths and opportunities, including important features such as international recognition, worldwide sustainable rehabilitation evaluation or huge benchmarking and differentiation potential. However, unnecessarily or high amount of non-related aspects are evaluated, some of the evaluated parameters are directly interrelated between them repeating the same parameter in more than one score, the final weight of the groups becomes completely subjective and normally the main objective is focused in obtaining a high score. In addition, MCVSE systems are not based on a standardized methodology. In fact, each system has a fully independent evaluation system, making the decision process more difficult.

Finally, as a result of the new requirements set out by the market (especially in the manufacturing sector) and the CEN/TC350 high standards,

ebaluazio irizpide ezberdinak erabiltzen ditu. Lehen taldea Energia Portaera Ziurtagirien (EPZ) sistemez osatua dago. 2002/91/EC eta 2010/31/EU bezalako zuzentarauetan oinarriturik, sistema hauek eraikin birgaitu baten portaera energetiko eta ingurumen portaera aztertzen dituzte eraikinaren erabilera etapan zehar.

Bigarren taldea Borondatezko Irizpide Anitzeko Jasangarritasun Ebaluazio (BIAJE) sistema bezala ezagutzen diren metodologiez osatua dago. Metodologia hauen onurak eta aukerak ugariak dira, nabarmentzekoak dira besteak beste internazionalki duten onarpena, birgaitzearen ebaluazio jasangarri orokorra, konparaziozko ebaluazioan duten potentziala edo merkatuaren aurrean duten desberdintzea. Bestalde, ahultasunen artean ditugu birgaitze energetikoarekin erlazionatuta ez dauden aspektu askoren ebaluazioa, puntu ezberdinetan aspektu berdina landuz puntuazio bikoitza bezala ezagutzen den efektua sortuz eta azkenik emaitzak lortzerakoan puntu ezberdinen ehunekoen banaketa subjektiboa. Ahultasun hauen ondorioz, helburua eraikinaren ekonomia eta ingurumen inpaktua murriztea izan beharrean puntuazio altua bilatzea izatera pasa daiteke. Gainera, BIAJE sistema bakoitza ez da metodologia estandarizatu batean oinarritzen, baizik eta sistema bakoitza independenteki new regulations allow for assessing energy rehabilitation performances during their life-cycle (LCA), taking into account the impact of each of their stages. This type of assessment estimate also has many strengths and opportunities, including noteworthy standardization of estimation criteria. Such standardization, as defined by the EN15978:2011 and FprEN16627:2014 regulations (the methodology for social estimation has not been standardized yet), avoids duplication, eliminates weighting schemes, facilitates the process of optimizing the impact of each life-cycle stage and therefore, allows for making decisions from a scientific and numerical point of view, avoiding subjectivity. It also allows for making decisions in accordance with a new decision-making line, taking into consideration the impacts within the whole life-cycle of a building and providing added value. On the contrary, the evaluation of each of the stages of the building life-cycle extends considerably the working process, making it difficult to prioritize energy rehabilitation performances.

ebaluatzen da, azken erabakiak objektiboki hartzea zailduz.

Azken taldeari dagokionez, merkatuak definitutako behar berrien (batez ere produktuen fabrikazioaren sektorean) eta CEN/TC350 eginiko lan handiaren ondorioz, araudi berriek eraikin baten birgaitze energetikoa bere bizi zikloan (BZA) zehar lantzeko aukera ematen dute, bizi zikloko etapa bakoitzean sorturiko inpaktuak kontuan izanik. Metodologia hauek onura eta aukera ugari dituzte, nabarmentzekoa delarik kalkulu irizpideen estandarizazioa. EN 15978:2011 eta FprEN 16627:2014 (kalkulu sozialerako metodologia oraindik ez dago estandarizatua) araudietan definitutako estandarizazioak bikoizketak saihesten ditu, haztapen sistemak ezabatzen ditu, bizi zikloaren etapa bakoitzaren inpaktua optimizatzea errazten du eta ondorioz, ikuspegi zientifiko eta zenbakizko batetik erabakiak hartzea ahalbidetzen du, subjektibotasunak saihestuz. Aldi berean erabakiak ildo berri batean oinarrituta hartu daitezke, eraikinaren bizi zikloa osatzen duten inpaktu guztiak kontuan hartuz eta balio erantsia emanez. Ahultasunen artean etapa bakoitzaren analisiak lan prozesua asko luzatzen duela aipa daiteke, proiektuaren epeak luzatuz eta birgaitze energetiko ezberdinei lehentasuna ematea zailduz.

Table / Taula 8 Summary of the aim characteristics of the different evaluation system groups / *Ebaluazio sistema talde desberdinen ezaugarri nagusien laburpena*

	EPC / *EPZ*	**MCVSE / *BIAJE***	**LCA / *BZA***
Difficulty / *Zailtasuna*	Low / *Baxua*	High / *Altua*	High / *Altua*
Quantitative / *Kuantitaboa*	Yes / *Bai*	No / *Ez*	Yes / *Bai*
Qualitative / *Kualitatiboa*	No / *Ez*	Yes / *Bai*	No / *Ez*
Weighting system / *Ehunekoen banaketa*	No / *Ez*	Yes / *Bai*	No / *Ez*
Double counting / *Puntuazio bikoitza*	No / *Ez*	Yes / *Bai*	No / *Ez*
Assessment of the operational energy use stage / *Erabilera etaparen ebaluazioa*	Yes / *Bai*	Yes / *Bai*	Yes / *Bai*
Assessment of all life cycle stages / *Bizi zikloko etapa guztien ebaluazioa*	No / *Ez*	Yes* / *Bai**	Yes / *Bai*
Standardized / *Estandarizatua*	Yes / *Bai*	No / *Ez*	Yes / *Bai*

*The evaluation of each life cycle stage is not realized by a standardized calculation criterion / *Bizi zikloko etapa bakoitzaren ebaluazioa ez da kalkulu irizpide estandarizatu batean oinarritzen.*

The summary of table 8 shows how the evaluation by means of MCVSE systems is based on high quality unstandardized estimations, hindering the decision-making process with regards to comparative and objective criteria. Therefore, it could go up to a point which suggests that all these MCVSE systems become a "guide" for architects, planners, engineers… where their buildings and refurbishment strategies with greater environmental, economic and social sensitivity will be projected.

Regarding the other two methodologies -EPC and Life-Cycle (LC) - their estimation criteria are fully standardized, allowing for estimations, impact evaluation and the prioritization of energy rehabilitation performances of buildings in a quantitative and harmonized way.

Therefore, the decision-making

8. taulako laburpenak erakusten duen bezala, BIAJE sistemak ebaluazioa maila kualitatibo altua duten kalkulu ez estandarizatuetan oinarritzen dira, irizpide konparatibo eta objektibo baten bidez erabakiak hartzea zailduz. Hori dela eta, BIAJE sistema guzti hauek ebaluazio sistema ordez, arkitekto, hirigintzako arduradun, ingeniari, etab.-entzako gida bilaka daitezke, eraikinak eta birgaitze estrategiak ingurumen, ekonomia eta gizartearekiko sentsibilitate handiago batekin diseinatuz.

Beste bi metodologien kalkulu irizpideak, hau da EPZ eta Bizi Ziklo analisia (BZ), guztiz estandarizatuak daude, eta ondorioz modu kuantitatibo eta bateratu batean kalkuluak egitea, inpaktuak ebaluatzea eta eraikinen birgaitze energetikoen estrategia ezberdinen artean egokienak lehenestea ahalbidetzen dute.

methodology suggested by this research work shall focus on the structure of such methodologies, which in accordance with the standardized criteria, allow for quantifying and achieving the most "real" possible reading on the environmental and/or economic impacts of an energy rehabilitation strategy.

However, as shown in figure 22, there is a considerable difference between these two approaches: their **boundary system**. The EPCs only evaluate the influence of energy rehabilitations in the operational energy use stage of buildings, while the LC methodology evaluates the impact of each stage of their life-cycle, reasonably increasing the complexity of the work process.

Hau da, ikerketa lan honetan proposaturiko erabakiak hartzeko metodologia azkenengo bi hauen egituran oinarritzen da. Modu honetara, irizpide estandarizatuak oinarri hartuta, birgaitze energetikoaren estrategiak dakartzan ingurumen eta ekonomia inpaktuak neurtu eta irakurketa egiazkoago bat lortzen da.

Hala ere, *22.* irudiak *erakusten duen bezala, lehen azaldutako bi metodologia hauen artean ezberdintasun bat dago:* ***ebaluazio sistemaren irismena****. EPZ metodologiek birgaitze energetiko batek eraikinaren erabilera etapan duen eragina bakarrik ebaluatzen dute. BZA metodologiek, eraikin birgaituaren bizi zikloko etapa bakoitzeko inpaktuak ebaluatzen dituzte, azterketa prozesuaren zailtasuna nabarmenki handituz.*

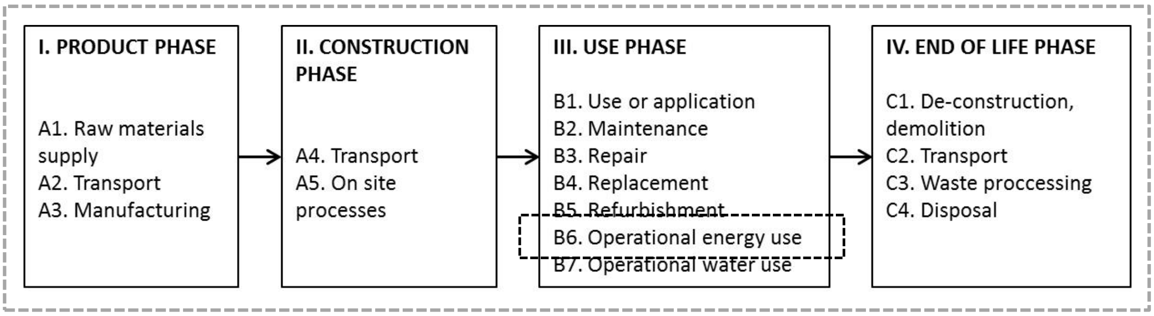


Figure / Irudia 22 Difference of the system boundary between EPC and LCA methodologies / *EPZ eta BZA metodologi sistemen irismenaren ezberdintasuna.*

This simplification characteristic of the EPCs and of works based on the quantification of the buildings' use stage, significantly eases the technical effort and focuses all efforts on reducing

EPZ metodologiek erabiltzen duten sinplifikazio honek edo eraikin baten erabilera etapan bakarrik oinarritzen diren lanek, birgaitze lana ebaluatu behar duen teknikoaren esfortzua asko the energy impact in the use stage to the minimum. Therefore, it is one of the most used methodologies in today's marketplace.

On the other hand, despite the calculation criteria and LC methodologies have already been standardized, allowing for the evaluation of the environmental and economic impact of energy rehabilitation performances during their life-cycle; despite the increasing number of scientific publications justifying their application; and despite the fact that the EPBD recast (2010/31/EU) suggests to integrate this methodology in future EPC systems, even in the year 2015, the vast majority of experts in this area suggest against the use of this methodology from the beginning, limiting its use to the research area.

errazten da eta lan guztia erabilera etapan sorturiko inpaktuen murrizpenean oinarritzen da. Horregatik, oraindik gaur egungo merkatuan gehien erabiltzen den metodologietako bat izaten jarraitzen du.

Bestalde, nahiz eta BZA metodologia eta bere kalkulurako irizpideak estandarizatu eta eraikinen birgaitze energetikoaren ingurumen eta ekonomia inpaktuak bizi zikloan zehar ebaluatzeko aukera izan, gero eta argitalpen gehiagok metodologia honen aplikazioa justifikatu, edo eraikinen eraginkortasun *energetikoaren inguruko* zuzentarauak *(2010/31/EU) metodologia hau geroko EPZ sistemetan sartzea gomendatu, oraindik 2015.urtean BZ metodologiaren erabilera batik bat ikerketa mundura mugatzen da eta orokorrean eraikuntza sektoreko beste teknikoek metodologi hau beren proiektuetan hasieratik erabiltzea baztertu egiten dute.*

EPC / *EPZ*

FACILITY to evaluate only the impact generated during the operational energy use stage / *Erabilera etapan bakarrik sorturiko inpaktuen neurketen* ***ERRAZTASUNA***

LCA / *BZA*

ACCURACY of the calculation / *Kalkuluen* ***ZEHAZTASUNA***

LIFE CYCLE approach / ***BIZI ZIKLOAREN*** *ikuspegia*

In the cases in which a life cycle approach has been applied on an assessment of new buildings, there is a general consensus that the use phase contributes more than 80%–85% share in the total life cycle energy use of new

*Eraikin berriak ebaluatzeko bizi zikloaren ikuspegia erabili den kasuetan ondorioztatu da eraikin berrien bizi zikloaren energia erabileraren %80-85 erabilera etapari dagokiola (*Sharma *et al., 2011; Ramesh et al., 2010; Chang et al.,* buildings (*Sharma et al., 2011; Ramesh et al., 2010; Chang et al., 2015; Richman, 2009).* As shown in figure 23, Ramesh's overview (*Ramesh, 2010*) evaluates 72 studies of buildings' LCAs, showing that the mean value of the primary energy impact of the product stage compared to the impact of the operational stage in residential buildings is 13.8% and 16.9% in tertiary buildings (offices).

2015; Richman, 2009). *23. irudian ikus daitekeen bezala, Ramesh-ek egindako laburpenak (Ramesh, 2010) BZA bidez landutako 72 eraikinen emaitzak lantzen ditu, etxebizitza eraikinetan ekoizpen etapako oinarrizko energiaren inpaktuaren bataz besteko balioa erabilera etaparekiko %13.8koa dela eta zerbitzu eraikinetan (bulegoak) %16.9koa dela adieraziz.*

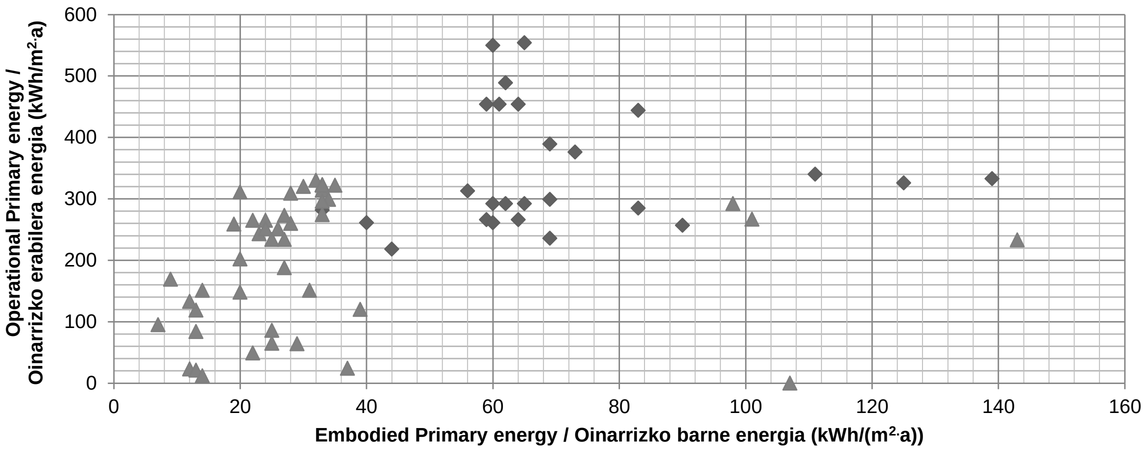


Figure / Irudia 23 Relation between Embodied and Operational primary energy use / *Ekoizpen eta erabilera etapen oinarrizko energiaren arteko erlazioa.* Source / *Iturria:* Own elaboration with data from (Ramesh, 2010)- *en datuetan oinarritutako norbere garapena.*

The study carried out by Karimpour (*Karimpour et al., 2014*) shows that when considering the time value of carbon, in relation to emission targets, the embodied energy (total energy required for the extraction, processing and manufacture of building materials) can represent up to 35% of the future emissions target of a building in a mild climate. In buildings with a very low energy use in the operational phase, logically other phases of the life cycle like raw materials supply, product manufacturing, transport and

Karimpour-ek egindako ikerketa lanak (Karimpour et al., 2014) erakusten du karbonoaren denbora-balioa kontuan izandako kalkuluetan, barne energiaren balioa (eraikuntza materialen ustiapen, banaketa eta eraldaketarako beharrezko oinarrizko energia) %35eko izan daitekeela klima ez gogorretako eraikinetan. Erabilera etapan oso energia kontsumo baxua duten eraikinetan (kontsumo ia zeroko eraikinak) bizi zikloaren beste etapak (lehengaien hornikuntzak, produktuaren ekoizpenak, banaketa eta deuseztapen installation, and end of life would have a much larger relative impact, becoming the only energy related impact in the so called “zero energy buildings”. In that sense, Celluras study (*Cellura et al., 2014*) has emphasized the embodied energy of the building as a key issue to not be neglected in the exhaustive evaluation of the primary energy demand of low energy buildings, whereas according to Lützkendorf (*Lützkendorf et al., 2014*) the embodied energy of a passive house could be 44% higher than its operation energy for a 60 years lifespan. Finally, the study by Stephan (*Stephan et al., 2013*) shows that the embodied energy of passive houses can represent up to 77% of the total embodied and operational energy over 100 years, proving that current building energy efficiency certifications might not ensure a lower energy demand and can, paradoxically result in an increased energy consumption because of their limited scope.

As buildings are extremely complex systems entailing an enormous amount of products, systems, stages and processes, a fully-fledged application of the LCA methodology is still not widely applied, and analysts usually apply some simplifications (see table 6) to reduce the amount of time and facilitate the interpretation of the results. Some previously conducted research works (see section 2.4.2), quantitatively justify

etapak) bilakatuko dira eraikinaren inpaktu energetiko eta ingurumen inpaktu bakarrak. Puntu hau abiapuntu harturik, Cellurak garaturiko lanean (Cellura et al., 2014) eraikin bateko barne energiak duen garrantzia azpimarratzen da, batez ere oinarrizko energia eskari baxua duten eraikinen kasuan. Era berean, Lutzkendorf-en lanean (Lützkendorf et al., 2014) ikus daiteke nola eraikin pasibo baten barne energiaren inpaktua eraikinaren erabilera etapan sorturiko inpaktua baino %44 handiago dela 60 urteko bizi iraupenean. Azkenik, Stephan-en lanean (Stephan et al., 2013), 100 urteko bizi iraupena duen eraikin pasibo baten barne energia %77ako izatera irits daitekeela erakusten da, non, paradoxikoa izan arren, EPZ sistemen irismen mugatzearen ondorioz eraikin askotan oinarrizko energia eskaria handitu daitekeela frogatzen den.

Eraikinak sistema oso konplexu bat dira, hainbat produktu, sistema, etapa eta prozesuz osatuak. Ondorioz, oraindik ez dira bizi zikloaren analisia osoki hartzen duten aplikazioak gehiegi erabiltzen eta bai ikertzaile edo bai teknikoek denbora aurreztu eta emaitzen interpretazioa errazteko sistema sinplifikatuak erabili ohi dituzte (ikus 6. taula). Orain arte egindako ikerketa lan batzuk (ikus 2.4.2 atala) sinplifikazio hauek burutzeko arrazoiak modu kuantitatibo batean erakusten dituzte, frogatuz bizi zikloko the reasons for simplification, arguing the low influence of the impact (less than 1%) of one stage compared to the overall impact of the building. However, in many cases, the boundary system reduction is limited to the lack of information, hindering the achievement of a consensus with regards to the impact of each stage of the rehabilitation strategies assessment life-cycle.

From these observations it is clear and generally accepted that when undertaking an environmental assessment of a new building, it is necessary to evaluate all its phases with a life cycle approach. However, the effort needed for such analysis is relatively large, and the discussion about whether the evaluation of all building phases is also necessary in building energy refurbishment projects arises.

When talking about the energy renovation of an existing building, aimed primarily at reducing the impact of the use stage of such building, the need and added value of the application of a LC methodology when making decisions and prioritizing strategies with regards to their impact is brought into question, just like a growing number of matters like the following:

- Is it necessary to evaluate an energy rehabilitation performance as rigorously as we do with new buildings?
- To what extent can the boundary

zenbait etapen inpaktuak eraikinaren inpaktu orokorrarekiko duen eragin baxua (%1 baino baxuagoa). Hala ere beste kasu batzuetan sistemaren irismenaren sinplifikazioa informazio faltan oinarritzen da, birgaitze estrategien ebaluazioko bizi zikloaren etapa bakoitzaren inpaktuen inguruko adostasun batera iristea zailduz.

Orain arteko emaitzen irakurketa egin ostean, nahiko garbi geratu da eraikin berri baten ingurumen analisia egiterakoan beharrezkoa dela bizi zikloaren etapa guztiak ebaluatzea. Hala ere, metodologia honen aplikazioak esfortzu nahiko luzea eskatzen duela ikusirik, birgaitze energetikoetan ere etapa guztien analisia beharrezkoa denaren inguruan eztabaida handituz doa.

Gaur egungo erakinen birgaitze energetikoaren helburu nagusia erabilera etapako inpaktua murriztea da. Hau kontuan izanik, bizi zikloaren metodologia erabiltzeko beharra eta honek eman dezakeen balio erantsia inpaktuen aurrean erabakiak hartu eta birgaitze estrategiak lehenesteko orduan zalantzan jartzen hasi da, gero eta galdera berri gehiago sortuz:

- *Birgaitze energetikoa eraikin berriak bezalako zehaztasunaz ebaluatzea beharrezkoa al da?*
- *Ze punturaino sinplifikatu daiteke*

system be simplified without compromising the accuracy of the results and the resulting decisions?

- What is the relationship between the impact reduced during the use stage and the impact generated during the other stages of the life cycle? Is the impact of these other stages relevant?

- Should the same boundary system be applied when assessing the environmental and economic impact of a rehabilitation strategy on every type of building?

- What are the most relevant parameters and/or stages when conducting a study and making a decision?

sistemaren irismena emaitzen zehaztasuna eta ondorioztatutako erabakiak arriskuan jarri gabe?

- *Zein da erabilera etapako inpaktuen murrizketaren eta bizi zikloko beste etapetan sortutako inpaktuen arteko erlazioa? Beste etapa hauen inpaktua garrantzitsua da?*

- *Birgaitze estrategia baten ingurumen eta ekonomia inpaktuak ebaluatzean sistemaren irismen berdina erabili behar al da edozein eraikin motetarako?*

- *Zein dira azterlan bat egin eta erabakiak hartzerakoan eragin handiena duten parametro edota etapak?*

Thesis Proposal

Based on the aforementioned issues and concerns with regards to the effectiveness and applicability when using complex methodologies such as the Life Cycle Assessment for making decisions, this research work suggests a new methodology which allows for:

1- Removing the barrier of unawareness of the difference between simplified methodologies that only evaluate the use stage and complex methodologies that evaluate all stages of the life cycle. Thus, as shown in figure 24, the methodology suggested by this research work shall define the optimal effect of a rehabilitation study, revealing the relationship between the

Tesiaren proposamena

Aurretik proposatu edo azaldu diren galdera ezberdinen eta erabakiak hartzeko orduan Bizi Zikloa bezalako metodologia konplexuak erabiltzeak dakartzan operatibotasun eta erabilgarritasunaren inguruko kezkak ikusirik, ikerketa lan honek jarraian metodologia berri bat proposatzen du:

1- *Erabilera etapa bakarrik ebaluatzen duten metodologia sinplifikatuen eta etapa guztiak ebaluatzen dituen bizi zikloko metodologia konplexuen artean sortzen den zehaztasun ezberdintasunak dakartzan oztopoen muga gainditzea. Horrela, 24. irudiak erakusten duen bezala, ikerlan honek birgaitze energetiko baten azterlanaren* reduction of the environmental and economic impact during the use stage and the impact of the other life-cycle stages.

2- Making decisions and prioritizing energy rehabilitation strategies with added value and a more strategic perspective, based on a multi-criteria system adapted to those who take part in each performance.

With the sole purpose of suggesting, one of the first decisions of this research work focuses on defining the sustainability scope of the methodology. Ideally, making decisions on energy rehabilitation using a complete multi-criteria system would be the most desirable option and would allow for analysing and improving the three aspects of existing buildings: environmental, economic and social.

irismen hoberena definitzea ahalbidetuko du, erabilera etapako inpaktuen (ingurumen eta ekonomia inpaktuak) murrizpenak beste etapetan sortutako inpaktuekiko duen erlazioa ezagutuz.

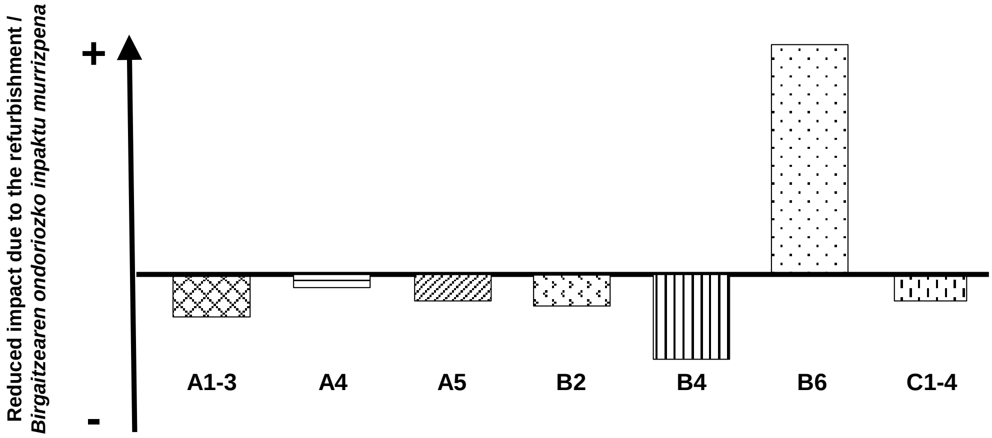


Figure / Irudia 24 Generated and reduced impacts in different life cycle stages due to the energy refurbishment strategy / *Eraikin baten birgaitze estrategia bat aplikatu ondoren bizi zikloko etapa ezberdinetan zehar sorturiko eta murriztutako inpaktuak.*

2- Proiektu bakoitzeko partaideei egokitutako irizpide anizdun sistema batean oinarrituz erabakiak hartu eta birgaitze energetikoak lehenestea ahalbidetuko du balio erantsia emanez eta ikuspegi estrategikoago baten bidez.

Ikerketa lan honen hasierako erabakietako bat jasangarritasunaren esparrua edo irismena definitzean datza. Egoera perfektu batean irizpide anizdun sistema bat erabiliz birgaitze energetikoaren erabakiak hartzea izango litzateke egokiena. Honela, gaur egungo eraikinen 3 aspektu nagusiak aztertu eta hobetuko lirateke: ingurumena, ekonomia eta soziala.

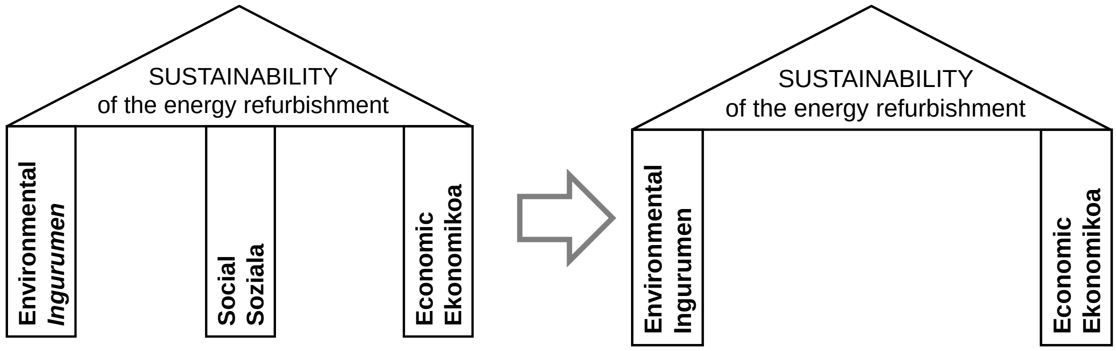
Hala eta guztiz ere, bi arrazoi nagusi

However, this methodology shall focus on defining a partial multi-criteria system, which shall evaluate environmental and economic impacts, omitting the evaluation of the social impact, for two reasons:

- This methodology shall be based on the lines of work set out by the Directive 244/2012 (*Regulation 244/2012, 2012)*, which states the need to make decisions with regards to the results of environmental and economic impacts.
- Social impact categories and methods of assessment still are not standardized (*Touceda et al., 2014*) and nor does the life cycle initiative propose methods for social impact assessment. Indeed, this initiative recognizes the feasibility of the classification step (to assign impact categories to the inventory data), but recommends not to aggregate or weight results of the three methodologies (environmental, social, economic), due to the early stage of Social Life Cycle Assessment (SLCA) (*UNEP/SETAC, 2011*) (more information about the Social Life Cycle Assessment during the annex 7.3). Otherwise, based on standards such as EN 15978: 2011 or FprEN16627: 2014, the methodologies to assess the Environmental and Economic impact with life cycle perspective are already developed, allowing define this methodology with greater rigor and standardization.

direla eta, metodologia honek irizpide anizdun sistema partzial bat definituko du. Honi esker, ingurumen eta ekonomia inpaktuak ebaluatuko dira, inpaktu sozialen ebaluazioa alde batera utziz.

- *No 244/2012 zuzentarauak (Regulation 244/2012, 2012) ezarritako lan ildoan oinarrituko da metodologia hau. Zuzentarau honek ingurumen eta ekonomia inpaktuetan oinarrituz erabakiak hartzeko beharra zehazten du.*
- *Inpaktu sozialen kategoriak eta ebaluazio metodoak oraindik ez daude estandarizatuta (Touceda et al., 2014) eta bizi zikloaren analisiak ere ez ditu inpaktu sozialak definitzeko metodoak proposatzen. Hain zuzen ere iniziatiba honek sailkapen etapa honen bideragarritasuna aitortzen du (bizi zikloaren inpaktuen emaitzak inbentarioko datuei esleitzeko), baina oraindik ez gehitzea gomendatzen du (UNEP/SETAC, 2011) bizi ziklo sozialaren analisiaren etapa goiztiarra dela eta (bizi zikloko analisi sozialaren inguruko informazio gehiago 7.3 eranskinean). Bestalde, EN 15978:2011 edo FprEN16627:2014 legeak direla eta, bizi ziklo baten ikuspuntutik ingurumen eta ekonomia inpaktua ebaluatzea ahalbidetzen duten metodologiak oso aurreratuta daude eta zehaztasun eta estandarizazio maila altu batez definitu daitezke.*



Complete Multi-criterial methodology / *Irizpide anizdun metodologi osoa*

Proposed Partial Multi-criterial methodology / *Proposatutako irizpide anizdun metodologi partziala*

Therefore, although one of the main features of every decision is aimed at improving some of the social aspects of the people living in the building subject to evaluation or those aspects that define the rehabilitation strategy (comfort, quality of life, health, labour rights, etc.), this methodology shall not quantify or evaluate the social impact of each and every rehabilitation performance.

Finally, thanks to the results of this new methodology, stakeholders shall be able to make decisions and give an answer to questions like:

Economic questions

- How long does it take until investments in energy efficiency or renewable energy measures have paid back?
- Does energy efficiency measures applied to the building envelope have a longer payback period than renewable energy measures, like e.g. installing PV panels on the roof?

Hau guztia dela eta, lan metodologia honetan zehar ez dira birgaitze estrategia ezberdinen inpaktu sozialak neurtu eta ebaluatuko, nahiz eta erabaki guztien oinarrian aspektu nagusienetako bat ebaluatu beharreko eraikineko bizilagunen edo birgaitze prozesuko partaide ezberdinen aspektu sozialen bat hobetzea izan (konforta, bizi kalitatea, osasuna, lan eskubideak, etab.).

Azkenik, partaide ezberdinek erabakiak hartu eta ondorengo galderei erantzun ahal izango die metodologia berri hau erabiliz lortutako emaitzen bidez:

Ekonomiaren inguruko galderak

- *Zenbat denbora behar da eraginkortasun energetikoan edo energia berriztagarrietan egindako inbertsioa berreskuratzeko?*
- *Eraikinen fatxada eta estalkian eraginkortasun energetikoa hobetzeko hartutako neurrien inbertsioa berreskuratzeko energia berriztagarriena berreskuratzeko*

- To what extent are grants and subsidies needed to make investments in the energy efficiency retrofit of a building economically positive?
- Contrasting the investment costs with the annual energy cost savings, how much money can be saved during its life cycle?

Environmental questions

- Which amount of Primary Energy can be saved with the deployment of renewable energy sources?
- Which is the environmental impact of the products and systems applied in the refurbishment strategy?
- Which are the energy refurbishment strategies with the greatest potential?

(adibidez teilatuan eguzki energia fotovoltaiko panelak ipintzea) baino denbora gehiago behar al da?

- *Ze neurritaraino dira diru laguntzak beharrezkoak eraginkortasun energetikoan oinarritutako birgaitze inbertsioak ekonomikoki positiboak izateko?*
- *Inbertsio kostua eta urtero aurreztuko den energia kostua alderatuz, zein izango da bizi zikloan zehar aurreztuko den diru kopurua?*

Ingurumenarekin lotutako galderak

- *Zenbat oinarrizko energia aurreztu daiteke energia berriztagarrien erabilerarekin?*
- *Zein da erabilitako produktu eta sistemek ingurunean duten eragina?*
- *Zein dira potentzial handiena duten birgaitze energetikoko estrategiak?*

CHAPTER 4 – New methodology

Techno-economic methodology to prioritize buildings energy refurbishment strategies with life cycle approach

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4 ATALA – Metodologia berria

Bizi zikloaren ikuspegitik eraikinen birgaitze energetikoen jarduerak analisi teknoekonomiko bidez lehenesteko metodologia

Most of the information about the tables and figures is available in English in annex 7.4

4. Bizi zikloaren ikuspegitik eraikinen birgaitze energetikoen jarduerak analisi teknoekonomiko bidez lehenesteko metodologia

Atal honetan proposaturiko metodologiaren bidez birgaitze energetikoaren jarduera batek edozein eraikinen bizi zikloan zehar sortzen duen **ingurumen eta ekonomia inpaktu** murrizpena ebaluatu ahal izango da. Horretarako, metodologian zehar definituriko parametro bakoitzaren balioak zehaztu ondoren, erabiltzaileak nahikoa informazio izango du landuko duen eraikinaren bizi zikloko analisiaren irismena optimizatu eta era horretan, doitasun maila zehatz batekin, hainbat inpaktu adierazleren arabera birgaitze estrategia ezberdinen artean lehenestera iristeko. Metodologiaren kalkulu eskema 5 fase nagusietan banatuko da (ikus 25. irudia):

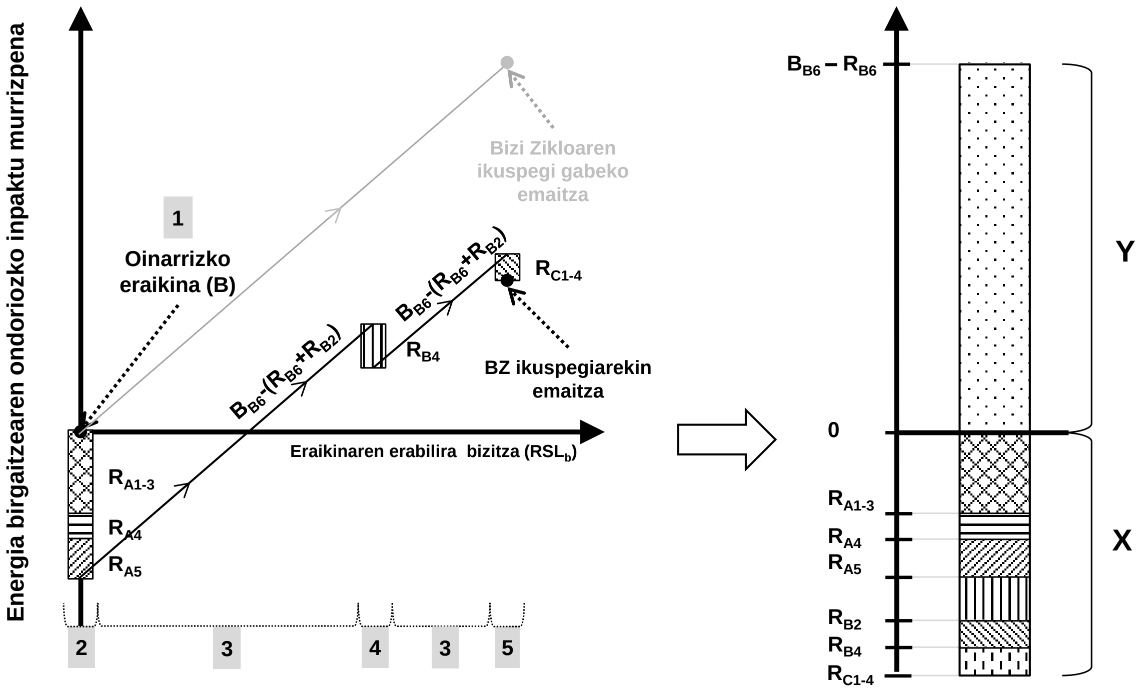
1- Azterlanaren hasiera puntua aukeraturiko baseline (B) edo oinarrizko egoeraren **ingurumen eta ekonomia inpaktua** kalkulatzean datza (aldakorra azterlanaren helburuaren arabera).

2- Behin oinarrizko egoera ebaluaturik, teknikoak birgaitze estrategia ezberdinak proposatuko ditu, zeintzuk beren ekoizpen (A1-3), banaketa (A4) eta eraikuntza prozesuko (A5) etapetan zehar hasierako inpaktu negatibo bat sortzen duten (ingurumen+ekonomikoa) Hau da, birgaitze estrategiak oinarrizko egoeraren inpaktua murrizten hasi aurretik, beharrezkoa da etapa hauen hasierako inpaktu negatiboa kontuan hartzea.

3- Birgaitze energetikoaren estrategia ezberdinak ezarri ondoren, oinarrizko eraikinaren erabilera etaparen **ingurumen eta ekonomia inpaktua murrizten** da. Honen balioa, oinarrizko eraikinaren eta eraikin birgaituaren erabilera etaparen inpaktuen konparaketaren bidez kalkulatzen da (B_{B6}-R_{B6}). Hala ere, erabilera etapa honetan zehar, beharrezkoa da birgaitze estrategien **mantentzea** (B2) bezalako jarduerek **sorturiko inpaktua** kontuan hartzea, honek inpaktu negatiboa gehituko baitu.

4- Birgaitze estrategia ugariren aurreikusitako erabilera bizitza (ESL_m) birgaituko den eraikinaren erabilera bizitza (RSL_b) baino txikiagoa dela ikusirik, eraikinaren bizian zehar estrategia hauek produktu edo sistema berrien bidez **ordezkatzen** dira. Horren ondorioz, beharrezkoa izango da estrategia berriek sortutako ingurumen eta ekonomia inpaktua zenbatzea.

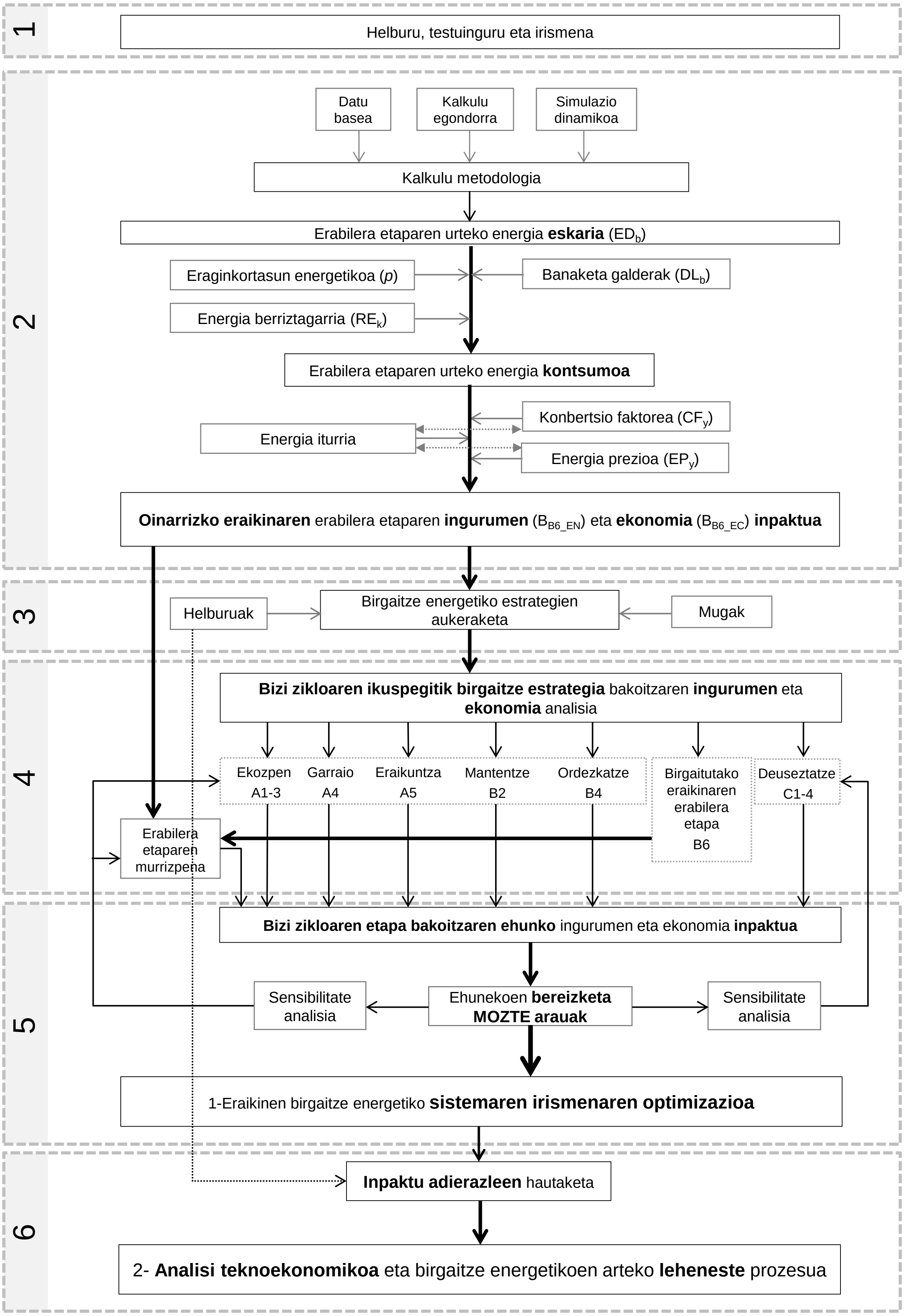
5- Birgaitze estrategien ordezkapenak aplikatu ondoren eraikinaren erabilera etaparen inpaktua murrizten jarraitzen da eraikinaren RSL_b mugara iritsi arte. Amaierako puntu honetan, birgaitze estrategien deuseztapen etaparen inpaktu negatiboa ebaluatzen da.



Irudia 25 Bizi zikloan zehar eraikin baten birgaitze energetikoaren ingurumen eta ekonomia inpaktuaren kalkuluaren eskema

Modu honetara, 5 etapak ebaluatu ondoren erabiltzaileak bi motatako emaitzak lortzen ditu. Alde batetik teknikoak birgaitze estrategia ezberdinak erabiltzearen ondorioz eraikinaren erabilera etapako (B6) inpaktu murriztua ezagutuko du (inpaktu positiboa – “Y”). Aldi berean teknikoak birgaitze estrategien bizi zikloko etapetan zehar sortutako inpaktuaren (inpaktu negatiboa – “X”) informazioa lortuko du (A1-A3, A4, A5, B2, B4, C1-C4). Bizi zikloan zeharreko birgaitze estrategia bakoitzaren inpaktuak nola kalkulatu behar diren definitu, sistemaren irismena hobetu eta EN 15879:2011 (ingurumen) eta FprEN 16627:2014 (ekonomiko) –ko kalkulu metodologian oinarrituz irizpide anitzeko sistema batekin estrategiak lehenesteko helburuarekin, 6 atalez osaturiko metodologia berri bat definitu da:

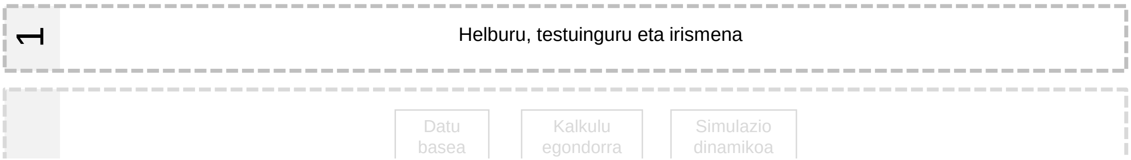
1- Helburua, testuingurua eta irismena.
2- Oinarrizko eraikinaren erabilera etaparen ingurumen eta ekonomi diagnostikoa.
3- Birgaitze energetikoko estrategien hautaketa.
4- Birgaitze energetikoko estrategia bakoitzaren aplikazioaren ondoriozko bizi zikloaren etapa bakoitzaren ingurumen eta ekonomia inpaktuen kalkulua.
5- Irismenaren optimizazioa.
6- Lehenetsi eta erabakiak hartu.



Irudia 26 Bizi zikloaren ebaluazio sistemaren Irismena optimizatu eta birgaitze energetikoen artean lehenesteko metodologiaren egitura

4.1. Helburua, testuingurua eta irismena

Lehenengo atala analisiaren helburua, testuingurua eta irismena definitzean datza eta azterlan motaren azalpen gisa balio du.



4.1.1. Helburua

Azterlanaren helburuak argi eta garbi azaldu beharko ditu aurreikusitako erabilera, azterlana aurrera eramateko arrazoiak eta hartzailearen ezaugarriak, hau da, azterlanaren emaitzak jasoko dituenarenak.

4.1.2. Testuingurua eta beharrak

Birgaitze proiektuetan, lehenengo puntu bezala beharrezkoa izango da lehen analisi baten bidez hobetzeko beharra duen eraikinaren aspektu ezberdinak modu orokor batean zehaztea, bizilagunen aspektu sozialetatik eraikinaren aspektu teknikoetaraino. Modu honetara, birgaitze proiektuaren ahalegin guztia eraikinaren aspektu bakar batean oinarritu beharrean, eraikineko bizilagunen arazo ezberdinetan hasieratik lan egiteko aukera egongo da.

4.1.3. Irismena

Azterlanaren irismenak zehazten du zein prozesu sartu behar diren. Bizi zikloaren inbentarioaren garapenean kontuan izan beharreko prozesuak zehazten dira azterlanaren irismenaren bidez. Lehen puntuan zehazturiko helburua lortzeko irismenaren xehetasuna eta sakontasuna ondo definitua egotea eta azterlanarekin bat datorrela ziurtatzea ezinbestekoak dira. Irismena definitzeko garaian beharrezkoa da ondorengo puntuak definitzea:

<u>Unitate funtzionala</u>

Bizi zikloaren ikuspegitik azterlanak alderatu eta ebaluatu ahal izateko parametro nagusienetako bat da. Unitate funtzionalak azterlanaren helburua eta irismenarekin koherentea izan behar du. Produktu, sistema edo eraikin baten inpaktuak alderatzerakoan, ezinbestekoa da unitate funtzional berdina erabiltzea. Horregatik, beharrezkoa da hasieratik kasu bakoitzean erabilitako unitate funtzionalaren ezaugarriak garbi zehaztea. Eraikin ezberdinen arteko emaitzak alderatzea errazteko helburuarekin, EN15879:2011 araudiak unitate funtzionalak eraikinaren deskribapenarekin batera ondorengo parametroen informazioa edukitzea gomendatzen du.

- Eraikinaren erabilera (bulegoak, etxebizitza etab.).
- Betebehar tekniko eta funtzionalak.
- Erabilera ereduak.
- Eraikinaren aurreikusitako erabilera bizitza.

Eraikin baten ingurumen eta ekonomia portaera lantzen duten azterlanek erabili beharreko unitate funtzionala estandarizatu eta normalizatzearen inguruan lan ugari egin den arren, 9. taulan ikus daitekeen bezala, azken urteetan egindako lanetan unitate funtzional ezberdinak erabili dira (bakarrik 2010etik aurrera garatutako zenbait lan erakusten dira).

Taula 9 Eraikinen bizi ziklo analisi desberdinetan erabilitako unitate funtzionalak

Unitate funtzionala	Unitatearen deskribapena	Azterlanak
m^2	Solairu azalera netoa	*Asdrubali et al., 2013*.
	Berotutako azalera	*Gustavsson & Joelsson, 2010; Allacker & De Troyer, 2013; Mosteiro et al., 2014.*
	Barne azalera gordina	*Bull et al., 2014*
	Solairu erabilgarri azalera	*Cuellar & Azapagic, 2012; Ramesh et al., 2012a; Sharma et al., 2012, Stephan et al., 2013, Paulsen & Sposto, 2013; Stephan & Stephan, 2014.*
	Solairu azalera gordina	*Junilla, 2004; Russell-Smith et al., 2014.*
	Bizitzeko azalera	*De Angelis et al., 2013; Rodriguez & Freire, 2014; Dodoo et al., 2014.*
	Zehaztapen gabeko solairu azalera	*Dodoo et al., 2010; Tae et al., 2011; Wallhagen et al., 2011; Iyer & Wong, 2012.*
m^2urte	Berotutako azalera	*Citherlet & Defaux, 2007; Oregi et al., 2015a.*
	Azalera bizigarria	*Nemry, 2008; Zabalza et al., 2009; Bastos et al., 2014*
	Solairu azalera netoa	*Gazulla & Oregi, 2012*
	Azalera erabilgarria	*Devi & Palaniappan, 2014*
	Azalera osoa	*Blengini & Di Carlo, 2010*
	Zehaztapen gabeko solairu azalera	*Malmqvist et al., 2011; Ramesh et al., 2012b; Rossi et al., 2012*
Urtea		*Cellura et al., 2014; Assiego de Larriva et al., 2014*
Bizilaguna		*Allacker & De Troyer, 2013*
Pertsona urteko		*Bastos et al., 2014*
Energia kontsumo osoa		*Utama & Gheewala, 2009; Hernandez & Kenny, 2010; Stephan et al., 2012.*
Ingurumen inpaktu osoa		*Oritz et al., 2010; Blom et al., 2010; Vrijders & Wastiels, 2013*

Unitate funtzional ezberdin guzti hauen erabilerak azterlan ezberdinen arteko konparazioa moteltzen du, balio aldakorretan oinarrituz erabakiak hartzea ahalbidetzen duen prozesu azkar eta unibertsala zailduz.

Eraikinaren erabilera bizitza (RSL_b)

Ekoiztutako edozein produkturentzat erabilera bizitza, esperientzia edo antzeko produktuen bidez nahiko zehaztasun handiarekin kalkulatu daiteke. Bestalde, erabiltzaile edo bizilagunaren profila, bere gizarte maila, eraikinaren ingurunea, klimaren gogortasuna, mantentzea etab. bezalako faktore ez teknikoak direla eta, ez da erraza eraikin bakoitzaren erabilera bizitza zehazterakoan balio finko bat definitzea. Adibidez, Europako batzordeak (*Regulation 244/2012, 2012*) etxebizitzentzat 30 urteko eta etxebizitza ez diren eraikinentzat 20 urteko analisi denbora ezartzen du. Hala ere, Cabezak egindako azterlan ezberdinen arteko analisian erakusten da (*Cabeza et al., 2014*) artikuluen %50ak 50 urteko RSL_b balioa erabiltzen duela, %19ak 40 urtekoa eta %9ak 80 edo 100 urtekoa.

Estandarizazio gabezia honek emaitza ezberdinen interpretazio azkar bat egitea zailtzen du. Hori dela eta, metodologia honek balio orokorrez edo azalera unitatezkoen gain, urtekako emaitzak azaltzea gomendatzen du, era honetan RSL_b kontzeptua barneratuz eta beste antzeko azterketa lan batzuekin alderatzea erraztuz.

Sistemaren irismena

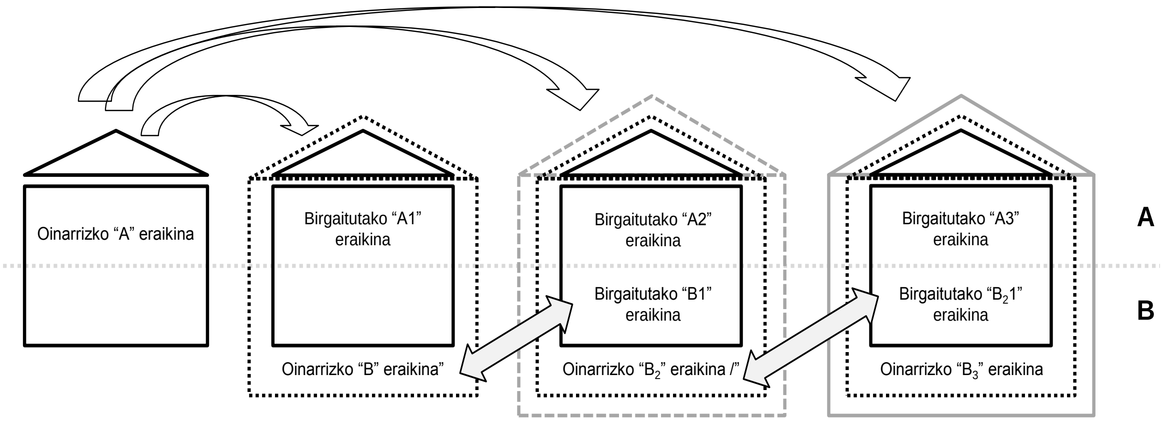
Sistemaren irismenak eraikinaren analisian kontuan hartuko diren unitate prozesuak zehazten ditu. Faktore ezberdinek zehazten dute sistemaren irismena, azterlanaren aurreikusitako erabilerak, egindako hipotesiek, mozketa irizpideek, datuek edo aurreikusitako erabiltzaileen bezalako faktoreek. Sistemaren irismenean zehar aukeratutako sarrera (input) - irteerak (output), kategori datuak eta sistemaren modelizazioa azterlanaren helburuekin bat etorri beharko dira.

EN15978:2011 arauak eraikin berrientzat sistemaren irismenak bizi ziklo osoa barne hartu behar duela definitzen du. Gaur egungo eraikinentzat aldiz, sistemaren irismenak gaur egungo egoeratik deuseztatze etapara arte dauden etapa guztiak kontuan izan beharko ditu. Metodologia berri honen bidez birgaitze energetiko baten ingurumen eta ekonomia inpaktua ebaluatzeko garaian, beharrezkoa da birgaituko den eraikinaren bi egoera ezberdin ebaluatzea: **hasierako egoera** eta **birgaitu ondorengo egoera**. Hala ere, bi egoera hauek lantzerakoan, 27. irudian ikus daitekeen bezala, erabiltzailearen helburuaren arabera 2 eszenatoki ezberdin aurki daitezke (A eta B), 4 irismen ezberdin definituz.

A metodologia: independenteki estrategia bakoitzaren ingurumen eta ekonomia inpaktuak murrizteko potentziala kalkulatzea ahalbidetzen du. Horretarako birgaitze egoera ezberdin guztiak oinarri berarekin alderatuko dira (normalki eraikinaren hasierako egoerarekin).

Oinarrizko “A” eraikina. Oinarrizko eraikinaren sistemaren irismenak bakarrik erabilera etapako ingurumen eta ekonomia inpaktuak hartzen ditu kontuan eta ez ditu neurtzen aurretiko inpaktu guztiak: eraikina eraikitzeko erabilitako produktu eta sistemak (ekoizpen etapa), hauen garraioa, eraikitze prozesua, mantentzea, ordezkatzea eta produktu hauek deuseztatzean sortutako hondakinen kudeaketa. Esan behar da eraikin askok beraien erabilera bizitzan zehar arrazoi ezberdinen ondorioz (segurtasuna, osasungarritasuna, irisgarritasuna edo eraginkortasun energetikoa) aldaketa asko jasan dituztela. Ondorioz, edozein kalkulu egin aurretik beharrezkoa izango da eraikinaren gaur egungo egoera zein den aztertzea eta hasierako oinarrizko eraikinarekiko egindako aldaketak zehaztea.

Birgaitutako “A” eraikina. Erabilera etapako inpaktuekin batera erabilitako birgaitze estrategiarekin zuzenki erlazionatutako inpaktu guztiak (ekoizpenetik hasi eta deuseztatze etaparainokoak) hartzen ditu kontuan “A” egoerako birgaitutako eraikin baten sistemaren irismenak.



Irudia 27 Oinarrizko eraikinaren eta birgaitze estrategiak lehenesteko egoeren arteko erlazioa

B metodologia: birgaitze estrategia talde bakoitza optimizatzea ahalbidetzen du. Hau da, erabiltzaileak, bere estrategiaren eraginkortasun mailaren igoera dela eta, ingurumen eta ekonomia inpaktuen murrizpena zein den ebaluatu ahalko du. Honela isolamenduaren lodieraren optimizazioa, teknologia berriztagarrien azalera edo leihoen ezaugarri termikoak bezalako erabakiak hartu ahal izango dira.

Oinarrizko “B” eraikina. Oinarrizko “B” eraikina eta “A” eraikinaren arteko ezberdintasun nagusia “B” eraikina birgaitua dagoelan datza. Horregatik, erabilera etapako inpaktuen neurketarekin batera, beharrezkoa da birgaitze estrategia horrek ingurumen eta ekonomian dituen inpaktuak ere neurtzea.

Birgaitutako “B” eraikina. B kalkulu metodologiako birgaitutako eraikinen sistemaren irismena A kalkulu metodologiakoen berdina da (birgaitutako “A” eraikina). Hala ere, ezberdintasun handiena birgaitze estrategia bakoitzarekin erlazionatutako inpaktua kalkulatzeko orduan dago. A metodologiaren barruan konparazioak beti oinarrizko “A” eraikinarekiko egingo dira, B metodologian aldiz konparazioak aurreko egoerarekiko egingo dira (normalki eraginkortasun energetiko maila baxuago batekiko).

Taula 10 Birgaitutako eraikinaren ebaluazioaren sistemaren irismena bizi zikloaren ikuspegitik (EN 15978an oinarritutako etapen nomenklatura)

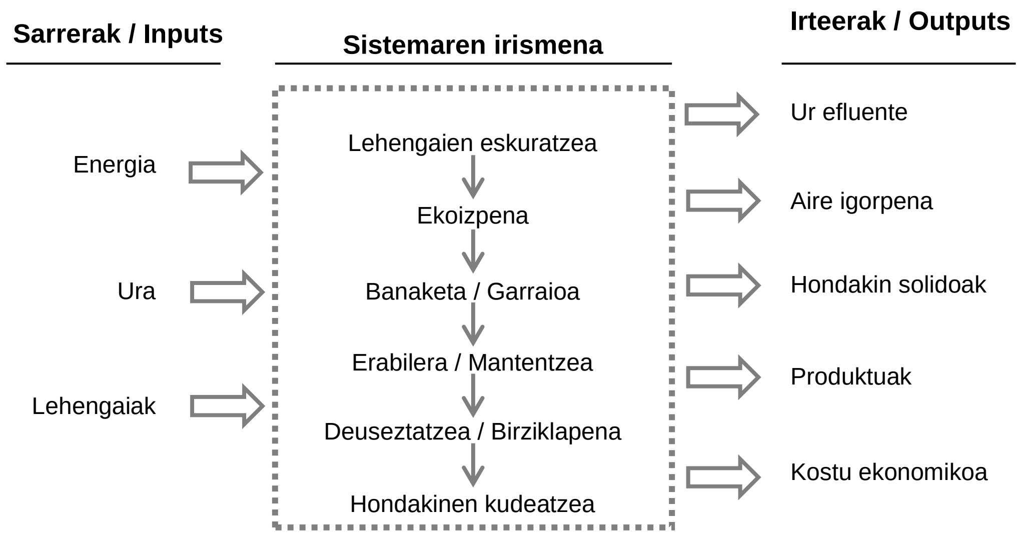
Etapa	Ebaluatutako aspektuak	Oinarrizko eraikina		Birgaitutako eraikina	
		A	B	A	B
A1-3	Birgaitze estrategi produktuen ekoizpen prozesuak		X	X	X
A4	Birgaitze estrategien produktuen garraioa		X	X	X
A5	Birgaitze estrategien eraikuntza prozesuak		X	X	X
B2	Birgaitze estrategien mantentze prozesuak		X	X	X
B4	Birgaitze estrategien ordezkatzeak		X	X	X
B6	Oinarrizko eraikinaren erabilera etapa	X			
RB6	Birgaituriko eraikinaren erabilera etapa		X	X	X
C1-4	Birgaitze estrategien deuseztatze prozesuak		X	X	X

Inpaktuen adierazleak

Birgaitze energetikoko estrategia ezberdinen puntu sendo eta ahulak ebaluatzeko beharrezkoa izango da zenbait aukeraketa egitea bizi-zikloaren inbentario eta bizi-zikloaren inpaktuen ebaluazio ezberdinen artean, aukeraketa hauek eragin zuzena izango baitute azken emaitzen irakurketa eta estrategia ezberdinen artean erabakiak hartzerakoan.

- Bizi Zikloaren Inbentarioa - BZI

Bizi zikloaren azterketaren fase honetan birgaituko den eraikinaren sistemaren irismenaren barruko prozesu guztietako sarrerei eta irteerei buruzko datuak biltzen dira. Era honetan, lehen fasean definituriko unitate funtzional batentzat, bizi zikloan zehar sistemaren (eraikin birgaitua) oinarrizko fluxuen balantzea garatuko da (ikus 28. irudia). Prozesuren batek momentu berean produktu bat baino gehiagorengan eragina baldin badu edo produktuaren hondakinak berrerabilgarriak eta birziklagarriak diren kasuetan, esleipen irizpide ezberdinak aplikatzea beharrezkoa izango da, inpaktuen banaketa egoki bat garatuz.



Irudia 28 Prozesu baten bizi zikloaren inbentarioaren eskema

11. taulan ikus daitekeen bezala, gaur egun bizi zikloaren inbentarioa osatzerako garaian, datu base ezberdinak aurki daitezke. Datu base hauetan hainbat motatako material eta prozesuei buruzko ingurumen eta ekonomia datuak gordetzen dira eta bertako informazioari esker bizi zikloan jasotako sarrera-irteera bakoitzari buruzko hainbat datu esleitzeko aukera dago. Datu base hauez gain, birgaitze estrategikoa osatuko duten produktu edo sistemen inguruko informazioa “Produktuaren Ingurumen Adierazpen” (PIA) ezberdinez ere lor daiteke, Hau da, bizi-zikloaren analisian oinarrituta, produktuaren ingurumen portaerari buruzko informazio gardena eta hirugarren alderdi independente batek egiaztatzeko modukoa eskaintzen duten dokumentuak dira PIAk.

Taula 11 Gaur egungo Bizi Zikloaren Inbentarioa (BZI) garatzeko zenbait datu base

Ingurumen datu base sektore-anitzak	
Europar bizi zikloaren 3.1 datu base eredua (*ELCD, 2009*)	Europar mailako bizi zikloaren inbentarioa, material, energia prozesu, garraio eta hondakinen kudeatzearen inguruko informazioarekin
EEBB-tako bizi zikloaren datu basea (*NRPE, 2012*)	EEBB-tako material, osagai edo sistema ezberdinen ekoizte prozesuan sortutako energia eta materialen fluxuaren inguruko informazioa
Danimarkako SI datu basea / (*2.0 LCA consultants, 1999*)	Danimarkako ekonomia eta ingurumen nazionaleko 1999ko estatistika balioetan oinarrituriko Sarrera-Irteera (input-output) datu basea
Ecoinvent v3.1 (*Ecoinvent, 2014*)	Industria, eraikuntza eta garraio prozesu eta sistemei buruzko informazioa duen nazioarteko BZI datu basea.
GaBi BZA datu basea (*GaBi, 2014*)	Industria, eraikuntza eta garraio prozesu eta sistemei buruzko informazio duen nazioarteko BZI datu basea
IVAM v.4.06 BZA datu basea (*IVAM, 2004*)	Herbeheretako material, garraio, energia eta hondakinen kudeaketa prozesuen inguruko datu basea
GEMIS 4.5 (*Gemis, 2009*)	Energia, garraio, material, birziklapen eta hondakinen kudeaketa

	prozesuz osatutako doako datu basea
Eraikuntza sektoreko ingurumen datu baseak	
Athena v.4, Canada (*ATHENA*)	Eraikinen material eta produktuen BZI datu basea.
Diogen, Frantzia (*Diogen*)	Eraikuntza eta ingeniaritza zibilean erabiltzen diren materialen ingurumen inpaktuen informazioa.
IBO, Austria (*IBO*)	Giza osasun eta ongizatean (Baubiologie) eta ingurumenean (Bauökologie) eraikin batek duen eraginari buruzko informazioa.
Ökobau, Alemania (*Emara & Ciroth, 2014*)	Alemaniako Ingurumen, Natura Babes, Eraikuntza eta Segurtasun Nuklearraren ministerioek (BMUB) garatutako Alemaniako eraikuntza material eta zerbitzuen datu-basea
ITec, Espainia (*ITEC, 2015*)	Informazio ekonomikoaz gain, eraikuntza elementuen inguruko ingurumen informazioa eskaintzen du.
Leitfaden, Luxenburgo (*CRTE, 2008*)	Eraikuntza material, osagai eta produktuen datu base publikoa
Minnesota, EEBB (*CSBR*)	Puntuazio edo rating balio ezberdinetan (ingurumen, ekonomia, deuseztatze edo bizi zikloko analisiaren inpaktuak) oinarrituriko eraikuntza materialen datu basea (Athena eta BEES datu baseetan oinarritua).
Eraikuntza sektoreko datu base ekonomikoak	
Europar eraikuntza kostua (*ECC*)	Europar eraikuntzaren prozesu eta produktu ezberdinen inguruko doako informazio orokorra
Precio Centro Guadalajara (*PCG, 2015*)	Guadalajarako Arkitekto teknikoi eta eraikuntza ingeniarien elkarteak garaturiko eraikuntzako prozesu eta produktu ezberdinen inguruko datu basea
BATIPRIX	Eraikuntza material, sistema eta prozesuen Frantziako datu basea

Datu base ekonomiko hauez gain, azken urteetan zehar Bundesverband Flachglas-ek (*VFF, 2014*), European Insulation Manufacturers Asssociation-ek (*Eurima, 2005; Eurima, 2010*), Department of Mechanical Engineering-ek (*Engblom, 2006*) edo EPYQR (Energy Performance, Indoor Environment Quality, Retrofit) (*EPIQR, 1996*) eta IMPRO-Building (*Nemry, 2008*) bezalako Europako ikerkuntza proiektuetan garaturiko argitalpen eta azterlan ezberdinen ondorioz, eraikinen birgaitze estrategien kostu ekonomikoaren inguruko hainbat informazio argitaratu da.

- Bizi-Zikloaren Inpaktuen Ebaluazioa (BZIE)

Etapa honetan zehar sistema batek ingurumenari edo ekonomiari sor diezazkiokeen inpaktuen neurria eta garrantzia ebaluatzen da. ISO 14040:2006 arauaren arabera, BZIE 3 nahitaezko etapetan oinarritzen da:

- **Hautaketa**: bizi zikloko analisian zehar erabili nahi diren ingurumen eta ekonomia inpaktuen kategoriak aukeratzean datza.

- **Sailkapena** BZI-aren emaitzak antolatu eta ingurumen eta ekonomia inpaktuen kategoria ezberdinei esleitzean datza. Era horretan, bizi-zikloaren inpaktuari buruzko datuak inpaktuen kategoriei esleitzen zaizkie.

- **Karakterizazioa.** Bizi zikloaren inpaktuen substantzia bakoitzak ingurumen edo ekonomia inpaktuen kategoria batean edo gehiagotan sailkatu ondoren, inpaktu kategoria desberdinak zehazteko faktore desberdinen bidez, bere balioa kategoria horretako erreferentziazko substantziarekiko kontuan hartuta kalkulatzean datza.

Bizi-zikloaren inpaktuen ebaluazioan eman beharreko nahitaezko urratsez gain, badira helburuaren eta aurreikusitako irismenaren araberako hautazko urrats batzuk ere:

- **Normalizazioa.** Ezaugarrien emaitzak unitate orokor neutro bihurtzea, bakoitza normalizazio faktore batekin zatituz. Faktore horien bidez adierazten da inpaktu kategoria bakoitzak tokiko ingurumen arazoei egiten dien ekarpena.

- **Taldekatzea.** Inpaktu kategoriak antzeko eraginak dituzten beste talde batzuetan sailkatzea.

- **Haztatzea.** Xehatutako balioen emaitzak unitate komun eta batugarri bihurtzea (metodologiak normalizazioa barnean hartzen duen kasuetan, normalizatutako balioetatik abiatuta), dagokien haztapen faktorearekin biderkatuta. Ondoren, horien guztien batura egingo da sistemak ingurumenari egiten dion inpaktuaren puntuazio bakar orokorra lortzeko. Orokorrean ISO 14044:2006ak hautazko etapa honen erabilera ekiditea proposatzen du, batez ere emaitzak beste azterlan batzuekiko konparatzeko erabili behar diren kasuetan.

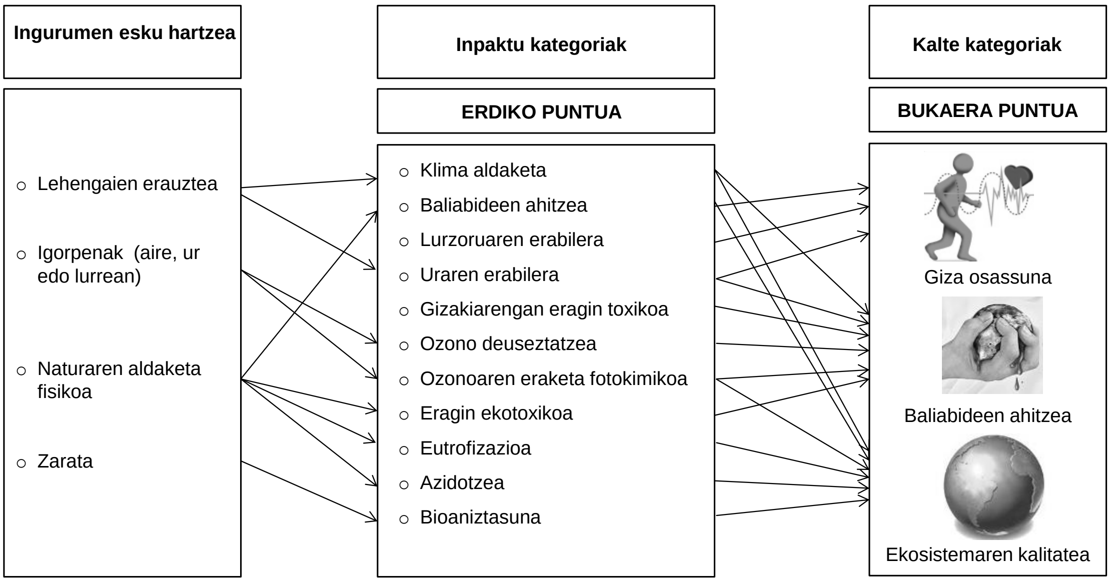
INGURUMEN BZIE metodologiak eta inpaktuen kategoriak.

Definitutako helburuaren eta aukeratutako inpaktu kategorien arabera, 3 BZIE metodologia aurkitzen dira:

- **Erdiko puntua (Midpoint).** Ohiko inpaktuen ebaluazio metodologia. Kasu honetan erdi puntuko inpaktu kategoriek bizi zikloan zehar neurtutako inpaktuak berotze globala, azidotzea, eutrofizazioa etab. ingurumen gaiekin erlazionatzen dituzte. Inpaktu kategoria honen barruan zenbait kalkulu metodologia aurkitzen dira. Aipatzekoak dira CML (*Guinée, 2001*), EDIP (*Hauschild & Potting, 2003*) (erdiko puntua normalizazioarekin), TRACI (*Bare, 2004*) edo Klima Aldaketari Buruzko Gobernu Arteko Taldeak garaturiko IPCC (*IPCC, 2013*) metodologiak.

- **Bukaerako puntua (Endpoint).** Metodologia hauen bidez lorturiko inpaktu kategoriek bizi zikloan zehar neurtutako inpaktuak gizakiaren osasuna edo ingurumen kalitatea bezalako bukaera puntu edo kalte kategoriekin lotzen dituzte. Inpaktu kategoria honen barruan zenbait kalkulu metodologia aurkitzen dira. Aipatzekoak dira besteak beste Ecoindicador 99 (*Goedkoop & Spriensma, 2001*), EPS 2000 (*Steen, 1999*) eta Ecopoints (*Braunschweig et al., 1998)* metodologiak

- **Erdi-puntu eta bukaerako puntu ikuspegi konbinazioa.** Inpaktu mota hauek IMPACT 2002+ (*Jolliet et al., 2003*), RECIPE (*Goedkoop et al., 2009*) edo LIME (*LIME2, 2012*) bezalako metodologien bidez lor daitezke



Irudia 29 UNEP/SETAC-ek definituriko ingurumen esparruko BZIE eskema, BZI-ko emaitzak erdiko puntu eta kalte kategoriekin lotuz. Iturria: (*Jolliet et al., 2003*)-en datuetan oinarritutako norbere garapena.

BZIE atalean aipatu den bezala, ISO 14044:2006ak hautazko etapen erabilera ekiditea proposatzen du. Horrela, ikusirik bukaerako puntuak proposatutako inpaktu kategoriak taldekatze eta haztatze etapetan oinarritzen direla, metodologia hau erdiko puntuan (midpoint) oinarrituriko inpaktu kategorien erabilerara mugatuko da. Ondorioz, EN15978:2011 arautegia oinarri harturik, eraikin birgaitu baten ingurumen inpaktuak adierazteko kategoriak erakusten dira 12. taulan zehar.

Taula 12 Ingurumen inpaktu kategorien adierazleak (EN 15978:2011 arautegian oinarritua)

Ingurumen inpaktuak	
Berotze osoaren potentziala (GWP)	Kg baliok. CO_2
Berotze global edo "berotegi-efektua / klima-aldaketa" bezala ezagutuak, lurrazaleko, aireko eta ozeanoetako batez besteko tenperaturaren igoerarekin guztiz lotua dagoen inpaktu adierazlea da. Tenperatura igoera honen ondorioz glaziar eta poloetako izotzak urtu eta itsas maila igo edo eskualde ezberdinen klimaren aldaketan ere eragin zuzena izan dezake.	
Estratosferako Ozono geruzaren deuseztatze potentziala (ODP)	Kg baliok. CFC 11
Klorofluorokarburoak (CFC) eta halonak gisako gasen isurketen ondorioz estratosferako ozono geruza mehetzen ari da, eguzkiaren erradiazioa ultramoreengandik babesteko duen gaitasuna urrituz. Mehetze honek eragin zuzena izan dezake, kalte zuzenak eraginez gizakiaren	

osasunaren, ekosisteman, ziklo biokimikoetan eta materialetan.	
Lurzoru eta uraren azidotze potentziala (AP)	Kg baliok. SO_2
Atmosferatik deskargatutako Sufre dioxidoa (SO2) eta nitrogeno oxidoa (NOx) edo "euri azidoa"-ren ondorioz, ur eta lurzoru sistemen azidotze maila igo daiteke. Azidotze maila igoera honek eragin zuzena izan dezake basoen gainbeheran, lurzoruaren azidotzean eta eraikinen materialen kalte zuzenean.	
Eutrofizazio potentziala (EP)	kg baliok. $(PO_4)^3$
Ongarri eta garbigarri asko erabiltzearen ondorioz ibaietako eta urtegietako urak artifizialki aberasten dira eta alga populazioa gehiegi hazten da. Ondorioz, uretako oxigeno asko kontsumitzen da.	
Ozono troposferikoaren eraketa potentziala (POCP)	kg baliok. Eteno
Eguzki-argiaren bidez zenbait aire kutsadurak eratutako konposatu kimiko erreaktiboak deskribatzen ditu adierazle honek. Berez, troposferan ozonoa eratu eta suntsitzen da kutsatzaile primarioekin izandako erreakzio kimikoen ondorioz. Gainazaleko ozonoa oso oxidatzailea denez, lurzoruengan, eraikuntza materialengan, uztengan, basoengan eta landareengan eragin kaltegarria du, azken hauen emankortasun biologikoa gutxituz. Batez ere trafiko handia duten hirietan udaran geratzen den "summer smog" edo "udako ke-lauso" (summer smog) efektuarekin guztiz lotua dagoen adierazlea da.	
Baliabide ez-fosilen abiotiko ahitze potentziala (ADP-elements)	kg baliok. Sb
Baliabide fosilen abiotiko ahitze potentziala (ADP-fossil fuels)	MJ, bero balore netoa
Energia baliabideen kontsumoa	
Oinarrizko energia berriztagarriaren erabilera	MJ
Oinarrizko energia ez-berriztagarriaren erabilera	MJ
Oinarrizko energiaren erabilera	MJ
Lehengaiak eskuratzeko, ekoizteko, banatzeko, erabiltzeko eta deuseztatzeko prozesuetan kontsumitutako energia kopurua.	MJ
Material sekundarioen erabilera	kg
Erregai sekundario berriztagarrien erabilera	MJ
Erregai sekundario ez berriztagarrien erabilera	MJ
Uraren erabilera	m^3
Hondakinen kategoria eta irteera fluxuak deskribatzen dituzten beste zenbait ingurumen adierazle	
Hondakin arriskutsu kudeatuak	kg
Hondakin ez arriskutsu kudeatuak	kg
Hondakin erradioaktibo kudeatuak	kg
Berrerabiltzeko osagaiak	kg
Birziklatzeko materialak	kg
Energia berreskuratzeko materialak	kg
Energia esportatua	MJ

EKONOMI BZIE metodologiak eta inpaktuen kategoriak

Atal ekonomikoa ebaluatu eta neurtzeko helburuarekin gaur egun jasotako datuak izaera ekonomikoko emaitza bihurtzen dituzten ebaluazio metodologia ezberdinak daude. Horien artean ondoregoak dira aipatzekoak:

- Sarrera-irteera (Input Output). Oreka orokorraren teoriaren oinarriaren inguruko ekonomiaren osagai ezberdinen artean dauden erlazioen analisiarentzako euskarri enpiriko bat ematen du (*Leontief & Wassily, 1986*).
- Kostu osoen neurketa (Full Cost Accounting). Kostuaren prezioan, egindako unitateen ekoizpen kostu guztiak barneratzen dituen kostuen sistema.
- Energiaren kanpo eragileak (“Externalities of the energy) Energiarekin erlazionatutako ingurumen eta gizartearekiko inpaktuak, inpaktu ekonomikoetan bihurtzen ditu diru-balioan adieraziz (*Extern E, 2005*).

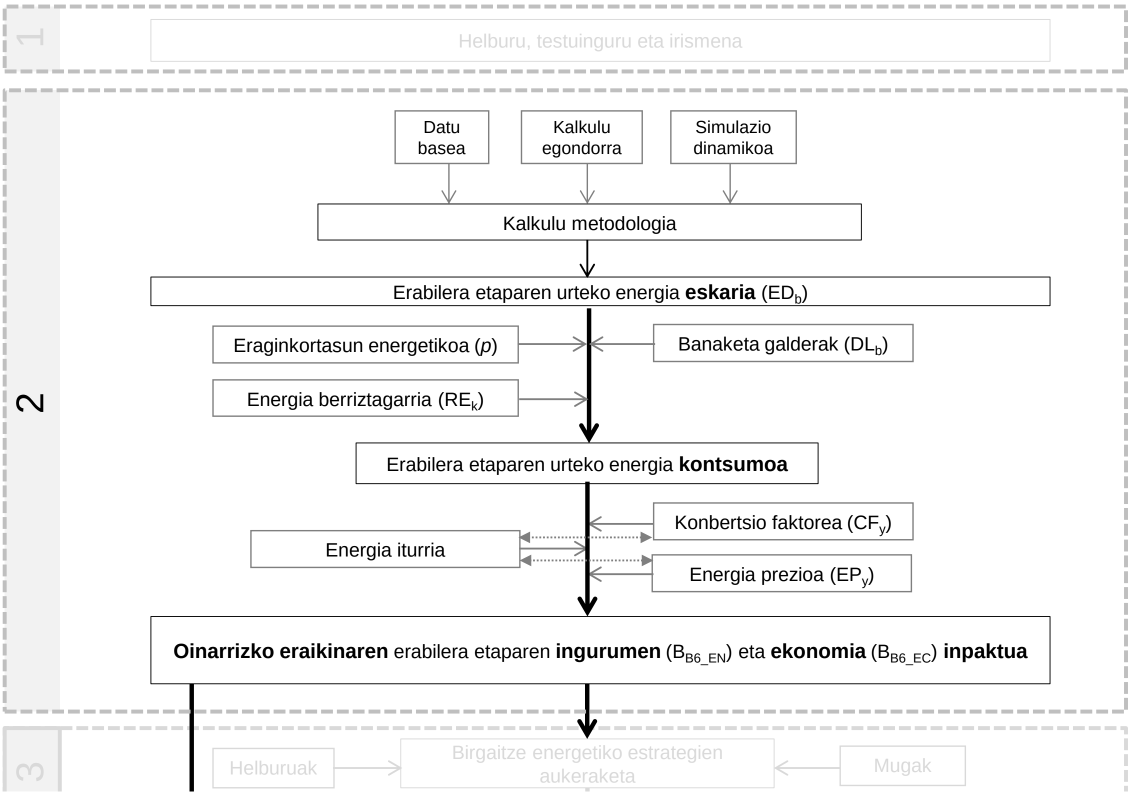
Metodologia hau “Full Cost Acounting” metodologian oinarrituko da. Emaitzak bateratzeko helburuarekin FprEN 16627 eta ISO 15686-5 (*ISO, International Standardisation Organisation, 2008a*) araudiek estandarizatutako inpaktu ekonomikoen irizpideak erabiltzea gomendatzen du. Besteak besteak, ekonomi inpaktu kategorien ondorengo adierazleak erabil daitezke:

- Epe laburreko ikuspegitik balioaren egonkortasuna (€).
- Epe ertain-luze ikuspegitik balioaren egonkortasuna eta portaera (€).
- Eguneratutako balio garbia.
- Inbertsioaren berreskuratze epea (Urteak).
- Barne Errendimenduaren Tasa (%).
- Errentagarritasuna (%).

Azkenik, CEN 350en oinarritutako araudi ezberdinek zehaztutako inpaktu kategoria adierazleekin batera, aipatzekoak dira SuperBuilding (*VTT, 2012*) proiektuan eraikinentzako definituriko jasangarritasun adierazleak (ikus 7.1 atala) edo Hernandez-ek (*Hernandez & Kelly, 2010*) garaturiko Energia Garbi Ratioa (“Net Energy Ratio – NER”) adierazlea. Azken hau, bizi zikloaren analisian oinarriturik, eraikuntza edo teknologia estrategia bat gizarteari energia hornitzerakoan zenbaterainoko eraginkorra den erakusteko erabiltzen den adierazlea da.

4.2. Oinarrizko eraikinaren erabilera etaparen ingurumen (B_{B6_EN}) eta ekonomia (B_{B6_EC}) inpaktua

Helburua eta sistemaren irismenaren definizioko parte diren ezaugarri ezberdinak definitu eta gero, erabiltzaileak oinarrizko eraikinaren energia portaera kalkulatzen du bere ingurumen eta ekonomia diagnosia lortuz.



Hau da, 1 eta 2 ekuazioen bidez, etapa honetan zehar jardueran dagoen gaur egungo eraikinak bizi zikloan zehar duen kontsumo energetikoaren ondorioz sortutako ingurumen eta ekonomia inpaktua kalkulatzen da.

$$B_{B6\_EN} = \sum_{n=1}^{RSL_b} \left(\sum_{m=1}^{m=k} \left[\left(\frac{ED_b}{\rho} + DL_b - RE_k \right) \times CF_y \right] \right) \Big/ FU \quad (1)$$

$$B_{B6\_EC} = \sum_{n=1}^{RSL_b} \left(\sum_{m=1}^{m=k} \left[\left(\frac{ED_b}{\rho} + DL_b - RE_k \right) \times EP_y \right] \times \left[1 + EPI_y^n \right] \right) \Big/ FU \quad (2)$$

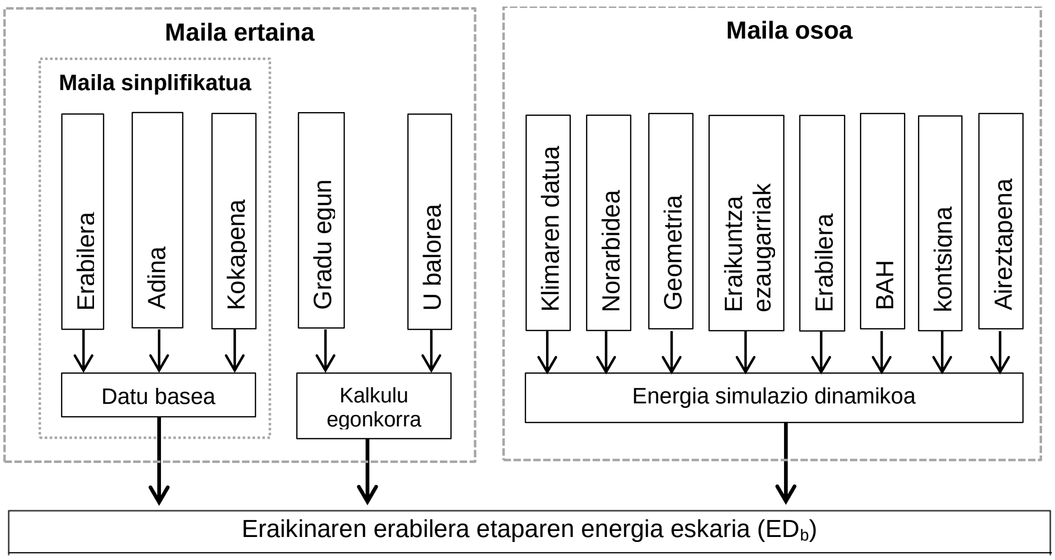
4.2.1. Eraikinaren erabilera etaparen energia eskaria (ED_b)

Etxebizitza txiki baten birgaitze energetikoaren proposamen baten lehenengo etaparako edo eraikin handi baten proiekturako, ezinbestekoa da teknikoak eskuhartuko den eraikinaren erabilera etapako energia eskariari (berokuntza, hozkuntza, ur beroa, aireztapena, argiztapena eta etxetresna elektrikoen erabilera) buruzko informazio egokia edukitzea zeren balioen arabera birgaitze energetikoaren estrategiak aldatu baitaitezke.

Ikusirik Europako etxebizitzen energia kontsumo handiena oraindik ere berokuntzan oinarritzen dela (*EEA, 2015*), Oregik (*Oregi et al., 2015*), Konstantinou-k (*Konstantinou & Knaack, 2011*) edo Karimpour-ek (*Karimpour et al., 2014*) egindako lanak birgaitze prozesuan kontsumo puntu hau murriztera bideratzen dira. Hala ere, Stephanek (*Stephan et al., 2013*), Ortizek (*Ortiz et al., 2010*) edo Blenginik (*Blengini & Di Carlo, 2010*) garatutako beste lan batzuetan aspektu energetiko guztiak ebaluatzen dituzte eraikinaren energia eskari guztia erakutsiz. Horregatik, puntu honetan erabiltzaileak ebaluatuko diren aspektu energetikoak zehaztu beharko ditu.

	Berokuntza	**Hozkuntza**	**Ur beroa**	**Aireztapena**	**Argiztapena**	**Etxe tresnak**
Aspektu energetikoak	Bai / Ez	Bai / Ez	Bai / Ez	Bai / Ez	Bai / Ez	Bai / Ez

Proiektuari buruz dagoen informazioaren, denboraren, emaitzen zehaztasun beharraren edo aurrekontuaren arabera, 30. irudiak metodologia honetan zehar proposatutako 3 kalkulu sistema erakusten ditu.



Irudia 30 Energia eskariaren kalkulurako metodologia desberdinen eskema

1- MAILA SINPLIFIKATUA

Maila hau eraikinen birgaitze energetikoak bere hasierako fasean (lehiaketak edo eskuhartze arkitektoniko edo administratibo ezberdinen aurreproiektuak) eta definizio maila baxuarekin ebaluatzeko dago garatua. 13. taulak erakusten duen bezala, erabilitako informazioa datu base publikoetatik, artikuluetatik eta ikerketa proiektuetatik lortutako informazio bibliografikoan oinarrituko da. Kasu hauetan, eraikin mota (erabilera) eta adina definituko dira sarrera datu bezala. Sarrerako datuen sinplifikazio hau dela eta emaitzen zehaztasuna baxuagoa da. Bestalde, metodologiaren zailtasun maila asko gutxitzen da bere erabilera erraztuz eta ebaluatutako elementuaren ikuspegi energetiko orokor bat lortuz.

Taula 13 Eraikinen energia eskariari buruzko informazioa duten Europako datu baseen laburpena

SUSREG (*Oregi et al., 2015b*) Etxebizitzen oinarrizko energi eskaria (MJ/m^2·a)

Eraikuntza berria	**Herbehereak**	**Danimarka**	**Espainia**
Eraikina	310	374	258
Familiabakarra	300	482	375
Gaur egungo eraikuntza			
Eraikina	520	662	428
Familiabakarra	500	752	625

TABULA, Typology Approach for Building Stock Energy Assessment (*TABULA*). EBko gaur egungo eraikinen energia eskariaren inguruko informazioa

ENTRANZE, Policies to ENforce the TRAnsition to Nearly Zero Energy buildings in the EU-27 (*Entranze*). EBko etxebizitza eta eraikin tertziarioen energia eskaria (kWh/m^2·a). Taula honetako balioak etxebizitza erabilerari dagozkie.

Austria	231	**Grezia**	202	**Polonia**	249
Belgika	288	**Hungaria**	233	**Portugal**	90
Bulgaria	133	**Irlanda**	197	**Errumania**	249
Zipre	100	**Italia**	124	**Eslovakia**	202
Txekia	240	**Letonia**	301	**Eslovenia**	218
Danimarka	190	**Lituania**	187	**Espainia**	115
Estonia	325	**Luxenburgo**	381	**Suedia**	240
Finlandia	294	**Malta**	69	**Erresuma Batua**	260
Frantzia	205	**Herbehereak**	194	**Serbia**	172
Alemania	232	**Kroazia**	195		

BPIE-Building Performance Institute Europe (*BPIE, 2011*). EBko etxebizitzen berokuntza eskaria (kWh/(m^2·a)).

	Erresuma batua	**Alemania**	**Suedia**	**Eslovenia**	**Portugal**	**Bulgaria**	**Italia**	**Letonia**
1920	585	250	196					150
1940	430	225	189		200	237	220	150
1960	350	246	158	179	195	255	180	150
1980	268	176	150	108	130	230	140	140
2000	103	87	124	68	110	131	95	90
2010		53		34	68	101		

Nabarmentzekoa da datu base mota hauek nagusiki berokuntzarekin erlazionatutako aspektu energetikoak erakusten dituztela eta oso kasu gutxitan hartzen direla kontuan aire girotuaren eskari balioak. Hala ere, ur beroaren hornikuntza, argiztapena edo etxetresna elektrikoen eskari energetikoaren balioak herrialdeka ezberdintzen dituzten datu baseak ez dira ohikoak eta aspektu energetiko hauen inguruko balioak era orokor batean definitzen dira (herrialdeka banatu beharrean, eraikinen erabileraren arabera desberdinduz).

2-MAILA ERTAINA

Proiektuari buruz informazio gehiago dagoen bigarren fase batean teknikoa kalkulu egonkor (stationary calculation) batean oinarritu daiteke (ikus 3 ekuazioa). Sinplifikatzeko helburuarekin parametro gutxi batzuk erabiliz, metodologia honetan aireztapenaren ondoriozko galera eta irabazi (eguzkiarenak edota barnekoak) termikoak kontuan hartu gabe, erabiltzaileak berokuntza eta aire girotuaren eskari energetikoaren inguruko balioak lor ditzake.

$$HED = HDD \times 24 \times \left(\sum_{m=1}^{m} U_m \times A_m \right) \qquad CED = CDD \times 24 \times \left(\sum_{m=1}^{m} U_m \times A_m \right) \qquad (3)$$

Urteko berokuntza energia eskaria Urteko hozte edo aire girotu energia eskaria

Kalkulu mota hau aplikatzeko helburuarekin, eraikina osatzen duten itxitura bakoitzaren azalera balioarekin batera (A_m), beharrezkoa da erabiltzaileak itxitura bakoitzaren transmitantzi termikoa (U_m) eta eraikinaren kokapenaren informazio klimatikoa ezagutzea (berokuntza eta hozte egun graduak). Datu hauen bidez eraikinaren itxitura ezberdinetatik kanporantz sortzen den fluxu energetikoaren trukea definitu daiteke.

Egun graduak / Degree days (HDD – CDD)

Zenbat graduetan eta zenbat denboraz (egunetan) kanpoko airearen tenperatura oinarrizko tenperatura baino baxuagoa (berokuntza egun graduak – HDD) edo altuagoa (hozteko egun graduak – CDD) den neurtzea ahalbidetuko du “egun gradu” baloreak. Balio hauek lortzeko aztertutako gune klimatiko bakoitzaren informazio zehatza eskaintzen duten formula matematiko edo datu base ezberdinak daude. Aldi berean, Eurostat (*Knoema*) edo *http: //www.degreedays.net/* bezalako web orriek garatutako aplikazioek mota honetako balioak lortzea errazten dute.

Taula 14 Berokuntza eta hozte egun gradu balioak (HDD – CDD)

Iturria: (*Gikas & Keenan, 2006*)

	HDD		HDD		HDD
Malta	564	Irlanda	2916	Austria	3569
Zipre	787	Hungaria	2917	Polonia	3605
Portugal	1302	Eslovenia	3044	Lituania	4071
Grezia	1698	Luxenburgo	3216	Letonia	4243
Espainia	1856	Alemania	3244	Estonia	4420
Italia	2085	Erresuma Batua	3354	Suedia	5423
Frantzia	2494	Eslovakia	3440	Finlandia	5823
Belgika	2882	Danimarka	3479		
Herbehereak	2905	Txekia	3559		

Iturria: (*Schild et al., 2010*)

	HDD	CDD		HDD	CDD
Finlandia	5991	0	Erresuma Batua	3129	68
Suedia	5438	0	Belgika	3095	102
Norvegia	5150	0	Herbehereak	3031	77
Letonia	4468	50	Bulgaria	2961	336
Lituania	4192	52	Erromania	2887	314
Danimarka	3837	73	Hungaria	2872	278
Polonia	3775	81	Frantzia	2402	169
Txekia	3542	110	Italia	1788	537
Austria	3539	112	Espainia	1481	535
Alemania	3407	93	Grezia	1476	887
Eslovakia	3353	145	Portugal	931	391
Suitza	3206	147			

Itxituraren transmitantzi termikoa (U balioa)

U balioa bero transferentzia adierazteko erabiltzen den koefiziente da. Adierazle honek elementu baten metro karratu bakoitzeko eta Kelvin gradu bateko ezberdintasunean beroa transferitzeko (watt-ioetan neurtua) duen gaitasuna neurtzen du ($W/(m^2 \cdot K)$). Honela, elementu bakoitzaren U balioa zenbat eta altuagoa izan, eraikinaren portaera termikoa orduan eta okerragoa izango da. Eraikin berrientzat, adibidez ziurtagiri energetikoaren bidez, itxitura bakoitzaren U balioa lortzeko informazio guztia eskura dago. Hala ere, birgaitze energetikoen kasuan, eraikinaren eraikitze data dela eta, oso zaila bilakatzen da itxituren U balioa lortzeko informazio nahikoa eskuratzea. Ondoren eraikinaren edo berau osatzen duten itxituren U balioak kalkulatzeko zenbait estrategia ezberdin proposatzen dira:

- **Neurketa proba.** Gaur egun merkatuan dauden TESTO neurketa sistema, Termo-flujometria analisia edo infragorrien termo-ikusmenaren (*Albatici & Tonelli, 2008*) teknikak aipa daitezke.
- **Datu baseak.** Europako lurralde gehienek datu base publiko bat dute. Hemen erabiltzaileek itxitura ezberdinen osaera edo itxituren materialen ezaugarriak bezalako

datuen bidez eraikin baten itxitura elementu ezberdinen transmitantzia termiko estandarra lortzeko informazio baliagarria bila dezakete.

Taula 15 Espainiako eraikinen fatxaden U balioa eraikinaren kokapenaren (gune klimatiko) eta adinaren arabera (*IDAE, 2012*)

	<1981	1981-2007				2008 urtetik aurrera				
Gune klimatikoa		Y-W	X	Y	Z	A	B	C	D	E
U balorea (W/(m^2·K))	3.00	1.80	1.60	1.40	1.40	0.94	0.82	0.73	0.66	0.57

- **Ikerketa proiektuak.** Azkenengo hamarkadan TABULA, ENTRANZE edo GEOCLUSTER (*Geocluster)* bezalako ikerketa proiektuak garatu dira, gaur egungo eraikinen eraikuntza itxitura ezberdinen U balioen inguruko informazioa erakutsiz.

<u>3-MAILA OSOA</u>

Kalkulurako maila zailena energia simulazio dinamiko software-ak aplikatzean datza. Erabiltzaileak, parametro berrien ebaluaketaren bidez, aztertu beharreko eraikinaren eskari energetikoaren balioa lortuko du. Beste kalkulu mailekin alderatuz gero sarrerako datuen kantitatea handia dela eta, kalkulu dinamikoen bidez balio zehatzagoak lortzeko aukera dago. Bestalde, beharrezko informazio guztia lortzeko garaian metodologia hau aplikatzeak esfortzu handiagoa eskatzen du, kalkuluaren prozesua zaildu eta luzatuz. Honekin batera, lan honetatik zehaztu nahi da simulazio dinamiko batean lortutako emaitzak, teknikoak definitutako parametroen islada direla eta kasu askotan aztertutako elementuaren benetako eskaria eta simulatutako eskari energetikoaren artean desbideratze handiak sor daitezkeela (puntu hau bizilagunen portaerarekin guztiz lotua baitago).

Gaur egungo merkatuan eraikinen energia simulazio dinamikoa ahalbidetzen duten software ugari daude, doakoetatik hasi, sinplifikatuak eta oso konplexuetarainokoak. Besteak beste Autodesk Green Building, CYPE-Building Services, Design Builder, DOE-2, EnergyPlus, eQUEST, IES edo TRNSYS aipa daitezke.

Software bakoitzaren definizio mailaren edo kalkulu egituraren arabera, ebaluatutako parametroak edo sarrerako datuen formatu mota alda daiteke. Hala ere, ondoren deskribatuko diren bezala, orokorrean eraikin baten simulazio energetiko dinamiko bat egiteko garaian sarrerako datuak antzekoak izango dira.

Klimari buruzko datuak. Eraikina kokatzen den klimak eragin handia du birgaitze energetikoen proiektuetan. Kanpoko airearen tenperatura eta eguzkitzapen mailak (eraikinaren kokapenarekin lotuak) zuzenean eragingo dute azken emaitzetan, energia baxudun eraikin birgaituak lortzeko estrategiak beraien artean ezberdinduz. Informazio guzti hau doan deskargatzeko gaur egun datu iturri asko daude, besteak beste Energy Plusen web orria (*EERE*), *www.clima.meteored.com* edo *www.mundomanz.com*.

Norabidea. Eguzki bidezko barne irabazi termiko edo eguzki sistema berriztagarrien erradiazio maila egokia neurtzeko ezinbestekoa izango da aztertu beharreko elementuaren orientazioa ondo definitzea

Geometria. Zenbakizko koordenaden eta modelizazio interfazen bidez ebaluatu beharreko eraikinaren geometriaren datuak sartuko dira. Simulazioaren definizio mailaren edo ebaluazioaren eskalaren arabera (gela batetik hasi eta eraikin osoraino) geometriaren definizioaren zailtasuna baldintza horietara moldatuko da (beti ere kalkuluen zehaztasuna arriskuan jarri gabe). Eraikinaren geometriarekin batera beharrezkoa da ebaluatu beharreko eraikinari itzala egin dakiokeen inguruko elementuen geometria ere marraztea.

Eraikuntza ezaugarriak. Eraikinaren eskari energetikoa zein den jakiteko beharrezkoa da besteak beste itxitura elementuen eraikuntza osaera ezagutzea, hau da, geruza bakoitzaren dentsitatea, eroankortasuna eta lodiera (adibidez TABULA bezalako proiektuek eskaintzen duten Europako eraikinen itxituren eraikuntza ezaugarriei buruzko informazioa aprobetxatuz).

Erabilera – okupazioa. Orokorrean eraikinen bi erabilera mota ezberdintzen dira, nahiz eta bakoitzaren barruan azpitalde gehiago egotea posible den: etxebizitza (familia bakarrekoa mehelin artean, familia bakarreko isolatua, blokea mehelin artean eta bloke isolatua) eta zerbitzuak edo tertziarioa (komertziala, bulegoa, ostalaritza, irakaskuntza, erlijiosoa, osasuna, kirola, etab.). Azpitalde hauetako bakoitzak okupazio profil (pertsona kantitatea eta ordutegia), sistemen eskari eta jarduera ezberdin bat edukiko ditu eta honen bidez sortutako barne irabazi termikoak edo beharrezko konfort termiko baldintzak bezalako aspektuak egoera batetik bestera aldatu egingo dira. Hau da, nahiz eta eraikin baten kokapena, orientazioa eta eraikuntza osaera berdinak izan, eraikin baten portaera termikoa eta energetikoa asko aldatu daitezke. Hala ere, esan behar da askotan oso zaila izaten dela eraikin baten benetako okupazioa zein den zehaztea (batik bat etxebizitza eraikinetan), simulazio balioen eta benetako balioen arteko ezberdintasuna handituz.

BAH – Argiztapen programazioa. Komenigarria da BAH ezberdinak (Berokuntza, Aireztapena eta Hozkuntza edo aire girotua) eta argiztapen sistema eraikinaren erabiltzaileen bizi erritmora egokitzea. Horrela, konfort maila egokitu eta kontsumo energetikoa hobetzen da. Hau da, eraikinaren espazio ezberdinen airearen barne tenperatura edo beharrezko argiztapen denbora eta sistema hauen ordutegira egokituz, bizilagunen konfort maila hobetu eta kontsumo energetikoa murrizteko aukera egongo da.

Kontsigna tenperatura. Eraikin bakoitzaren erabilera, okupazio profila eta jardueraren arabera biztanleen konfort termikoko baldintzak aldatu egingo dira. Nahiz eta Aurreikusitako Batazbesteko Boto ("Predicted Mean Vote - PMV") edo Aurreikusitako Kontentagaitz Ehunekoa ("Predicted Percentage of Dissatisfied - PPD") bezalako adierazleen bidez erabiltzaileen konforta neurtzeko aukera egon, oso zaila da unitate hauen bidez instalazio energetiko bat edo estrategia pasiboak programatzea. Horregatik, editatu daitekeen adierazle bakarrak berokuntza eta hozte sistemaren aktibazioko kontsignako tenperatura gisa definituko dira. Hauek eskari energetikoaren neurketan zuzenki eragingo dute.

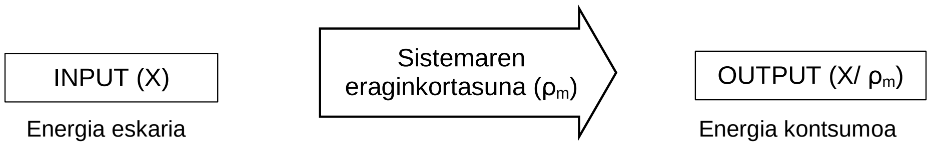
Aireztapena – aire iragazte maila. Aireztapena airearen hornikuntza eta ateratze prozesuan datza, eta naturalki edo mekanikoki egin daiteke. Erabiltzaileentzako elementu kutsakor arriskutsuen kontzentrazioa eta ongi izatearentzat kutsakor gogaikarriak saihesteko, eraikinaren aireztapena derrigorrezkoa da. Birgaitze proiektuetan, puntu garrantzitsuenetako bat kontrolatu gabeko aireztapenarekin erlazionatutako galera energetiko handiak konpontzean datza, hau da, infiltrazioak (arotzeriaren kalitatea edo egindako lanaren kalitatearekin zuzenki erlazionatua).

Taula 16 Energia eskaria kalkulatzeko metodologia ezberdinen ezaugarri orokorren laburpena

Sendotasunak	Ahuleziak
1-Sinplifikatua	
Kalkuluen erraztasuna Proiektuen hasierako faseetarako oso egokia Ikuspegi orokorra Doako datu baseak	Balio generikoen dependentzia Definizio maila urria Datuen kalitate baxua Aspektu energetiko guztien inguruko informazio gabezia
2-Ertaina	
Kalkuluen ziurtasun maila Eraikinaren inguruko informazio zehatzagoa Beharrezko balio generikoak lortzeko erraztasuna	Azterlan bakoitzaren datu zehatzak lortzeko zailtasuna Energia eskariaren kalkulu partziala Eraikinaren erabilera, okupazio edo bizilagunen portaeraren inguruko parametroen analisi falta
3-Osoa	
Eraikinaren definizio zehatza Eraikinaren portaera energetikoarekin lotura duten parametro gehienen inguruko definizioa Simulazio software-n bidez balio errealetara hurbiltzeko aukera	Oso kalkulu luze eta konplexua Datu sarrera asko zehatz definitzeko informazio falta Zenbait software-n kostu ekonomikoa Horrenbeste datu sarrera zehazteko lan karga handia

4.2.2. Energia sortzeko sistemaren eraginkortasun energetikoa (ρ)

Energia sortzeko sistema baten eraginkortasun energetikoa sistemak eskaintzen duen energia kopurua eta energia hau sortzeko behar duen energia kopurua erlazionatzen dituen balioa da. Hau da, eraginkortasunak sistema bakoitzaren sarrera eta irteerako energia kopurua erlazionatzen ditu, energia eskaria energia kontsumo bilakatuz.



Energia iturria, sistemaren adina, mantentze lanak, isolamendu maila, hoztaile mota etab. dela eta, energia sortzaile den sistema bakoitzaren eraginkortasun energetikoa asko aldatu daiteke, galdaretan 0,6 – 1,1 arteko edo hozteko sistemetan 1,7 – 3,5 arteko balioak lortuz.

4.2.3. Banaketan zeharreko galerak (DL_b)

Eraikin baten sorkuntza termikoaren ekipoa sistema zentralizatu baten parte denean, (komunitateko berokuntza edo auzo berokuntza (“district heating”)) distribuzio hodien luzera, isolamendu termiko maila edo hodien kokapena bezalako ezaugarriak direla eta, banaketan zeharreko galera termikoak kontuan hartzekoak izan daitezke, nagusiki eraikin zaharretan. Analisi gehienetan oso zaila da hodien egoera nolakoa den jakitea, normalki irisgarriak ez diren instalazioen espazio edo adreiluzko bi pareten artean dagoen aire kameran egoten baitira kokatuak.

4.2.4. Eraikinean sorturiko energia berriztagarria (RE_k)

Iturri ez berriztagarria duen kontsumitutako energiarekin batera beharrezkoa da sistemaren mugen barruan iturri berriztagarriko sistemarekin energia sortzen ote den ebaluatzea. Energia positibo bezala ulertzen da eta ondorioz ordezkatutako energiari (energia termikoa edota elektrikoa) zuzenki kentzea proposatzen da metodologia honetan zehar. Eraikin baten birgaitze energetikoan sartzeko teknologia berriztagarrien artean nabarmentzekoak dira eguzki energia termiko edo fotovoltaiko bezalako teknologiak (informazio gehiago 4.3.3 atalean).

4.2.5. Oinarrizko eraikinaren erabilera etaparen energia kontsumoa

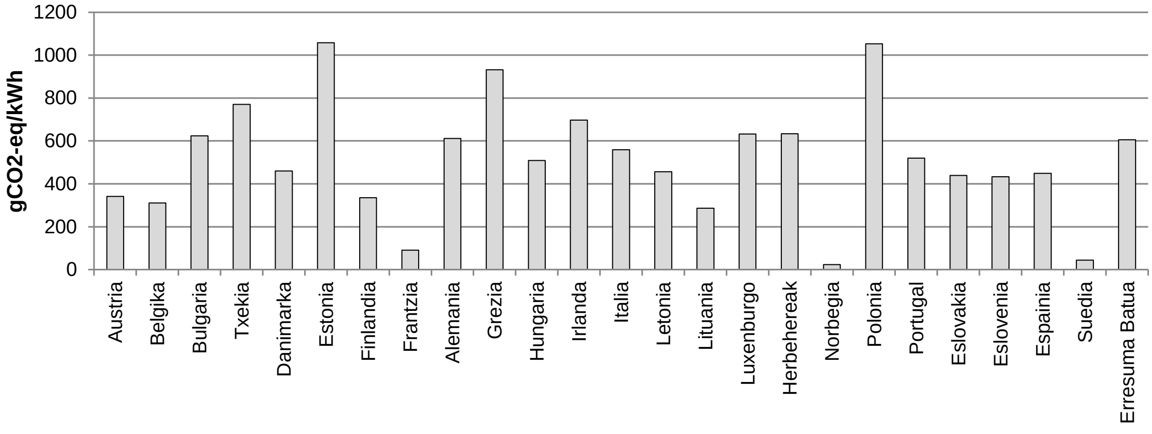
Eraikinen energia eskaria eta sistemen eraginkortasunaren parametroen bidez energia kontsumoa lortzearekin batera, monitorizazio edo fakturen irakurketa bidez benetako energia kontsumoa neurtzeko aukera ere dago. Gaur egun, monitorizazio digitala gero eta gehiago zabaltzen ari da. Honen bidez, aldiuneko benetako kontsumoa ikus daiteke kontsumo orokorrean gertatzen diren anomalietan erabakiak hartzea ahalbidetuz. Gainera, momentu bakoitzean erabakiak har daitezke eskari puntuen eta energia sorreraren arteko sinergia ezberdinak aprobetxatuz edo kontsumo energetikoaren aurreikuskapenean giza portaerak duen eragina ikusiz. Hala ere, balio hauek simulazio software-etan sartzeko orduan arazo handi bat aurkitzen da: sarrera datu ezberdintasuna. Hau da, monitorizazio sistemak eta batez ere fakturak energia kontsumoaren balioa energia iturriaren arabera islatzen dute (gas naturala, elektrizitatea, gasolio…). Adibidez, simulazio programen datu sarrera edo input-ak energi aspektu ezberdinetan banatuta egoten dira (berokuntza, hozkuntza, ur beroa, argiztapena edo aparailu elektrikoak). Ondorioz, beharrezkoa izaten da bigarren mailako beste analisi bat garatzea energia iturri bakoitzaren barruan zein energia aspektu hornitzen den ezagutzeko.

4.2.6. Konbertsio faktorea (CF_y)

Konbertsio faktore hauek eraikinaren erabilera etapan kontsumitutako azken energiaren 1MJ edo 1kWH balioa bihurtu eta transformatzeko sortutako ingurumen inpaktuaren kantitatea adierazten dute. Eraikuntza sektorean erabilitako energia iturriek (elektrizitate, gasolio, olio, gas natural, biomasa edo biogas) forma ezberdinak dituzte naturan, egurretik hasi eta nuklearreraino, bakoitzak ingurumenean sortuko duen inpaktua ezberdina izanik. Horregatik, prozesu energetiko bakoitzaren ingurumen inpaktua kalkulatu ondoren, modu homogeneizatuan inpaktuen adierazle ezberdinen bidez emaitzak ebaluatuko dira.

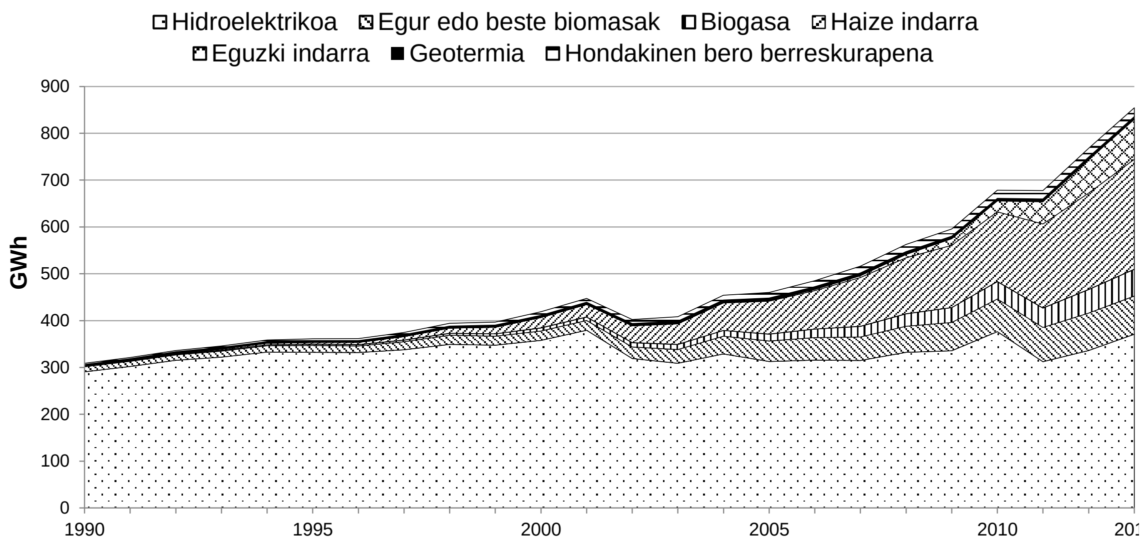
Etengabeak dira konbertsio faktore bakoitzaren balioa ahalik eta zehaztasun handienarekin egokitu eta definitzeko garatzen ari diren lanak, konbertsio faktore hauek EPZ bezalako kalifikazio sistemetan adierazle nagusiak baitira. Gas naturala, gasolioa edo biomasa bezalako iturri energetikoentzat, lurralde edo herrialde ezberdinetan berauen aldaketa prozesuaren antzekotasuna dela eta, ingurumen inpaktuak oso antzekoak izango dira. Hala ere, erabilitako iturri energetikoa elektrizitatea denean, kontsumitutako azken energia unitateko ingurumen inpaktu balioa guztiz alda daiteke, herrialde bakoitzeko mix elektrikoari zuzenki loturik baitago.

Estatu kide bakoitzak, bere politika energetikoen arabera, energia nuklearraren edo energia berriztagarriak indartzearen aurrean jarrera oso ezberdina hartzen du. Ondorioz, elektrizitate unitate bat sortzeko transformazio prozesuaren ingurumen inpaktua estatu kide batetik bestera guztiz aldatzen da. 31. irudiak erakusten du EBko estatu kide bakoitzean 1 kWh elektriko sortzeko isurtzen den CO_2 baliokide kopura guztiz aldakorra dela. Adibidez, prozesu hidroelektriko eta nuklearren garrantziaren ondorioz, Norvegian edo Frantzian mix elektrikoak isuritako CO_2 kopuruak EBko baxuenak izango dira.



Irudia 31 BZA bidez lorturiko mix elektrikoaren emaitzak. Iturria: (*Itten et al., 2014*) –en datuetan oinarritutako norbere garapena.

Horrez gain, iturri berriztagarriak eta baliabide mugagabeak erabiltzen dituzten politika energetikoek ingurumen inpaktu baxuagoa dute. 32. irudiak erakusten du 1990 eta 2012 urteen artean Europako iturri berriztagarrien bidezko elektrizitate sorkuntza %177 igo zela. Hori dela eta, 2013an iturri berriztagarrien bidezko elektrizitate sorkuntza elektrizitate sorkuntza guztiaren %25.4a zen (*Eurostat, 2013d*).



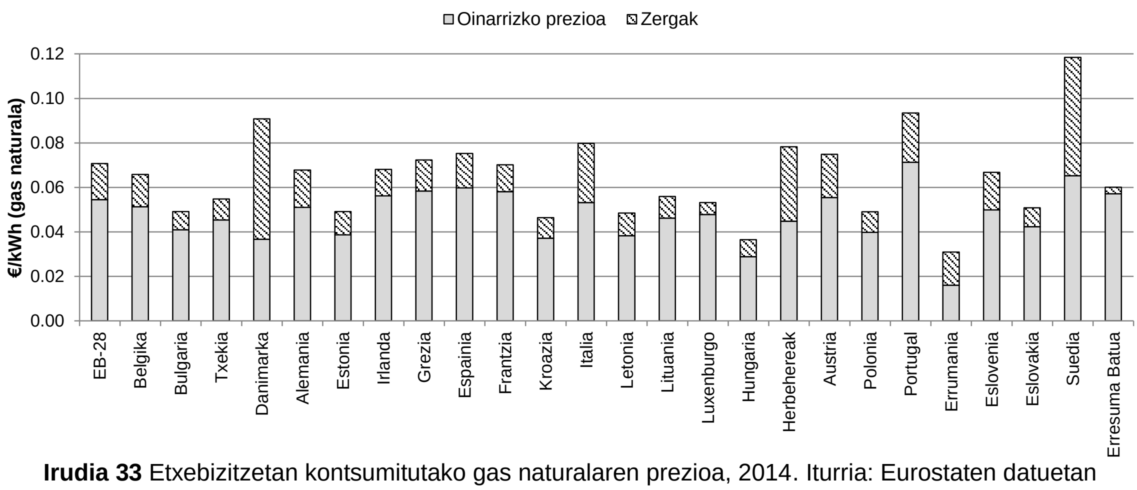
Irudia 32 EB-28ko iturri berriztagarrien bidez sorturiko elektrizitate kopurua. Iturria: (Eurostat, 2013d)–en datuetan oinarritutako norbere garapena.

Horrez gain, irudi honetan ikus daiteke nola EBn zentral hidraulikoen bidez lortu dela elektrizitate berriztagarriaren gehiengoa, %43a gaindituz. 2013. urtean, haize erroten bidez lorturiko elektrizitatea da bigarren iturri nagusia (elektrizitate berriztagarriaren %28a). Beste iturrien artean, eguzki bidez sorturiko energia gorantz doa (%10a sortuz), berriztagarri solidoek elektrizitatearen %9.5a sortuko dute, biogas edo biolikidoek %7a, hondakinen bero berreskurapenak %2a eta geotermiak %1a.

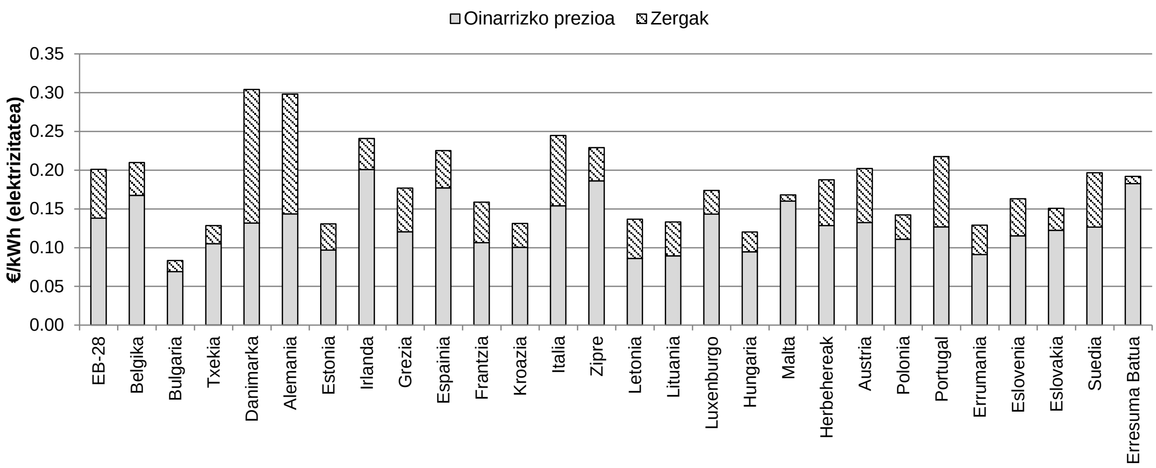
4.2.7. Energia iturriaren prezioa (EP_y)

Kontsumitutako energiaren unitate bakoitzaren prezioaren bidez, kontsumo energetikoa inpaktu ekonomikoan bihurtu daiteke. Lehengaien kostua, banaketa kostua, lurralde bakoitzeko egoera edo inflazioaren prezio orokorra dela eta, energia hornitzaileek kontsumitutako energia unitateei prezio ezberdinak jartzen dizkiete. Momentu bakoitzeko egoera dela eta, prezioaren balioa asko alda daiteke, balio dinamiko batean bihurtuz eta prezioaren balio estandar bat definitzea zailduz.

Adibidez, 2014an EB-28ko etxebizitzetan gas naturalaren eta elektrizitatearen bataz besteko oinarrizko prezioa 0.0545 €/kwh eta 0.138 €/kWh izan ziren hurrenez hurren (*Eurostat, 2014*). Europako estatu kideen artean, gas naturalaren oinarrizko prezioak 0.016 €/kwh-tik (Errumania) 0.0713 €/kwh-ra (Portugal) aldatu daitezke eta elektrizitatearen oinarrizko prezioak 0.0689 €/kWh-tik (Bulgaria) 0.2 €/kWh-ra (Irlanda). Analisiaren barruan tasak eta zergak kontuan hartuz gero, kontsumitutako energia unitate bakoitzaren prezioa igo egingo litzateke, gas naturalean 0.118 €/kWh-ko (Suedia) eta elektrizitatean 0.304 €/kWh-ko (Danimarka) balioetara iritsi arte.



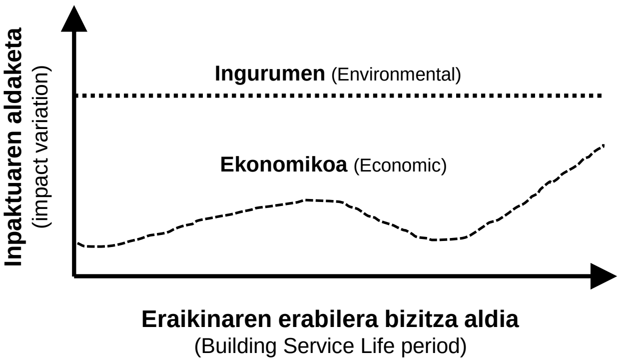
Irudia 33 Etxebizitzetan kontsumitutako gas naturalaren prezioa, 2014. Iturria: Eurostaten datuetan oinarritutako norbere garapena.



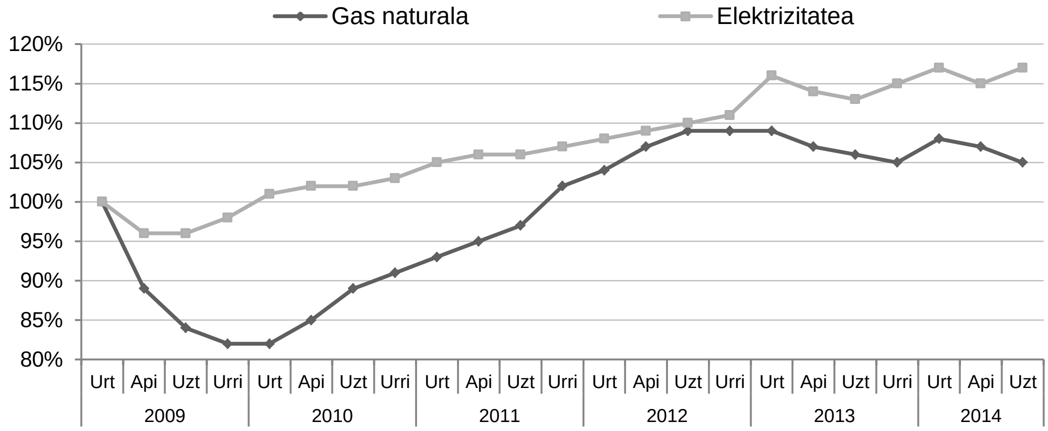
Irudia 34 Etxebizitzetan kontsumitutako elektrizitatearen prezioa, 2015, Iturria: Eurostaten datuetan oinarritutako norbere garapena.

4.2.8. Energia iturriaren prezioaren igoera (EPI_y)

Metodologia honen puntu garrantzitsuenetako bat eraikinaren inpaktua bere bizi zikloan zehar nola kalkulatu da. Nahiz eta Karimpour-ek (*Karimpour et al., 2014*) egindako lana bezalakoak beren ingurumen analisietan bizi zikloaren ikuspuntuarekin karbonoaren denbora balioa (isurketa helburuekin erlazionatuta) bezalako balio aldakorrak sartzen hasi diren, metodologia honetan eraikinaren erabilera bizitzan zehar (RSL_b), energia (termikoa edo elektrikoa) unitate baten kontsumoak sortutako ingurumen inpaktuak balio konstante bat edukitzea proposatzen da. Honen arrazoia balio hauen aldakortasun posiblea nagusiki lurralde bakoitzeko energia politikekin erlazionatutako erabakien menpe dagoela da (zati handi batean eremu zientifikotik kanpo) eta ondorioz, alde politikoa aparte utzi da.



Hala ere, azken irudi honek erakusten duen bezala, bizi zikloaren ebaluazio ekonomiko bat garatzerako orduan, energia prezioaren (EP_y) aldakortasuna kontuan hartu eta ebaluatzea beharrezkoa izango da. Era honetan, inpaktu ekonomikoa bizi zikloaren ikuspuntu batekin eta momentu eta leku bakoitzeko merkatuaren gorabeheren arabera ebaluatzea posible izango da.



Irudia 35 EBko etxebizitzetako energia prezioen (zergak kontutan izan gabe) garapena. 100% = 2009 urtea. Iturria: Eurostatendatuetan oinarritutako norbere garapena.

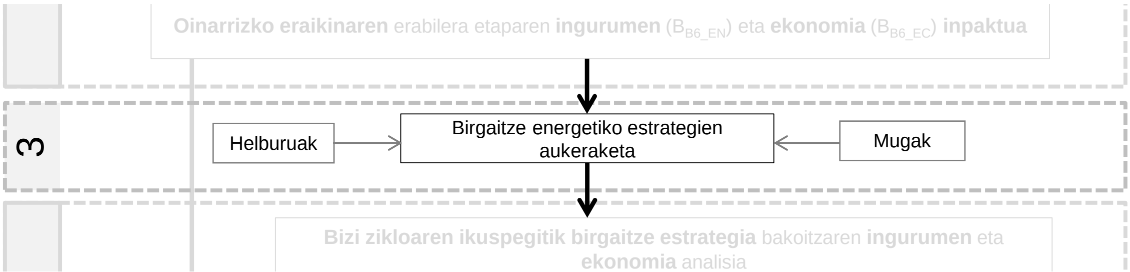
**Energiaren prezioaren garapenari buruzko egoera ezberdinen informazio gehiago Europako batzordeak argitaratutako lanetan* (*EC, 2012*) *edo Capros-en lantaldeak* (*Capros et al., 2010*) *garatutako azterlanean lor daiteke.*

Energiaren geroko prezioek eragin zuzena izango dute azken urteetan eta hemendik aurrera garatuko diren birgaitze energetiko ezberdinen errentagarritasun ekonomikoan. Adibidez, azken 5 urteetan EBko bataz beste etxebizitzetako elektrizitatearen prezioa urtean %4 igo da, gasaren prezioa urtean %3 eta biomasaren prezioa urtean %2.7 (*E-Control & VaasaETT, 2015*). Datu hauez gain, beste zenbait lanen arabera (*BCG, 2011*), gasaren eta petrolioaren inportazioaren kostuen igoera eta tarifa elektrikoaren defizitaren inbertsio eta amortizazioa dela eta, hurrengo bost urteetan kontsumo energetikoaren oinarrizko prezioa %20-50 artean igo daitekeela aipatzen da.

Hori dela eta, eraikinak erabilera etapan (birgaitu aurretik eta ondoren) sortutako inpaktu ekonomikoa ebaluatzeko orduan, metodologia honek beharrezkoa ikusten du kalkuluan energia iturri ezberdinen prezioaren igoera sartzea. Honen bidez, birgaitutako eraikinaren erabilera etapan zehar balore aldakor honek izan dezakeen eragina landu eta hainbat egoera proposatzeko aukera egongo da, bizi zikloaren analisi ekonomiko ezberdinak garatuz.

4.3. Birgaitze energetikoko estrategien aukeraketa

Merkatuan aurkitzen diren birgaitze energetikoko estrategia ezberdinen artean hautatzerakoan, lehenik eta behin, beharrezkoa da kasu bakoitzean garatu behar den birgaitzearen helburuen eta honek ezartzen dituen mugen inguruan oinarrizko azterketa bat egitea.



4.3.1. Helburuak

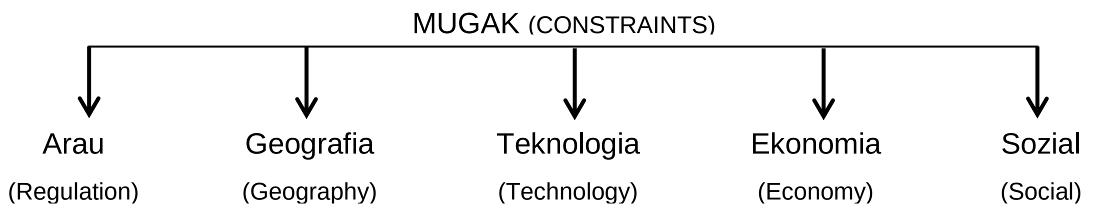
Birgaitze energetikoaren helburu nagusia eraikinaren errendimendu energetikoa hobetzea da, ingurumenari eragindako inpaktua murriztuz ahalik eta inpaktu ekonomiko txikiarekin. Hala ere, 17.taulan ikus daitekeen bezala, partaide ezberdinen, biztanleen profil sozialen, gabezi arkitektonikoen, pobrezia energetikoaren arazoen, administrazio-mugen, konfort edo erosotasun mailaren, hasierako inbertsioaren, kohesio sozialaren, ingurumen-sentsibilitatearen... arabera, azterlan bakoitzaren birgaitze energetikoari dagozkion hasierako helburuak guztiz alda daitezke.

Taula 17 Birgaitze proiektuen partaide ezberdinen zenbait helburu.

1-Herri/Eskualde/Nazio politikariak; 2-Bizilagunak; 3-Eraikinaren jabegoa; 4-Eraikuntza enpresa; 5- Ikertzailea; eta 6-Diseinu-kalkulu teknikoa	**Partaide interesatuak**					
	1	**2**	**3**	**4**	**5**	**6**
Energetikoa						
Energia kontsumoa murriztu		X	X			X
Eraikina zero energia kontsumoan bilakatu	X	X	X		X	X
Iturri berriztagarrien bidez kontsumitutako energiaren x% sortu	X	X	X		X	X
Arautegiak zehaztutako eraginkortasun energetikoaren inguruko balio minimoak bete	X					X
Ingurumen						
Barne energia baxudun produktuak eta sistemak lehenetsi	X			X	X	X
Energia sorkuntza sistemen ingurumen inpaktua murriztu	X					X
Beste energia iturri berriak sustatu	X				X	
Ekonomikoa						
Erabilera etaparen inpaktu ekonomikoa murriztu		X	X		X	X
Inbertsio estrategia egokiena aurkitu		X		X	X	
Estrategia ezberdinen gehienezko errentagarritasuna zehaztu		X			X	X
Bizi zikloan zehar inpaktu ekonomikoa optimizatu		X				
Soziala (tesi honetako metodologiaren irismenetik kanpo)						
Bizilagunen konfort termikoa eta bizi kalitatea hobetu		X				
Pobrezia energetikoa murriztu	X	X				
Bizilagunen ezaugarri sozio ekonomikoak kontuan izan	X	X				
Partaide ezberdinak prozesuaren etapa bakoitzean inplikatu	X	X	X	X	X	X
Birgaitu behar den eraikinaren ondare historikoa mantendu	X		X			X

4.3.2. Mugak

Europako gaur egungo eraikinetan egin beharreko birgaitze energetiko ezberdinek energian, ingurumenean eta ekonomian duten eragina ebaluatu edo aztertzeko helburuarekin garatu diren ikerketa eta kalkulu tresna gehienek ez dituzte kontuan izaten gizarte, ekonomia edo arauzko gaien ondorioz birgaitu beharreko eraikin askok mugak izan ditzaketela. Beraz, birgaitze kasu bakoitzean aurrera eraman beharreko estrategia mota zehazterakoan, helburuekin batera, dauden mugak kontuan hartzea beharrezkoa izango da, birgaitzearen lehen etapetan eragin zuzena izango baitute.



Eraikin, herri edo ordenantza bakoitzak kasu bakoitzerako eskakizun ezberdinak dituenez, zaila da mugen inguruko balio edo erabakiak orokortzea. Hala ere, lan honek 5 muga mota definitzen ditu.

<u>Herri arauak / ordenantzak / arau administratiboak</u>

Eraikinaren balio arkitektonikoa, kokapena, historia, erabilera, etab.-en arabera, eraikinetako ondarea babesteko plan bereziek, herri ordenazio planek edo eskualde bakoitzeko administrazioek geroko birgaitzeekin lotutako mugak defini ditzakete.

Taula 18 Eraikinen babes maila ezberdinak. Iturria: Donostiako udalerrian oinarritua.

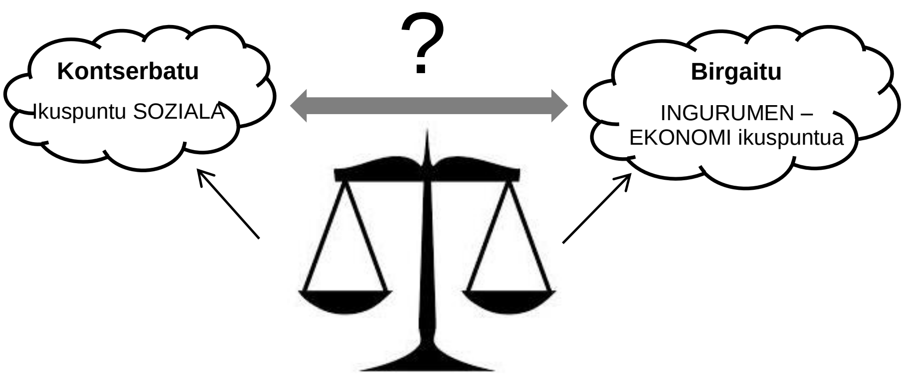
Maila	Azalpena
A	Eusko Jaurlaritzaren edota Estatuko Administrazioaren erabakiz babestutako edota babestu beharreko multzoak, eraikinak eta elementuak
B	Balio arkitektoniko bereziak dauzkaten eraikinak daude. Balio horiek kanpoaldean izan ditzakete (fatxada eta, hala badagokio, estalkia), edota barrualdean (ataria eta eskailerak, etxebizitzen kasuan; osotasuna, elizetan, eta abar).
C	Balio arkitektoniko berezia soil-soilik kanpoaldean daukaten eraikinak daude jasota (normalean, fatxadak; ezohiko, estalkiak).
D	Balio arkitektoniko berezirik ez daukaten arren, hiriaren eta inguruaren historiari edo sinbologiari dagokionez baliotsuak diren eraikinak daude. Balio horiek kanpoaldean daude islatuta (normalean, fatxadetan; ezohiko estalkietan).
E	Udalak hala erabaki duelako babestu beharreko multzo eta guneak daude jasota.
F	Hirigintza-jardueren fruitu diren askotariko elementu «artifizialak» daude: plazak, lorategiak, parkeak, zubiak, frontoiak eta antzeko eraikin zein instalazioak, iturriak eta hiri-altzariak.

Ezaugarri geografikoak. Birgaitu beharreko elementua kokatzen den hiri inguruneak edo geografikoak eragin zuzena izango du birgaitze estrategiak aukeratzeko orduan. Adibidez, eraikin askok kanpoaldera ematen duen fatxada bakarra dute eta ondorioz, oso zaila da fatxadaren erresistentzia termikoa handituta oinarrizko eraikinaren kontsumo energetikoa murriztea. Beste kasu batzuetan, inguruko eraikinek sortutako itzala dela eta, teilatuak jasotzen duen eguzki irradiazioa oso baxua izango da, eguzki energia termiko edo fotovoltaiko bezalako estrategien errendimendua murriztuz.

Ezaugarri teknikoak. Aukeratutako birgaitze estrategiaren ezaugarri teknikoen arabera, kasu askotan bizilagunen eguneroko bizitzan eragin zuzena izango dute: eraikinaren itxituren barrutik isolamendu termikoa jartzearen ondorioz etxebizitzen barne espazioen murriztea, espazio publikoan aldamioak jartzeak dakartzan arriskuak edo segurtasunaren ondorioz birgaitzeko momentuan eraikina utzi beharra.

Ezaugarri ekonomikoak. Inbestitzaile edo bizilagun ezberdinek jarritako muga ekonomikoak ezagutzea beharrezkoa da. Hauen artean nabarmentzekoak dira hasierako inbertsio kopuruaren muga, denbora tarte bateko gutxieneko errentagarritasuna, urte kopuru zehatz bat baino lehenago inbertsioaren itzulera, etab.

Ezaugarri sozialak. Birgaitze estrategia ezberdinak aukeratzeko orduan presio sozialak eragin zuzena izan dezake. Kasu batzuetan, nagusiki energia sortzeko proiektuetan, presio hori talde ekologistek sortzen dute eta ingurumenarekiko duten ikuspuntua eskaintzen dute. Beste batzuetan, presio hori hiriaren itxurarekiko edo eraikinen edo azpiegituren konposizio arkitektonikoa eta hiri osaerarekiko sentsibilizatutako taldeek sortzen dute. Ikuspuntu sozial batean oinarrituz, pentsamendu mota honek hirien eta bere elementu guztien izaeraren kontserbazioa babesten du, elementu askoren portaera termikoa edota energetikoa hobetzea zailduz eta ondorioz, biztanle askoren konfort termikoa edo bizi kalitatea hobetzea mugatuz.



Bestalde, biztanleen konfort termikoa hobetzeko helburuarekin edo eraikinen energia kontsumo altuak ingurumenean duen inpaktu negatiboaren kezkan oinarrituta, beste ikuspuntu batzuk gaur egungo eraikinen birgaitze energetiko masiboa bultzatzen dute. Normalki, alde energetikoan bakarrik oinarritzen dira eta ez dituzte birgaitu beharreko eraikinaren ezaugarri arkitektonikoak, historia, gizartearen eta elementu arkitektonikoaren arteko erlazioa edo babes maila bezalako aspektuak ebaluatzen.

Hau guztia dela eta, beharrezkoa da partaide (stakeholder) ezberdinen artean adostasun batera iritsiz babes arkitektoniko nahi horren eta birgaitze obsesio horren arteko mugak hautsi eta konponbide berriei buruz eztabaidatzea.

4.3.3. Eraikinaren birgaitze energetikoaren estrategiak

Gaur egun, ekoizle, argitalpen, ikerketa lanek, etab. argitaratutako dokumentu guztien bidez birgaitze energetikoko estrategia ezberdinei buruz informazio asko dago eskuragarri. Hori dela eta, 2.2 atalean definitutako hiru zutabeak (energiaren kontserbazioa, energia berriztagarrien erabilera eta energiaren erabilera eraginkorra) oinarri hartuta, azterlan honek eraikin baten portaera energetikoa hobetzea ahalbidetzen duten estrategia eta teknologia nagusiak orokorki deskribatzen ditu.

Energiaren kontserbazioa

Eraikinaren azaleko elementuen erresistentzia termikoa handitzea da energia kontserbatu eta ingurumen eta ekonomia inpaktua murrizteko modurik errentagarriena. Hala ere, ez da birgaitutako eraikinean energia kontserbazioa hobetzeko sistema bakarra, instalazioen tutuak edo hodiak isolatzea, itzala emango duten elementuak diseinatzea, infiltrazioen tasa murriztea, etab. bezalako estrategiak ere aplika baitaitezke. Ondorengo puntuetan estrategia hauetako batzuen ezaugarri nagusienak deskribatzen dira:

- **Isolatzaile termiko diren materialen erabilera.** Eraikinaren itxitura termikoaren elementu opaku ezberdinetan isolatzaile termiko diren materialen erabilerak itxituraren erresistentzia termikoa asko hobetuko du, eraikinaren berokuntza eta hozkuntza eskaria murriztuz. Honekin batera, isolamendu hori leku egokian jartzeak biztanleen konfort termikoa asko hobetuko du. Horregatik, energia kontserbazioa, bero transferentzia eta energia eskariaren ikuspuntutik, birgaitze energetiko bateko material garrantzitsuena isolamendu termikoa izango da.

Egoki jarritako isolamenduak eraikinaren azalaren zati guztietako (lurzoru, fatxada, sabai edo estalki) energia eraginkortasuna ziurtatzen du. Isolatzailea lurralde hotzetan bezalako garrantzitsua da lurralde beroetan. Lurralde hotzetan isolamenduak eraikina bero mantentzen du eta berokuntza energia eskaria mugatu. Lurralde beroetan berriz isolamendu sistema berdinak beroa kanpoan mantentzen du eta aire girotuaren beharra murriztu, erabiltzailearen konfort termikoa eta ongizatea hobetuz.

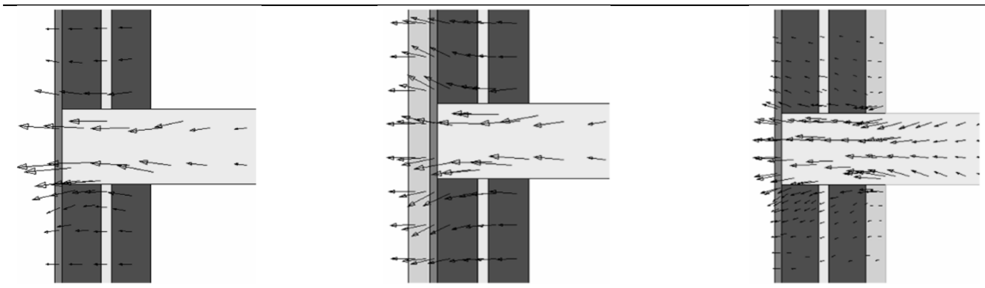
Dentsitatea, porositatea eta suaren aurreko erreakzioarekin batera, hiru dira birgaitze estrategia bezala isolatzaile termikoa den material bat erabiltzen denean eraikinaren portaera ebaluatzeko orduan aztertu beharreko aspektu nagusiak:

_Material isolatzailearen lodiera, U balorearekin zuzenki erlazionatua.

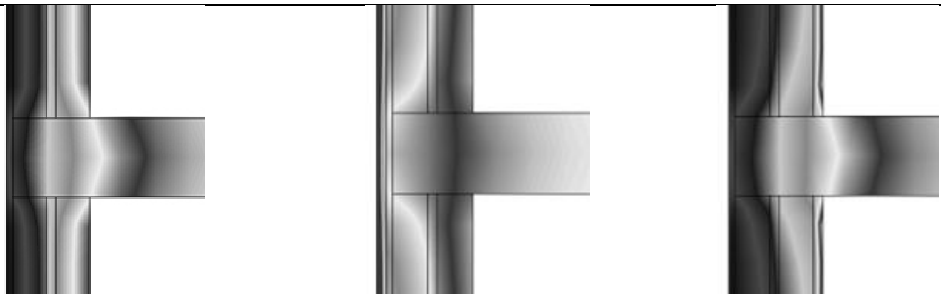
_Eroankortasun termikoa (W/(m·k)). Eroankortasuna zenbat eta baxuagoa izan, sortzen duen erresistentzia termikoa orduan eta handiagoa izango da, honela eraikinaren portaera termikoa hobetuz eta bere energia eskaria murriztuz. Material isolatzaileen eroankortasun balioak 0.05 W/(m·k) (kortxoa) eta 0.02 W/(m·k) (poliuretano proiektatua) artean ibili daitezke.

_Kokapena. Material isolatzailearen kokapenaren arabera, zubi termikoak (pertsiana kaxa, forjatuen aurrekaldea, zutabeak…) bezalako puntuek portaera termiko ezberdina izango dute.

Oinarri egoera (isolamendurik gabe)	**6 cm isolamendua kanpotik**	**6 cm isolamendua barrutik**



Fluxuaren marren analisiak erakusten du nola isolamendua barrutik jartzeak beroaren fluxu guztia forjatuaren aurrean sortzen duen, itxituraren haustura termikoa indartuz.



Isolamendua kanpotik jartzen denean aldiz, barruko aurpegiak barruko tenperaturatik gertu mantentzen dira, azaleko kondentsazioak saihestuz.

Irudia 36 Kasu ezberdinetan isolamenduaren kokapenaren arabera eraikinaren forjatuaren aurrealdeak duen portaera termikoa. Therm simulazio programan (*LBNL*) oinarritutako norbere garapena

Fatxadaren itxura aldatzeko aukera, gaur egungo kanpo itxituraren babesa, arriskuak gutxitzea… bezalako faktoreekin batera, 36. irudiko balioek erakusten dute teorian konponbide termikorik onena material isolatzailea itxituraren kanpotik jartzea dela, isolamendu kapa guztiz jarrai bat lortuz. Hala ere, arrazoi ezberdinak direla medio, irtenbide hau ez da beti posible, isolamendua kanpotik jartzeak hormaren lodiera hiri espaziorantz handitzen baitu eta gaur egungo eraikinaren itxura aldatu, kasu askotan hiri edo herri arauekin (mugak) arazoak sortuz. Horregatik, muga hauek isolamendua kanpotik jartzea ekiditen duten kasuetan isolamendua itxituraren barrutik jarri edo itxitura ezberdinen artean sortzen den aire kameran injektatu daiteke.

- **Leihoen ordezkapena.** Leihoaren (arotzeria eta beira) ezaugarri termikoak eta eguzkiarekiko ezaugarriak hobetzeko estrategia, bero galerak murriztu, eguzki irradiazio zuzenaren sarrera erregulatu eta infiltrazioen eraginez sortutako galerak murriztean datza. Leiho berriaren transmitantzia termiko murriztuak leihotik jasandako bero galerak gutxituko ditu, eraikinaren energia eskari orokorra murriztuz. Leku beroetan eguzki faktore baxu batek eguzki irradiazioaren sarreraren kontrola hobetuko du, barneko tenperatura murriztuz, gainberotze arazoak saihestuz eta hozkuntza eskaria murriztuz.

- **Infiltrazioen gutxitzea.** Gaur egungo eraikin gehienak, baita orain dela gutxi eraikitakoak ere, hermetiko izatetik urruti daude eta nahigabeko aire infiltrazioek bizilagunei eta eraikinaren erabiltzaileei ingurumen, ekonomia eta osasun kostu handiak sortzen dizkiete. Infiltrazio asko duen etxebizitza batean bero galerak direla eta, diseinatutako berotze sistemek ezingo dute eskatutako airearen barne tenperatura lortu. Hori dela eta, birgaitze estrategia aukeratzeko orduan beharrezkoa izango da analisiaren barruan infiltrazioen murriztearen eragina kontuan hartzea.

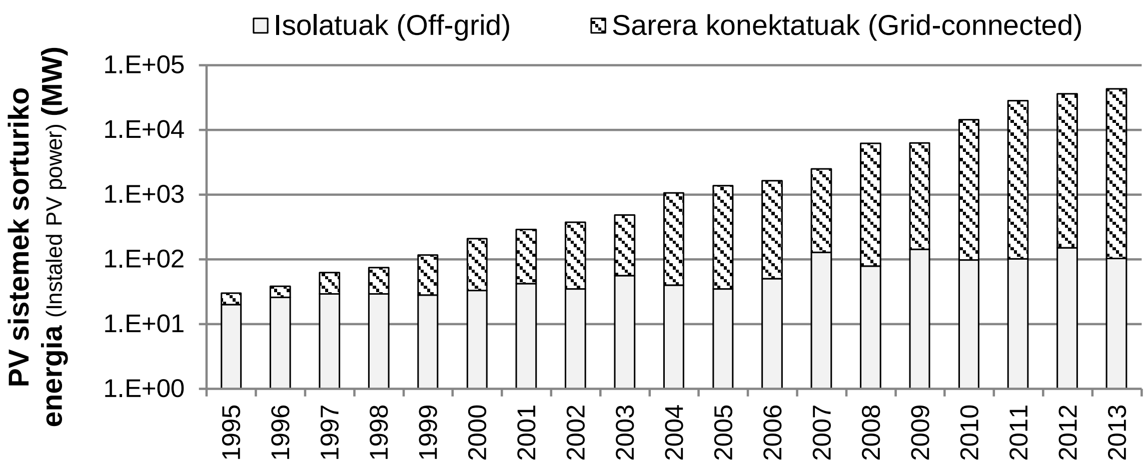
- **Sistema termikoaren banaketa tutuen isolamendua.** Gaur egungo eraikin askotan, berokuntza eta ur bero sistemaren banaketa tutuak ez dira termikoki isolatuta egoten, kontuan izan beharreko bero galerak sortuz. Kasu hauetan, interesgarria izango da tutu hauek isolatzailea den material bidez babestu eta horrela sistema hauen eraginkortasun energetikoa hobetuko da.

<u>Energia berriztagarrien erabilera</u>

Nahiz eta gaur egungo merkatuan iturri berriztagarrietatik energia sortzen duten teknologia ezberdinak egon, metodologia hau eraikinaren eskalan erabili daitezkeen teknologietara mugatuko da eta itsaso barruko haize errota edo azalera handidun eguzki energia termiko-fotovoltaiko bezalako teknologiak alde batera utziko ditu.

- **Eguzki energia termikoa.** Eguzki energia termiko teknologiek eguzki kolektorea erabiltzen dute eguzki irradiazioa bero bihurtzeko. Eguzki irradiazioa eguzki xurgapena hobetzen duen xurgatzaile baten bidez hartzen da (normalean beltza eta material berezia edo “selektiboa”). Bero hau jariakin eramaile baten bidez lagunduz biltegi tanke batera eramaten da, bero hori mantentzeko termikoki ongi isolatua dagoena. Eman beharreko zerbitzuaren eta jariakinak lan egingo duen tenperatura tartearen arabera kolektore mota ezberdinen artean aukeratuko da: kolektore zapala (beiratua edo ez beiratua) edo huts kolektorea. Sistema hauen jariakinaren eta kanpoko aire tenperaturaren ezberdintasunaren arabera, teknologia bakoitzaren errendimendua aldatu egingo da. Txina bezalako herrialdeen potentzialaren ondorioz, munduko energia berriztagarri termiko kolektoreen azaleraren %70a kolektore hutsetan oinarritzen zen. Aldiz, EBko egoera guztiz ezberdina da, energia berriztagarri termikoen kolektoreen azaleraren %89a kolektore zapaletan oinarritzen delarik (*Mauthner et al., 2013*). Teknologia hau tradizionalki eguzki irradiaziotik beroa sortuz eraikinen ur bero edo berokuntza energia eskariak asetzeko helburuarekin erabili itzan da. Gaur egun, teknologia hobetu heinean, bere aplikazioa zabalagoa izaten ari da, elektrizitatea sortzeko eta eguzki hozkuntza bezalako teknologietan aplikatuz.

- **Eguzki energia fotovoltaikoa (PV).** Teknologia hau eguzki irradiazioko energiatik elektrizitatea sortzean oinarritzen da. PV sistemaren bi mota orokor daude: isolatuak (OFF) eta sarera konektatuak (ON). Isolatutako sistemak elektrizitatea sare elektrikoarekiko independenteki hornitzen du, aldiz sarera konektatutako sistema sare elektrikoari konektatuta dago eta saretik hartuko litzatekeen elektrizitatea sortu eta ordezkatzen du. Energia bilketa sistemarik behar ez denez, sarera konektatutako PV sistemaren kostua baxuagoa izango da. Abantaila ekonomiko ezberdinak eta araudiaren muga ezberdinak direla eta, 2013an jarritako PV sistemen %99a sarera konektatutako (ON) sistemak izan ziren.



Irudia 37 Sarera konektatutako eta isolatuak diren PV sistemek sorturiko energia kopurua. Iturria: (*IEA, 2014*) -ren datuetan oinarritutako norbere garapena.

Teknologia eraginkorrak

Hirugarren estrategia taldea geratzen diren baliabideekin eraginkorra izatean datza. Nahiz eta egoera ezin hobe batean ohiko erregaien erabilera zero-arte murrizteko aukera egongo den, hau ez da beti posiblea, eta ondorioz ohiko erregaien ahalik eta erabilera eraginkorrena bultzatu beharko da. Ondoren eraikin baten birgaitze energetikoan erabil daitezkeen teknologia eraginkor batzuen ezaugarri orokorrak deskribatzen dira.

Metodologia honetan zehar alde batera utzi dira auzo berokuntza ("district heating"), energia termikoaren sasoian sasoiko metaketa ("seasonal thermal energy storage") edo hondakinen bero berreskurapena ("waste heat recovery technologies") bezalako teknologiak, beraien erabilera eskala auzo edo hiri batekin lotzen baita (teknologia hauei buruzko informazio gehiago 7.7 eranskinean).

- **Bero bonbak.** Bero bonbak energia tenperatura baxu batetik (exergia baxua) altu batera pasatzeko gai dira, berotze eta hozte sistema bezala erabiliz. Berotze edo hozte eskarien arabera, posible da bero iturri ezberdinak erabiltzea: airea-airea, airea-ura, ura-airea, lurra-airea edo lurra-ura. Sistema hauen eraginkortasun energetikoa, 1.5 eta 4 inguruko balioen artean aurki daiteke, eraikin birgaituaren kontsumo energetikoa hainbat murriztuz.

- **Biomasa.** Etxebizitzen birgaitze energetikoaren esparruan, beste energia iturri batzuekin alderatuz sortzen duen ingurumen inpaktu baxuaren ondorioz biomasaren erabilera batez ere gaur egungo galdara biomasa bidezko galdara batengatik ordezkatzean datza. Azkenengo urteetan, munduko egurrezko peleten merkatuak izugarrizko hazkundea jasan du. Mundu mailako produkzioa 2007an urtean 8 milioi tona izatetik 2009an 13 milioi tona baino gehiago izatera pasa zen (*EUBIA*), hauetatik europar lurraldeek 8 milioi tona baino gehiago kontsumitu zituztelarik. Hazkuntza honen ondorioz bere kostu ekonomikoa ere asko murriztu da azken urteetan.

- **Kogenerazioa.** Energia sortzeko dagoen sistema kogenerazioko sistema batez ordezkatzeak eraginkortasuna asko hobetu dezake. Kogenerazioa elektrizitatea eta beroaren baterako ekoizpenean oinarritzen da. Lortutako abantailak ahalik eta handienak izateko, kogenerazioaren printzipio garrantzitsuena sistema honen prestazio eta ezaugarriak eraikinaren berokuntza eskarian oinarrituta egotean datza. Sistema honen potentzia ezberdinen arabera, bere erabilera banakako eraikin batetatik auzo berokuntza/hozkuntza sistema bateararte zabal daiteke. Berokuntza eta elektrizitate sorkuntza sistema arruntekin alderatuz gero, kogenerazio sistemaren eraginkortasun altuaren ondorioz, %15-40 bitarteko energia aurrezpena lor daiteke.

- **Kontrol sistemak.** Eraikinaren barne tenperatura edo espazio bakoitzaren argiztapen maila egokitzea ahalbidetzen duten kontrol sistemak barneratzeak sistema energetikoaren edo argiztapen sistemaren eraginkortasuna hobetu dezake.

Sentsibilizazio

Nahiz eta erabiltzaile bakoitzaren sentiberatzea izan gaur egungo eraikuntza sektorearen inpaktu altua murriztuko duen oinarrietako bat, pertsona bakoitzaren subjetibitate eta azken erabakiak aspektu honen ebaluazio kuantitatiboa zailtzen du. Horregatik, estrategia hau azterlan honen irismenetik kanpo geratzen da.

Laburpena

Azkenik, 19. taulak birgaitze energetikoaren estrategia talde bakoitzaren ezaugarri orokorrak laburtzen ditu. Horrez gain, eraikinaren aspektu ezberdinetan bakoitzak duen eragina islatzen du, energia eskaritik hasi eta eraikinaren babes maila ezberdinekin duen erlazioraino.

Taula 19 Birgaitze energetikoko estrategi taldeen ezaugarri eta mugen laburpena

		Itxituren isolamendu termikoa	**Leiho ordezkapena**	**Infiltrazio murrizketa**	**Tutuen isolatzea**	**Eguzki energi termikoa**	**Eguzki energi fotovoltaikoa**	**Bero bonba**	**Biomasa**	**kogenerazioa**	**kontrol sistema**
Energia eskari / kontsumo murrizketa	Berokuntza	X	X	X	X			X		X	X
	Hozkuntza	X	X	X				X		X	X
	Ur beroa				X			X		X	
	Argiztapena										X
	Etxe tresna elektrikoak										X
	Aireztapena										X
Bizilagunen konfort termikoren hobekuntza		X	X	X							X
Ingurumen inpaktu murrizketa		X	X	X	X	X	X	X	X	X	X
Inpaktu ekonomiko murrizketa		X	X	X	X	X	X	X		X	X
Babestutako eraikina	A maila				X			X	X	X	X
	B maila			X	X	X*	X*	X	X	X	X
	C maila	X**		X	X	X*	X*	X	X	X	X
	D maila	X		X	X	X*	X*	X	X	X	X
	E maila	***	***	***	***	***	***	X	X	X	X

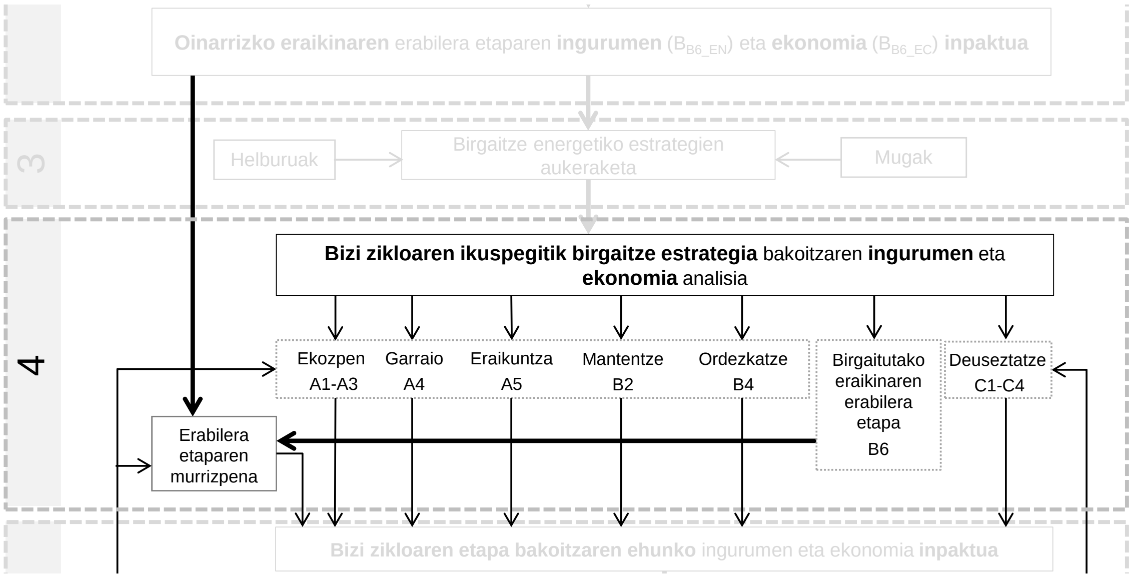
** Babes mailaren arabera, teilatuan ezkutatuak eta barneratuak geratu behar dute.*

*** Eraikinaren portaera termikoa hobetu daiteke baina isolatzaile termiko diren materialak eraikinaren itxituraren barrualdetik edo itxituraren aire kameran injektatuz.*

**** Udal bakoitzaren mugen arabera birgaitze proiektu ezberdinak aplikatzeko aukera egongo da.*

4.4. Bizi zikloaren ikuspegitik birgaitze estrategia bakoitzaren ingurumen eta ekonomia analisia

Metodologia honek gaur egungo EPZ (Energia Portaera Ziurtagiria) sistemekiko eskaintzen duen ezberdintasun nagusi eta balio erantsia eraikinaren birgaitzearen bizi zikloko etapa guztien ebaluaketan datza.



4.4.1. $R_{A1\text{-}3}$. Birgaitze estrategia bakoitzaren ekoizpen prozesuaren hasierako ingurumen barne inpaktua ($IEE_{A1\text{-}3}$) eta kostu ekonomikoa ($IC_{A1\text{-}3}$)

Analisi hau sehaskatik aterako (cradle to gate) etapetan oinarritzen da (A1etik A3ra *(EN 15643-2, 2012)*). Lehengaien ekoizpenetik lantegian banaketa prozesurako prest dagoen amaitutako produktua garatu bitarteko ekoizpen prozesu guztiak hartzen ditu kontuan etapa honek.

A1	Lehengaien erauzte eta prozesatzea
A1	Aurretiko produktu edo materialen berrerabilpena
A1	Produktua ekoizteko erabilitako material sekundarioen prozesatzea
A1	Oinarrizko energia baliabideetatik sortutako elektrizitate, lurrun eta beroa
A2	Lantegira arteko eta lantegi barruko garraioa
A3	Aurre-produktu eta material osagarrien ekoizpena
A3	Produktu eta ko-produktuen ekoizpena
A3	Paketatze fabrikazioa

Sistema eta produktu bakoitzaren ekoizpen etaparekin lotutako hasierako ingurumen barne inpaktua 4a ekuazioa (aldagarrietarako ikus nomenklatura atala) erabiliz kalkulatu da. Metodologia honetan, birgaitze prozesuetan erabilitako material edo sistemen ingurumen barne inpaktuen balioak (EE_m) eskuratzeko Ecoinvent (*Ecoinvent, 2014*), GaBi (*GaBi, 2014)* eta Produktuaren Ingurumen Adierazpena (PIA) bezalako informazio iturriak erabiliko dira (ikus 11. taula). Produktu edo sistema bakoitzaren kantitatea (Q_m) proiektu teknikoan zehar definituko da. Hasierako kostuak birgaitze estrategia bakoitzean erabilitako produktu edo sistema bakoitzaren ekoizpenarekin lotutako kostu ekonomikoa adierazten du eta 4b ekuazioa erabiliz kalkulatu da. Etapa hau kalkulatzeko, erabiltzaileak datu base publikoetatik (ikus 11. taula) edo hornitzaile bakoitzaren azken aurrekontuetatik hartutako datuak erabili ditzake. Analisiaren helburua eta irismenaren arabera, zergei dagokien inpaktua kontuan izan edo ez erabakiko da.

$$IEE_{A1-3} = \sum_{m=1}^{m=k} EE_m \times Q_m \Big/ FU \qquad (4a)$$

$$IC_{A1-3} = \sum_{m=1}^{m=k} EC_m \times Q_m \Big/ FU \qquad (4b)$$

Kasu askotan, inpaktua (EE_m - EC_m) definitzeko erabilitako sistema edo produktuaren deklaratutako unitatea edo unitate funtzionala eta birgaitze estrategia horretan aplikatutako produktu edo sistemaren kantitatea zehazteko momentuan erabilitako unitatea ezberdinak izan ohi dira (adibidez, datu baseak material isolatzaile baten ingurumen edo ekonomia inpaktua m^3-en bidez definitzen du eta erabiltzaileak eraikinaren azalean jarriko den material isolatzailearen azalera datua du (m^2)). Kasu hauetarako, ondorengo taulan erakusten den bezala, ebaluatu beharreko produktuaren lodiera edo dentsitatea bezalako parametroen bidez ebaluazio guztian zehar unitate berdinekin lan egiteko aukera egongo da.

EE_m - EC_m unitatea	Q_m unitatea	Inpaktu kalkulua
m^2	m^2	1 Q_m inpaktua= EE_m edo EC_m –aren inpaktua → $m^2 = m^2$
m^3	m^2	1 Q_m inpaktua = (EE_m edo EC_m inpaktua) x produktuaren **lodiera** → $m^3 = m^2$ x m
kg	m^2	1 Q_m inpaktua = (EE_m edo EC_m impact) x produktuaren **lodiera** x produktuaren **dentsitatea** → kg = m^2 x m x (kg/m^3)

4.4.2. R_{A4}. Birgaitze estrategia bakoitzaren garraiatze prozesuaren hasierako ingurumen (ITE_{A4}) eta ekonomia (ITC_{A4}) inpaktua

A4 etapa fabrikazio gunetik (edo eskualdeko biltegitik) birgaituko den eraikinaren puntura produktuak garraiatzean sortutako inpaktuekin dago lotua.

A4	Fabrikazio gunetik eraikuntza puntura material eta produktuen garraiatzea
A4	Birgaituko den eraikinaren puntura arte eraikuntza ekipamenduen garraiatzea
A4	Garraiatze prozesuan sorturiko galeren inpaktua

Produktu eta sistema bakoitzaren garraiatze prozesuaren inpaktua 5a eta 5b (aldagarrietarako, ikus nomenklatura atala) ekuazioak erabiliz kalkulatu da.

$$ITE_{A4} = \sum_{m=1}^{m=k} D_m \times Q_{mt} \times IA_t \Big/ FU \qquad (5a)$$

$$ITC_{A4} = \sum_{m=1}^{m=k} D_m \times Q_{mt} \times EC_t \Big/ FU \qquad (5b)$$

Lehen kalkulu parametroa produktu edo sistemaren garraiatze distantzia da (D_m), ekoizpen edo fabrikazio puntutik birgaituko den eraikinera garraiatzeko dagoen distantzia zehaztuz (km). Parametro honen zailtasuna bere balioaren kuantifikazio egoki bat egitean datza, normalki benetako ekoizpen puntua zehaztea oso zaila izaten baita. Hau da, azken erabiltzaileak banatzaile bati erosten dio bere produktua, bere kokapena eta birgaitutako eraikinaren arteko distantzia ezagutuz. Hala ere, kasu gehienetan, banatzailea produktu edo sistema horren ekoizlea ez dela jakinik, hauen benetako jatorria ezagutzea zail bilakatzen da, adierazle honen balioaren ziurgabetasuna handituz. Bigarren parametroa tonatan zenbatutako garraiatutako produktu kantitatea da (Q_{mt}). Erabiltzaileak erabilitako produktu bakoitzaren pisuari buruzko informazio zehatza ez duen kasuetan, beharrezkoa izango da produktu bakoitzaren lodiera edo dentsitatea bezalako balioak aplikatzea.

Q_m unitatea	Q_{mt} unitatea	Unitate eraldatzea
m^2	t	1 Q_{mt} = Q_m x produktuaren **lodiera** x **dentsitatea** / 1000 → t = m^2 x m x (kg/ m^3) / 1000
m^3	t	1 Q_{mt} = Q_m x produktuaren **dentsitatea** / 1000 → t = m^3 x (kg/ m^3) / 1000
kg	t	1 Q_{mt} = Q_m / 1000 → t = kg/ 1000

Azkenik, hirugarren parametroak garraiobide sistema ezberdin bakoitzak sortutako ingurumen (IA_t) eta ekonomia (EC_t) inpaktua zehazten du. Informazio hau, besteak beste, 11. taulak erakutsitako datu base ezberdinetatik lortu ahal izango da.

4.4.3. R_{A5} . Birgaitze estrategia bakoitzaren eraikuntza prozesuaren hasierako ingurumen (ICE_{A5}) eta ekonomia (ICC_{A5}) inpaktua

A5 etapa eraikuntza tokian birgaitze estrategia ezberdinek eraikuntza prozesuan zehar sortutako inpaktuekin dago lotua.

A5	Produktuen biltegiratzea
A5	Eraikuntza puntuan zehar material, produktu, hondakin eta ekipamenduen garraiatzea
A5	Aldi baterako lanak
A5	Eraikuntza puntuan produktuen eraldaketa
A5	Eraikinean produktu ezberdinen muntadura
A5	Eraikuntza prozesuan zehar sorturiko galerekin loturiko inpaktuak
A5	Eraikuntza prozesuan zehar sorturiko hondakinen kudeaketa prozesua

Birgaitze estrategia baten eraikuntza etaparekin loturiko ingurumen inpaktua normalean ez da kontuan hartzen, eraikinaren bizi zikloko energia eskariaren %1 baino gutxiago izaten baita (*Wadel et al., 2011*). Hain zuzen ere, Andersen-ek egindako analisiak erakusten du nola bizi zikloko etapa honetan zehar kontsumo energetiko altuena duten prozesuak tokian hormigoiaren lehortzea (44 kWh/t), hormigoizko elementuen lehortzea (25 kWh/t) edo lurraren hondeaketa eta ezabaketan (32 kWh/m^3) oinarritzen direla (*Andersen et al., 1993*). Hau da, birgaitze energetiko batean zehar ohikoak ez diren eraikuntza prozesuak izango dira etapa honen ingurumen inpaktu sortzaile nagusiak (zuzenki lotuak eraikin berri baten analisiarekin).

Datu hauek ikusirik, eta batez ere zenbait datu lortzeko zailtasuna edo birgaitze energetiko batean eraikin berri batekiko erabiltzen den produktu kantitate baxua direla eta, metodologia honek bizi zikloko etapa honen inguruan sinplifikazio bat proposatzen du: produktuen biltegiratze, eraikuntza puntuan zeharreko garraiatze, aldi baterako lanak, eraikuntza puntuan produktuen eraldaketa eta eraikuntza prozesuan zehar sorturiko galerekin loturiko inpaktuak ez dira zenbatuko. Aldiz, birgaitze estrategia bakoitzak eraikuntza prozesuan zehar sorturiko hondakinen kudeaketa prozesua (hondakinen garraiatze eta deuseztatze prozesuak) zenbatzea beharrezkotzat ikusten du lan honek, kasu batzuetan prozesu honek kontuan hartu beharreko inpaktua sortu baitezake (oso kutsagarriak diren materialen kasuan batik bat). Ondorioz, ingurumen inpaktua (ikus 6a ekuazioa) ebaluatzea proposatzen da.

$$ICE_{A5} = \sum_{m=1}^{m=k} ([(Q_{mt} \times WP_m) \times DW_m \times IA_t] + [(Q_{mt} \times WP_m) \times ENW_m]) \Big/ FU \qquad (6a)$$

Ebaluazio ekonomikoari dagokionez, hondakinen kudeaketa prozesuaz gain, muntadura prozesuan sorturiko inpaktua ere zenbatuko da, erabilitako sistema osagarrien edo aukeratutako estrategiaren arabera birgaitze proiektuaren inpaktu ekonomiko osoaren %5-8 izatera irits baitaiteke (ikus 6b ekuazioa).

$$ICC_{A5} = \sum_{m=1}^{m=k} ([(Q_{mt} \times WP_m) \times DW_m \times EC_t] + [(Q_{mt} \times WP_m) \times ECW_m] + [Q_m \times CC_m])/FU \qquad (6b)$$

Etapa honetako kalkulurako ekuazio ezberdinak aplikatzeko orduan, parametro ezberdinak hartzen dira kontuan. Alde batetik birgaitze estrategia bakoitzeko material eta sistemen kantitatea dago (Q_{mt}). Balio hau sortutako hondakinen (WP_m) ehuneko faktore batekin biderkatuz, birgaitze estrategia bakoitzak eraikuntza prozesuan zehar sortuko duen hondakinen kantitatea lortuko da. DW_m parametroaren bidez eraikin birgaitutik hondakinen kudeaketa gunerako garraio distantzia definituko da. IA_t eta EC_t parametroak garraiatze prozesuaren ingurumen eta ekonomia inpaktua (tona eta km-ko) zehazteko erabiliko dira hurrenez hurren. ENW_m eta ECW_m parametroen bidez, birgaitze prozesuan sortutako hondakin bakoitzaren kudeaketak sortutako ingurumen eta ekonomia inpaktua kalkulatuko da. CC_m parametroak birgaitze energetikoko estrategia bakoitzaren eraikuntza prozesuaren lanak egin ahal izateko langile bakoitzaren kostu ekonomikoa hartzen du kontuan. Hala ere, langileen joan-etorriekin eta mantenuarekin erlazionatutako kostu ekonomikoa ez du kontuan hartzen.

Azkenik, aipatu behar da metodologia honen sistemaren irismenak kanpoan uzten dituela eraikuntza prozesuko langile bakoitzaren zeharkako inpaktuak edo langile hauen eraikuntza tokirako joan-etorrian sorturiko inpaktuak.

4.4.4. R_{B2}. Birgaitze estrategia bakoitzaren mantentze prozesuaren inpaktu ekonomikoa (MC_{B2}).

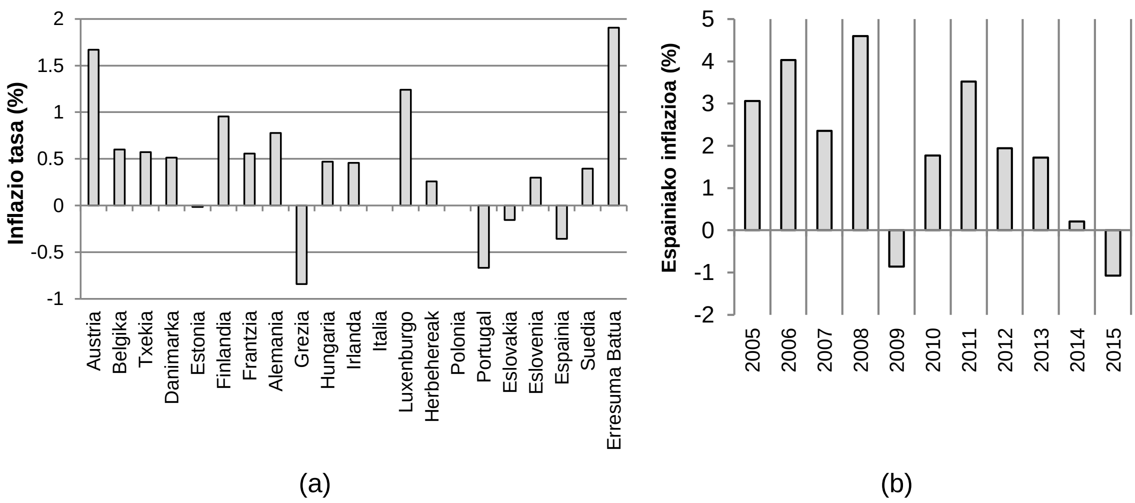
B2 etapa eraikinaren erabilera etapan zehar egindako mantentze lanetan sortutako inpaktuekin dago lotua.

B2	Mantentzerako erabilitako osagai eta produktu osagarrien ekoizpena eta garraioa
B2	Eraikinaren barruko eta kanpoko garbitze prozesu guztiak
B2	Errendimendu funtzional, teknikoa, zein ezaugarri estetikoa mantentzeko prozesuak.

Informazio falta eta birgaitze estrategia ezberdinen mantentze prozesuek beraien bizi zikloan zehar sortutako inpaktuaren balioak lortzeko zailtasuna dela eta, metodologia honek ez du etapa honen ingurumen inpaktua kontuan hartzen. Hala ere, sistema berriztagarriak bezalako estrategiak erabiltzen direnean nagusiki, aurretik egindako azterlan ezberdinek erakusten dute eraikinaren bizi zikloan zeharreko mantentzearekin erlazionatutako inpaktu ekonomikoa altua izan daitekeela.

Birgaitze estrategia bakoitzak, aldagarri ezberdinen arabera, mantentze behar ezberdinak edukiko ditu. Ondorioz, mantentze lan mota hauen aldizkakotasuna (Aurreikusitako Mantentze Aldia – “EMP”) birgaitutako eraikinaren erabilera bizitzan zehar kasu bakoitzerako (sistema berriztagarrien kasuan mantenu altua edo aire kameran isolamendua injektatzea bezalako estrategiak erabiltzean ia mantenurik ez) aldakorra izango da.

Honekin batera, ikusirik eraikinaren bizi zikloan zehar behin baino gehiagotan egingo den esku hartze bat izango dela, beharrezkoa da RSL_b-an zehar mantenuaren inpaktua nola aldatuko den ebaluatuko duen parametro berri bat sartzea. Horretarako, metodologia honek inflazio tasaren (%) parametro ekonomikoa barneratzen du, diruaren erosteko ahalmenaren murrizpena edo gaur egungo benetako balioaren galera islatuz. Europako batzordeak (*Regulation 244/2012, 2012)* egindako lanek mota honetako birgaitzearen ebaluazioak egiteko orduan %3 bezalako interes tasak erabiltzea proposatzen dute. Hala ere, mundu mailako ezegonkortasun ekonomikoa dela eta, lurralde ezberdinetan egindako azterketa lan ezberdinetan inflazio tasa balio bera erabiltzea oso zaila da. 38. irudian ikus daitekeen bezala, EBko estatu kide bakoitzaren inflazio tasen balioak guztiz ezberdinak baitira (2014 urtea). Balioen aldaketa honi gaur egungo merkatuaren egoera konplexua dela eta, denbora gutxian estatu kide bakoitzaren inflazio balioak asko aldatu daitezkeela gehitu behar zaio (ikus 38 a-b irudiak), inflazioaren parametroaren definizio egokia gehiago zailduz.



Irudia 38 a) EBko estatu kide bakoitzaren 2014ko inflazio tasa (%). b) Espainiako inflazio tasaren denborarekiko aldaketa (%). Iturria: (*Global Rates*) –en datuetan oinarritutako norbere garapena.

Bi zailtasun hauek ikusirik (mantentzearen aldizkakotasun ezberdinak eta inflazioaren parametroa barneratzearen beharra), metodologia honek 7. ekuazioaren bidez birgaitutako eraikinaren bizi zikloan zehar birgaitze estrategia bakoitzaren mantentzearen inpaktu ekonomikoa ebaluatuko du. Kalkulu hau garatzerakoan 5 dira kontutan izan beharreko parametroak. Alde batetik, birgaitze estrategia bakoitzaren MC_m parametroa (mantentzearen kostu ekonomikoa) eta Q_m (material eta sistemen zenbatekoa) parametroen balioak biderkatuz, birgaitze estrategia bakoitzaren mantentze inpaktu ekonomiko arrunta zenbatuko da. Hala ere, inflazioaren eragina kontuan izateko, metodologia honek, EMP_m parametroaren bidez (aurreikusitako mantentze periodoa) mantentze inpaktu ekonomiko arrunta urteko mantentze inpaktu ekonomikoan bilakatzen du. Era horretan, estrategia bakoitzak urte bakoitzean eragingo duen mantentze inpaktua jakinda, eraikinaren erabilera bizitzan (RSL_b) zehar inpaktu honengan inflazioak izango duen eragina integratuz (IR_n) mantentze etaparen bizi ziklo osoko inpaktu ekonomikoa zenbatuko da.

$$MC_{B2} = \sum_{n=1}^{RSL_b} \left(\sum_{m=1}^{m=k} \frac{MC_m \times Q_m}{EMP_m} \right) \times (1 + IR_n) \Big/ FU \qquad (7)$$

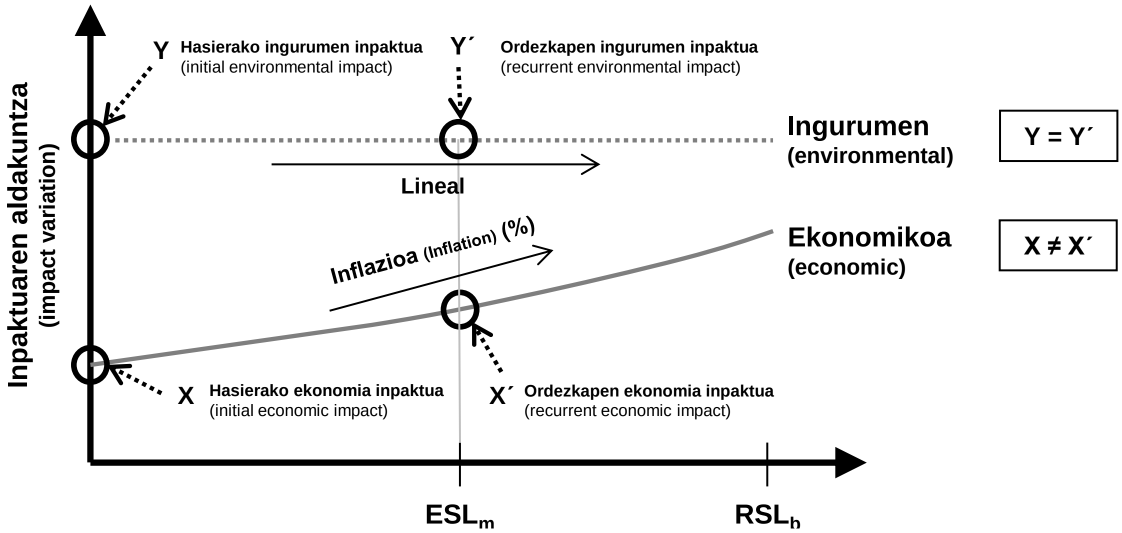
4.4.5. R_{B4}. Ordezkatze etapan sorturiko ingurumen eta ekonomia inpaktua

B4 etapa eraikinaren erabilera etapan zehar egindako ordezkapen jardueretan sortutako inpaktuekin dago lotua.

B4	Ordezkatzeko produktuen ekoizpena
B4	Ordezkatzeko produktuen garraioa
B4	Ordezkatzeko produktuen eraikuntza prozesua
B4	Ordezkatutako produktuen hondakinen kudeaketa

ISO 15686-8:2008ren arabera (*ISO, International Standardization Organization, 2008b*), normalki eraikuntza materialek eta sistemek duten aurreikusitako erabilera bizitza (ESL_m) ez da erreferentzia eraikinaren erabilera bizitzaren (RSL_b) berdina izaten, eraikinaren erabilera bizitzan zehar ordezkapen bat edo gehiago egin behar izaten baitira. Produktu baten aurreikusitako erabilera bizitza zenbat eta baxuagoa izan, erakinaren bizitzan zehar ordezkatu beharreko produktuen ekoizpen, garraio, eraikuntza prozesu eta hondakinen kudeaketa etapekin loturiko ingurumen eta ekonomia inpaktua orduan eta handiagoa izango da. Mantentze etaparen kalkulu ekonomikoan gertatu den bezala, bizi zikloaren analisian oinarritzen den metodologia honek, parametro batzuen aldakortasunaren bidez, birgaitze estrategien ordezkapenaren inpaktuek eraikinaren erabilera bizitzan zehar denborarekiko izango duten aldaketa kuantifikatzea ahalbidetuko du. Era horretan, birgaitze estrategia bakoitzaren gaur egungo ingurumen eta ekonomia inpaktua hemendik 20, 30 edo 50 urtera zenbatekoa izango den jakiteko aukera egongo da.

Estatu kide bakoitzaren politika energetikoei dagozkien erabakien ondorioak zehazteko zailtasuna dela eta, metodologia honek birgaitze estrategia bakoitzak bere zikloan zehar sortuko duen ingurumen inpaktua lineala izatea proposatzen du. Aldiz, 39. irudian ikus daitekeen bezala, inflazio tasaren ondorioz, eraikinaren bizi zikloan zehar birgaitze estrategia bakoitzaren ordezkapenaren inpaktu ekonomikoa kalkulatzean, egoera guztiz aldatuko da.



Irudia 39 Ingurumen kalkuluen linealtasuna eta inflazioaren barneratzea kalkulu ekonomikoetan

Hasierako inpaktuen egitura orokorra mantenduz, ordezkapen etapa hau 3 taldetan banatuko da: ekoizpena, garraioa eta bizi amaierako etapak. Nahiz eta 4a-b, 5a-b eta 6a-b ekuazioen egitura orokorra mantendu, 2 parametro edo kontzeptu berri gehituko zaizkie ordezkapen etapako inpaktuak kalkulatzeko ekuazioei:

- Birgaitutako eraikinaren erabilera bizi (RSL_b) eta birgaitze estrategia bakoitzaren aurreikusitako erabilera bizitzen (ESL_m) arteko erlazioa. Era honetan, bizi zikloan zehar birgaitze estrategia bakoitzaren ordezkapen kopurua zehaztuko da.

$RSL_b / ESL_m \leq 1$, Ordezkapenik ez (ESL_m-ren balioa RSL_b-ren balioaren berdina edo handiagoa).

$RSL_b / ESL_m > 1$, Ordezkapena beharrezkoa da. Kasu honetan RSL_b / ESL_m zatiketaren balioa goraka borobildu behar da.

- Kalkulu ekonomikoetan, inflazioaren eragina kontuan izango da. Horretarako, ordezkapena gauzatu behar den urteko (ESL_m balioaren bidez definituta) inflazio tasaren balioa bizi zikloko etapa ezberdinen hasierako inpaktu ekonomikoarekin biderkatuz, denboran zehar birgaitze estrategia bakoitzaren ordezkapenak izango duen inpaktu ekonomikoaren aldaketa zenbatzeko aukera izango da.

_Birgaitze estrategia bakoitzaren ordezkapenaren ekoizpen prozesuaren ingurumen barne inpaktua ($REE_{B4(A1-3)}$) eta inpaktu ekonomikoa ($RC_{B4(A1-3)}$):

$$REE_{B4(A1-3)} = \sum_{m=1}^{m=k} EE_m \times Q_m \times \left((RSL_b/ESL_m) - 1\right) \Big/ FU \tag{8a}$$

$$RC_{B4(A1-3)} = \sum_{m=1}^{m=k} EC_m \times Q_m \times \left((RSL_b/ESL_m) - 1\right) \times (1 + IR_{ESLm}) \Big/ FU \tag{8b}$$

_Birgaitze estrategia bakoitzaren garraiatze prozesuaren ordezkapenaren ingurumen ($RTE_{B4(A4)}$) eta ekonomia ($RTC_{B4(A4)}$) inpaktua:

$$RTE_{B4(A4)} = \sum_{m=1}^{m=k} D_m \times Q_{mt} \times IA_t \times \left((RSL_b/ESL_m) - 1\right) \Big/ FU \tag{8d}$$

$$RTC_{B4(A4)} = \sum_{m=1}^{m=k} D_m \times Q_m \times EC_t\left((RSL_b/ESL_m) - 1\right) \times (1 + IR_{ESLm}) \Big/ FU \tag{8e}$$

_Birgaitze estrategia bakoitzaren eraikuntza prozesuaren ordezkapenaren ingurumen ($RCE_{B4(A5)}$) eta ekonomia ($RCC_{B4(A5)}$) inpaktua:

$$RCE_{B4(A5)} = \sum_{m=1}^{m=k}\left(([(Q_{mt} \times WP_m) \times DW_m \times IA_t] + [(Q_{mt} \times WP_m) \times ENW_m]) \times [(RSL_b/ESL_m) - 1]\right)/FU \tag{8f}$$

$$RCC_{B4(A5)} = \sum_{m=1}^{m=k}\left(([(Q_{mt} \times WP_m) \times DW_m \times EC_t] + [(Q_{mt} \times WP_m) \times ECW_m] + [Q_m \times CC_m]) \times [(RSL_b/ESL_m) - 1]\right) \times (1 + IR_{ESLm}) \Big/ FU \tag{8g}$$

4.4.6. R_{B6}. Birgaitutako eraikinaren erabilera etaparen ingurumen (R_{B6_EN}) eta ekonomia (R_{B6_EC}) inpaktua

B6 etapa jardueran dagoen eraikinaren bizi zikloan zeharreko kontsumo energetikoa dela eta sortutako inpaktuekin dago lotua.

B6	Berokuntza
B6	Hozkuntza
B6	Etxeetako Ur Beroaren hornikuntza
B6	Aireztapena
B6	Argiztapena
B6	Etxe tresna elektrikoak

Etapa honen kalkulu irizpidea 4.2 puntuan azaldutakoaren antzekoa da (oinarrizko eraikinaren erabilera etaparen inpaktua), berriz ere kalkulua zazpi parametro nagusitan oinarrituz: energia eskaria (ED_b), energia sortzeko sistemen eraginkortasun energetikoa (ρ), banaketan zeharreko ondoriozko galerak (DL_b), iturri berriztagarrien bidez sortutako energia (RE_k) eta erabilitako energi iturriaren konbertsio faktorea (CF_y), prezioa (EP_y) eta prezioaren igoera (EPI_y).

$$R_{B6\_EN} = \sum_{n=1}^{RSL_b} \left(\sum_{m=1}^{m=k} \left[\left(\frac{ED_b}{\rho} + DL_b - RE_y \right) \times CF_y \right] \right) \Big/ FU \quad (9a)$$

$$R_{B6\_EC} = \sum_{n=1}^{RSL_b} \left(\sum_{m=1}^{m=k} \left[\left(\frac{ED_b}{\rho} + DL_b - RE_y \right) \times EP_y \right] \times \left[1 + EPI_y^n \right] \right) \Big/ FU \quad (9b)$$

Erabilitako birgaitze estrategiaren arabera, berriro kalkulatu beharreko parametroak ezberdinak izango dira. Estrategia pasibo ezberdinak aplikatu diren kasuetan, aldatuko den parametro nagusia itxitura elementu berriaren transmitantzia termikoa (U balioa) izango da, energia eskariaren murrizpenean (ED_b). eragin zuzena izanez. Esku hartze mota hauetan, eraikinaren zubi termikoetan izango duen eragina ebaluatzea beharrezkoa da. Estrategia sistema termikoen banaketa tutuen isolamenduan oinarritzen denean, ebaluatu beharreko parametro bakarra DL_b izango da. Birgaitzearen helburua iturri berriztagarria duten energia sortzeko sistema berriak sartzea denean, erabiltzaileak sistema hauen bidez sortutako energia kantitatea kalkulatu beharko du (RE_y). Azkenik, estrategia teknologia eraginkor berrien bidez energia sortzen duen sistemaren ezaugarriak hobetzea bada, sistemaren eraginkortasun energetiko berria (p) eta erabilitako energia iturri berriaren datuak definitu beharko dira: konbertsio faktorea (CF_y), prezioa (EP_y) eta prezioaren igoera (EPI_y).

4.4.7. R_{C1-4}. Birgaitze estrategia bakoitzaren deuseztatze etaparen ingurumen (EL_{C1-4_EN}) eta ekonomia (EL_{C1-4_EC}) inpaktua

Bizi zikloko etapa hau eraikina erabileraz kanpo geratu eta beste erabilerarik aurreikusten ez denean hasten da.

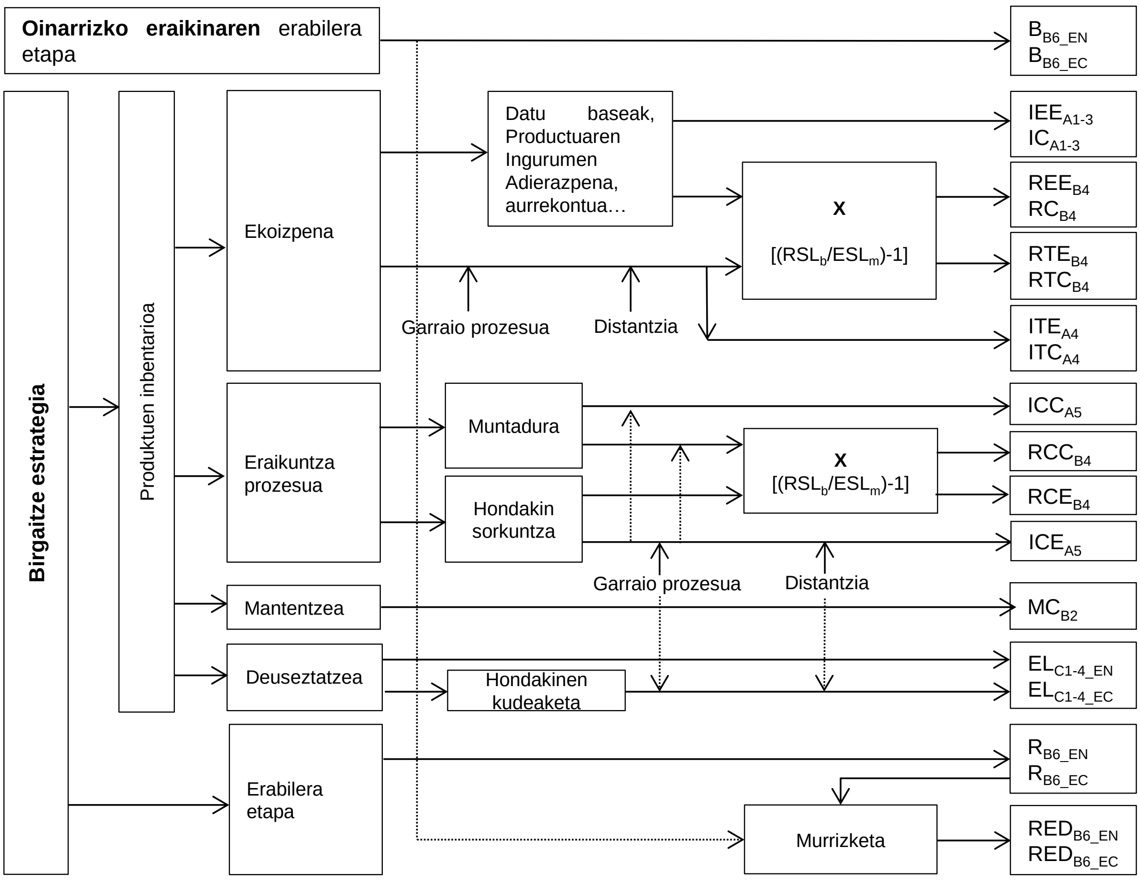
C1	Eraikina behin erabileraz kanpo geratzean eraikin bertan garatzen diren eraispen prozesuak
C2	Hondakinen kudeaketa gunera arteko garraio prozesua
C3	Hondakinen kudeaketa eta oinarrizko fluxuak
C4	Hondakinen deuseztapena, aurre tratamendua eta zabortegiko kudeaketa

Metodologia honek birgaitze estrategia bakoitzaren parte diren produktu eta sistemen kudeaketa gunera arteko garraio (C2) eta hauen deuseztatze (C3-C4) prozesuaren (hasierakoa eta ordezkapenekoa) inpaktuak bakarrik zenbatzen ditu. Aldiz, oinarrizko eraikinaren parte ziren beste produktu eta sistemen (egitura, zimendatze, barruko itxiturak, etab.) garraio eta deuseztatze prozesuen inpaktua ez da zenbatuko. Etapa honek birziklatze eta berrerabilpen prozesuekin loturiko ingurumen eta ekonomia abantailak ez ditu kontuan hartzen, azterketaren irismenetik kanpo geratzen baitira. Azkenik, etapa honek ez du kontuan hartzen hondakinen errausketaren sistema ezberdinen bidez sortu eta berreskuratu daitekeen energia.

$$EL_{C1-4\_EN} = \sum_{m=1}^{m=k} ([Q_{mt} \times DW_m \times IA_t] + [Q_{mt} \times ENW_m]) \times (RSL_b/ESL_m) \Big/ FU \qquad (10a)$$

$$EL_{C1-4\_EC} = \sum_{m=1}^{m=k} ([Q_{mt} \times DW_m \times EC_t] + [Q_{mt} \times ECW_m]) \times (RSL_b/ESL_m) \Big/ FU \qquad (10b)$$

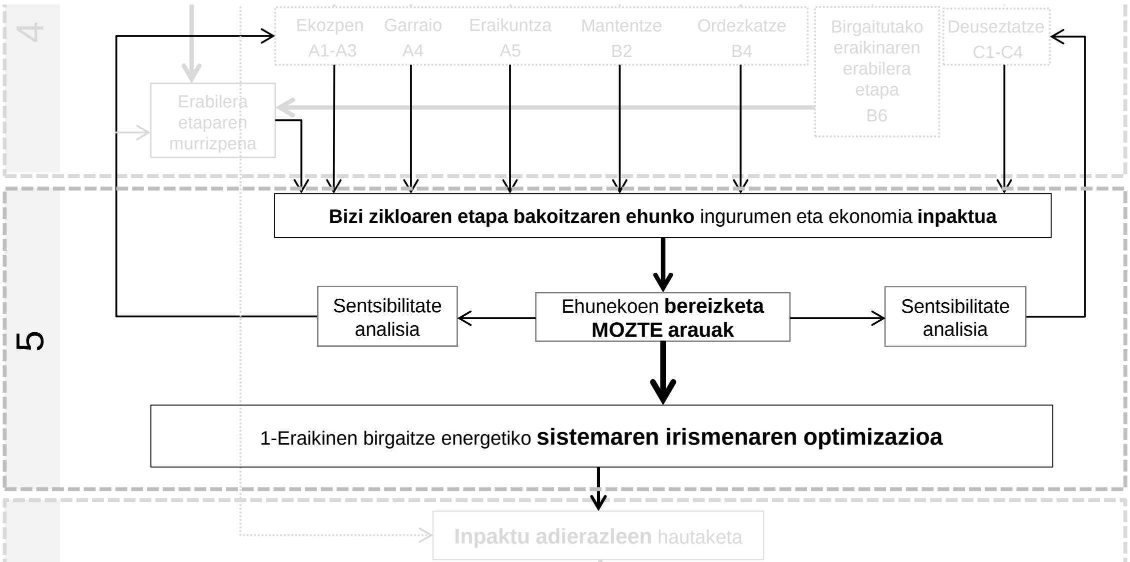
4.4.8. Laburpena



Irudia 40 Birgaitze estrategien bizi zikloaren etapa bakoitzaren ingurumen eta ekonomia inpaktuaren analisi eskema

4.5. Sistemaren irismenaren optimizazioa. Mozte arauak

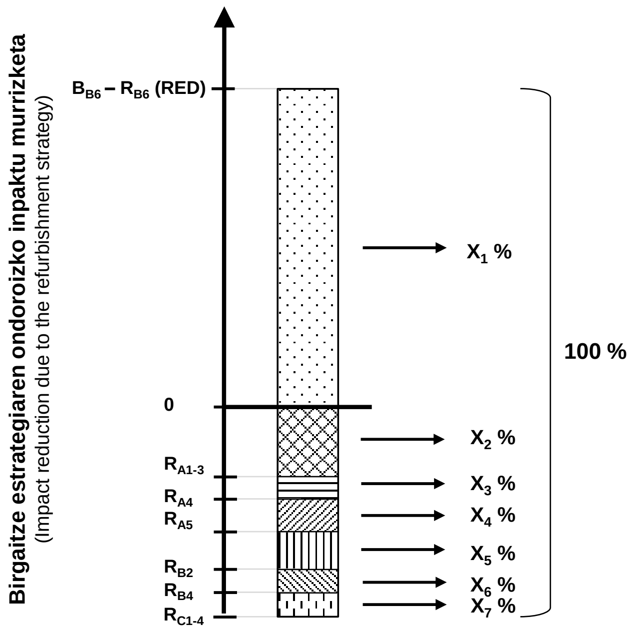
Birgaitze estrategien bizi zikloaren etapa bakoitzaren ingurumen eta ekonomia inpaktuak zenbatu eta gero, eraikin birgaituaren sistemaren irismena kuantitatiboki optimizatu ahal izateko nahiko informazio duen puntura iristen da metodologia, ikerketa lanaren lehen helburua lortuz.



Alde batetik, oinarrizko (B_{B6}) eta birgaitutako (R_{B6}) eraikinaren erabilera etapen inpaktu balioen arteko ezberdintasunak eraikinaren erabilera etapan zeharreko inpaktu murrizpenaren (RED_{B6}) balioa kalkulatzea ahalbidetzen du. Bestalde, bizi zikloaren beste etapetan birgaitze estrategia bakoitzak sortutako inpaktua edo inpaktu negatiboaren inguruko informazioa ere ezagutzen da. Honela, metodologia honi esker. 11. ekuazioan eta 41. irudian oinarrituz, bizi zikloko etapa bakoitzak birgaitze estrategia bakoitzaren aplikazioaren inpaktu osoarekiko duten eragina ehunekoetan ebaluatzeko aukera egongo da.

$$Etaparen\ eragina\ (\%) = \frac{Ebaluatutako\ bizi\ ziklo\ etaparen\ inpaktua}{Murrizketa\ positiboa_{X1}\ +\ Murrizketa\ negatiboa^{*}_{(X2+X3+X4+X5+X6+X7)}} \quad (11)$$

**Balio guztiak balio absolutu bidez definitu.*

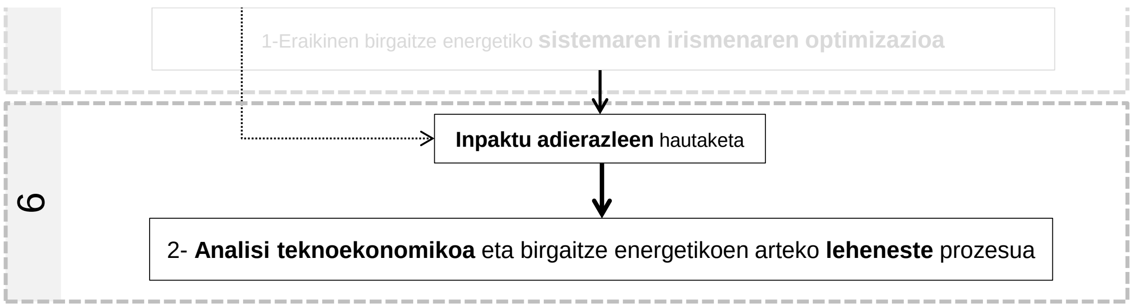


Irudia 41 Bizi zikloaren etapa bakoitzak birgaitze estrategia baten ebaluazioan duen eragina (Influence of each life cycle stage in a refurbishment strategy assessment)

Etapa bakoitzaren ehuneko balioa lortu ondoren, sistemaren irismena optimizatzeko helburuarekin, metodologia ehunekoen bereizketa edo **mozte arauetan** oinarritzen da. Horretarako, datuen zehaztasun maila edo kalitatearen arabera, tekniko bakoitzak bere azterketarako gutxieneko edo bereizketako balio bat definitzen du. Adibidez, zehaztasun handiko azterketetan %0.5 bezalako bereizketa balio murriztuak definituz edo azterketa orokor edo hasierakoetan %5 edo %10 bezalako balioak proposatuz.

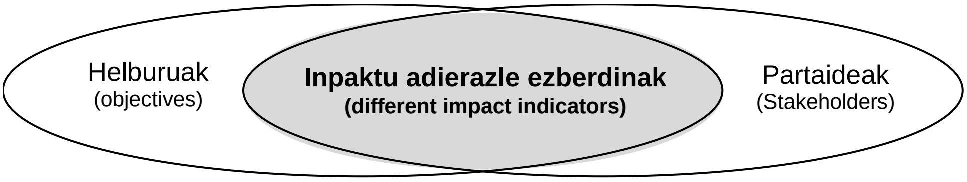
4.6. Analisi teknoekonomikoa eta birgaitze estrategia desberdinen arteko leheneste prozesua

Metodologiaren azkenengo etapa eraikin birgaituaren sistemaren irismena optimizatu ondoren lortutako emaitza ezberdinak ebaluatzean datza, erabakiak hartu eta birgaitze energetikoen artean lehenestea posible eginez.



Azken fase honetarako, bi dira metodologiak zehaztu dituen erabakiak: zein diren emaitzak erakusteko garaian erabiliko diren adierazleak eta nola erakutsi adierazle hauek.

17. taulan ikus daitekeen bezala, birgaitze energetiko batean parte hartzen duten partaideen arabera, hasierako **helburua**k asko aldatu daitezke, erabakiak hartzera iristeko beharrezkoa diren adierazleak kasu bakoitzerako **ezberdinak** izatera iritsi arte. Partaide batzuek estrategiak ingurumen inpaktuen murrizpenean bakarrik oinarrituz lehenetsiko dituzte, beste batzuek inbertsio ekonomikoaren berreskurapena ebaluatuko dute eta azken batzuek ingurumen eta ekonomia aspektuekin erlazionatutako adierazleetan oinarrituz lehenetsiko dituzte.



Ondorioz, proposatuko metodologia berri honek, ingurumen eta ekonomia inpaktuen adierazle ezberdinetan oinarrituz birgaitze estrategien aspektu ezberdinak ebaluatzea erraztuko du. Irizpide anitzeko emaitza berri hauen bidez, ikuspegi partzialak ekidin eta jasangarritasunaren 2 puntutan oinarritutako erabakiak hartzeko aukera eskainiko da.

4.6.1. Ingurumen inpaktu adierazleak

Metodologia honetan ondorengo ingurumen inpaktu adierazleak erabiliko dira.

<u>1- Ingurumen inpaktuaren murrizketa</u>

12. taulan aipatutako ingurumen adierazle ezberdinen aplikazioaren bidez (berotze osoaren potentziala, estratosferako ozono geruzaren deuseztatze potentziala, energia baliabideen kontsumoa, etab.), oinarrizko eraikinarengan birgaitze estrategia bakoitzak eragin duen ingurumen inpaktuaren murrizpena ebaluatzen da. Azterketaren irismen, helburu edo zehaztasun mailaren arabera, inpaktuen adierazle bat edo gehiago ebaluatuko dira.

Ingurumen inpaktuaren murrizpenaren balio absolutu honen bidez, birgaitze bakoitzaren bidez lorturiko zenbakizko eragina ezagutzen da. Bestalde, balio honen bidez ezin dira erabaki orokorrak hartu, esku hartze bakoitzaren ondorio orokorra ezagutzea oso zaila baita. Hau da, ondorengo galderei erantzuteko adierazle honek ez du nahikoa informazio eskaintzen: 25 $kgCO_2/m^2$·a-ko murrizpena, asko da? Oinarrizko eraikinarengan ehuneko zenbatekoa da murrizpen hau? Klima aldaketa europarraren politikek zehaztutako helburuak betetzera iristeko nahikoa al da?

2- Ingurumen inpaktuaren murrizketaren ehunekoa (%)

Oinarrizko eta birgaitutako eraikinaren ingurumen inpaktua ebaluatu eta kalkulatu ondoren, birgaitze estrategia bakoitzak sortutako ingurumen inpaktu murrizketaren ehunekoa kalkulatzeko aukera dago.

$$Murrizpenaren\ ehuneko\ (\%) = \frac{Birgaitzea\ dela\ eta\ ingurumen\ inpaktuaren\ murrizpena}{Oinarrizko\ eraikinaren\ ingurumen\ inpaktua} \quad (12)$$

Bestalde, ehuneko balio honen bidez, birgaitze estrategia ezberdinak bultzatu, lan lerro berriak zehaztu edo 20/20/20 bezalako joerak ebaluatu daitezke. Aldiz, ehuneko balio honek erabaki zehatzak hartzea zailtzen du, erabiltzaileak ez baitu inpaktuaren murrizpenaren balio absolutua ezagutzen. Hau da, zein da %30aren murrizpenaren eragina? Zenbakizko balioetan, hau asko ala gutxi da?

3- Bizi zikloaren energia portaeraren adierazlea. Energia Garbi Ratioa (Net Energy Ratio – NER)

Hernandez-ek (*Hernandez & Kelly, 2010*) garaturiko adierazle honen bidez birgaitze estrategia bakoitzaren bizi zikloan zeharreko eraginkortasun energetikoa zehazten da.

Adierazle honek ez du unitaterik eta modu erraz batean, birgaitze estrategia bakoitzak bere bizi zikloan zeharreko barne energia “zenbat aldiz” aurrezten duen adierazten du.

$$NER\ birgaitzea = \frac{\text{Erabilera etaparen urteko inpaktu murrizketa}}{\text{Urteko barne energia inpaktua}} = \frac{AEU1 - AEU2}{AEE2 - AEE1} \quad (13)$$

Oinarrizko eraikinak (1) gaur egungo eraikina islatzen duenean (“A” metodologia), oinarrizko eraikinaren urteko barne energiaren inpaktua (AEE1) zero da

Adierazle honen erabileraren bidez, birgaitze estrategia bakoitzak bere bizi zikloko etapa ezberdinetan sorturiko ingurumen inpaktua edo produktu bakoitzaren ESL_m balioarekin erlazionatutako ingurumen aspektuen garrantzia azpimarratzen da. Hala ere, ondoren adierazten den bezala, birgaitze estrategiak lehenesteko orduan inpaktuen adierazle hau bakarrik erabiltzeak zailtasunak sor ditzake, bere dimentsionamendu gabeziak askotan irizpide garbi batekin erabakiak hartzea zailtzen baitu.

Adibidea: 3 birgaitze estrategia ezberdin proposatzen dira. Lehenengoa fatxada aireztatu sistema batean oinarritzen da eta bere aplikazioak oinarrizko eraikinaren ingurumen inpaktua 150 MJ/(m^2·a)-

tan murrizten du. Bigarrena eraikinaren itxituraren barrutik gauzatzen den birgaitze energetiko batean oinarritzen da eta ingurumen inpaktua 85 MJ/(m^2·a)-tan murrizten du. Azkenik, hirugarren estrategia 50 m^2-ko eguzki energia fotovoltaiko sistema batean oinarritzen da, oinarrizko eraikinaren ingurumen inpaktua 11 MJ/(m^2·a)-tan murriztuz. Birgaitze estrategia bakoitzaren ingurumen barne energia inpaktuari dagokionez, balioak 50, 30 eta 1 MJ/(m^2·a) dira hurrenez hurren.

Estrategia	**AEU1 - AEU2** (MJ/(m^2·a))	**AEE2 – AEE1** (MJ/(m^2·a))	**NER**
1	150	50	**3**
2	85	30	**2,83**
3	11	1	**11**

Ingurumenaren adierazle honek erakusten du bizi ziklo guztia kontuan hartuz gero, hirugarren birgaitze estrategiaren aplikazioaren bidez, bizi zikloan zehar 11 aldiz aurrezten dela bere barne energia kopurua. Aldiz, 3.aukera honen beste birgaitze estrategiekiko murriztutako ingurumen inpaktua oso baxua da (ia 15 aldiz txikiagoa lehen aukerarekiko), ingurumen murrizketari dagokin helburuak lortzea zailduz.

Ondorioz, adierazle hau paraleloki, ingurumen inpaktuaren murrizketa kantitatea erakusten duen adierazle batekin erabiltzea gomendatzen da, emaitzak osatuz eta hartutako erabakien kalitatea hobetuz.

4.6.2. Ekonomia inpaktu adierazleak

Metodologia honetan ondorengo ekonomia inpaktu adierazleak erabiliko dira.

1- Barne Errendimenduaren Tasa (%) (Internal Rate of Return – IRR)

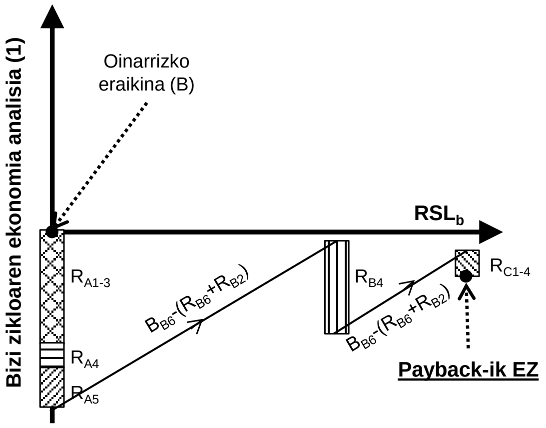
Hasierako ordainketa eta proiektuak sortutako diru irteera eta sarreren arteko ezberdintasun eguneratua (eguneratutako balio garbia) berdintzen dituen balioa da. Adierazle hau orokorrean proiektu ezberdinen arteko erakargarritasuna ebaluatzeko erabiltzen da. Proiektu edo birgaitze estrategia baten aplikazioak ikertzaileak definitutako IRR-ren balioak gainditzen baditu, proiektua ekonomikoki interesgarria bilakatzen da.

$$IRR\ (\%) = r_a + \left[\left(\frac{NPV_a}{NPV_a - NPV_b}\right) \times (r_b - r_a)\right] \qquad (14)$$

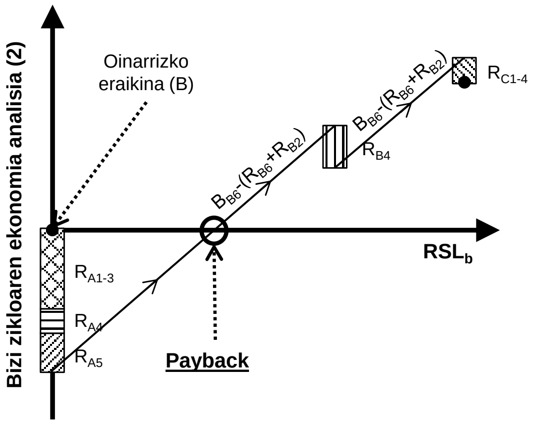
Birgaitze estrategiak lehenesteko prozesuan IRR adierazle ekonomikoa bakarrik erabiltzean zenbait zailtasun sortzen dira. Nahiz eta adierazle honek bere barnean analisi aldi edo epearen parametroa kontuan izan, azken erabiltzaile edo bizilagun askori oso zaila egiten zaie IRR-ak eskaintzen duen ehuneko balioa interpretatu eta aurrezki edo errentagarritasunarekin lotzea. Ondorioz, analisi ekonomiko batean, IRR adierazlea ondoren azalduko den “bizi zikloko berreskurapen epe” adierazlearekin batera erabiltzea proposatzen da.

<u>4-Bizi zikloko inbertsioaren berreskuratze epea (urteak)</u> (Life Cycle Payback – LC-PB)

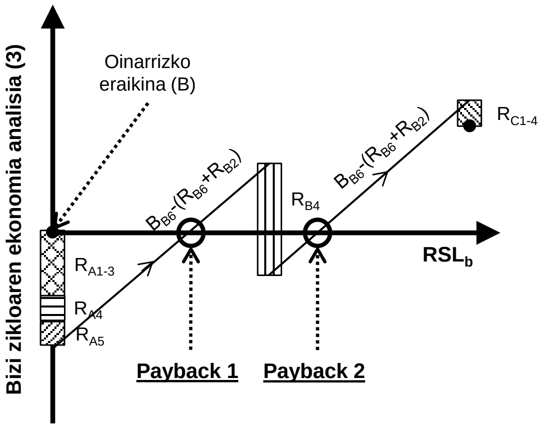
Berreskuratze epe (PayBack-PB) arrunt adierazleak eraikin baten birgaitze prozesuaren hasierako inbertsioari (A1-A5 etapak) aurre egiteko beharrezko denbora (urteak) adierazten du. Interpretazio sinplifikatua eta azken erabiltzailearengana iristeko erraztasuna dela eta, gaur egun birgaitze estrategiak lehenesteko orduan gehienetakoa erabiltzen den adierazle ekonomikoa da. Hala ere, ondoren ikus daitekeen bezala, ebaluazioa bizi zikloaren ikuspegitik egiten denean berreskuratze epearen kalkulua zaildu egiten da, interpretazio ezberdineko egoerak sortuz.



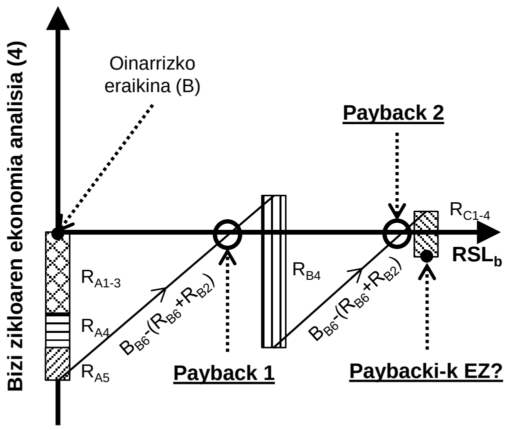
1-Birgaitutako eraikinaren erabilera bizitzan zehar (RSL_b) ez dago berreskurapen eperik. *(No Payback during the Reference Service Life (RSL_b) of the building).*



2-Berreskurapen epe bat eraikinaren RSL_b epean zehar. *(One Payback value during the RSL_b of the building)*



3- Ordezkatze etapan (R_{B4}) zehar eginiko inbertsio ekonomikoaren ondorioz, 2 berreskurapen epe balio ezberdin: hasierako inbertsio ekonomikoarentzat (PB_1) eta ordezkapen etapako inbertsioa kontuan eduki eta gero (PB_2). (*Due to the replacement investment, two different payback values: for the initial investment (PB_1) and after accounting the replacement impact (PB_2))*

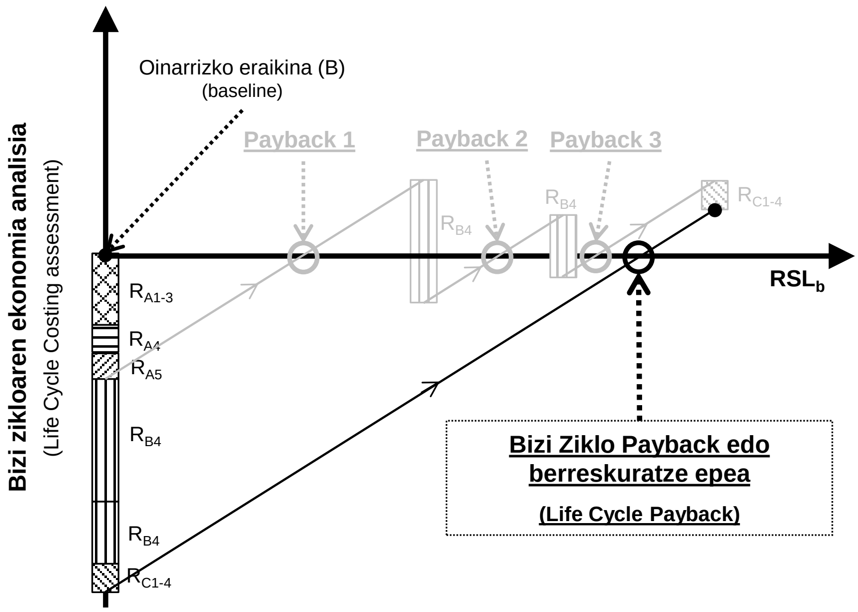


4- Eraikinaren RSL_b-an zehar 2 berreskurapen epe zehaztu arren, deuseztatze etaparen inpaktu ekonomikoa dela eta, azken emaitzak balio negatibo bat adierazten du. *(Although during the RSL_b of the building two different payback values are defined, due to the impact of the end of life stage, the final result shows a negative value.)*

Berreskuratze epe arrunt adierazleak sor ditzakeen arazo ezberdinak ikusirik, metodologia honek eraikin baten birgaitze prozesuaren bizi zikloan egin beharreko inbertsio ezberdinen kostuei aurre egiteko beharrezko denbora (urteak) zehazteko adierazle berri bat proposatzen du: Bizi Zikloko berreskurapen epea (*"Life Cycle Payback").* Adierazle berri hau 42. irudiko eskeman zehaztutako kalkulu irizpidean oinarritzen da. Irizpide berri honek birgaitutako eraikinaren bizi zikloan zehar egin beharreko inpaktu negatibo eta inbertsio ekonomiko ezberdinak azterketaren hasieran taldekatzea proposatzen du: hasierako inbertsioa ($R_{A1\text{-}5}$), ordezkapen ezberdinen kostua (R_{B4}) eta deuseztatze etaparen kostua ($R_{C1\text{-}4}$).

$$Bizi\ Ziklo\ PB\ = \frac{\sum \text{hasiera inbertsioak} + \sum \text{fluxu negatiboak}}{\sum \text{inbertsioaren ondoriozko urteroko fluxu positiboen batura}} \qquad (15)$$

Hasierako inbertsioaren balioa zuzenean zenbatuko da. Aldiz, beste etapetan zehar egindako inbertsio ezberdinen balioak zenbatzerakoan (ordezkapen eta deuseztatze etapa) inflazio tasak etapa hauengan izango duen eragina kontuan izango da, kostu ekonomiko ezberdinen inpaktua bizi zikloaren ikuspegi batetik landuz. Azkenik, egin beharreko inbertsio guztiak zenbatu eta taldekatu ondoren, birgaitutako eraikinak oinarrizko eraikinarekiko urtero murrizten duen inpaktu ekonomikoa kontuan hartzen hasten da (B_{B6}-(R_{B6}+R_{B2})). Erabilera etapa honetan izandako inpaktuen murrizpena zehazteko, ezinbestekoa izango da inflazioa (mantenu etapan) eta energia iturri ezberdinen prezioaren hazkundea (erabilera etapa) kontuan izatea.



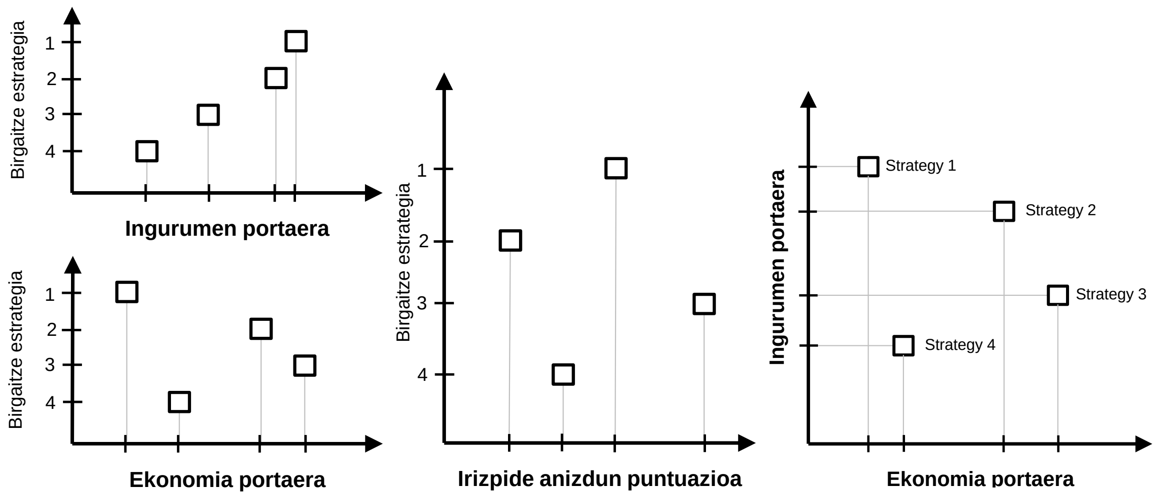
Irudia 42 Bizi Ziklo Payback edo berreskuratze epe balioa kalkulatzeko eskema. (*Scheme of the Life Cycle Payback value calculation*)

Metodologiaren azken zati honen 2. puntua **emaitzen erakusketan** datza. Irizpide anitzeko (ingurumen eta ekonomia inpaktuak lantzen baitira) sistema mota hauetan, 3 dira emaitzak erakusteko orduan erabiltzen diren aldagarri posibleak:

- **Banatua:** ingurumen eta ekonomia inpaktuak banatuta alderatzen dira. Nahiz eta emaitzen irakurketa eta adierazpena errazagoa izan, ingurumen eta ekonomia emaitzen arteko ezberdintasuna dela eta, aukera honek ikuspegi orokor batetik erabakiak hartzea zailtzen du.

- **Haztatze sistema:** haztapen sistema baten bidez, inpaktuen (ingurumen eta ekonomikoa) adierazle bakoitzari ehuneko balio bat aplikatzen zaio, birgaitze estrategia bakoitzaren ingurumen eta ekonomia portaera islatzen duen puntuazio bakarra lortuz. Hala ere, haztapen irizpide ezberdinek arazoak sor ditzakete birgaitze estrategiak lehenesteko orduan, partaide bakoitzaren helburuaren arabera inpaktuen (ingurumen eta ekonomia) adierazle bakoitzaren pisua ezberdinak izan baitaiteke.

- **Bateratuak:** ingurumen eta ekonomia inpaktuak azterketa bakarraren barruan ebaluatzen dira, baina banatuak. Horrela, informazio guztia ez edukitze edo haztapen sistemaren subjetibitatea bezalako aspektuak saihestearekin batera, erabiltzaileak emaitza bakarrean azterketaren informazio orokorra du.



1-Banatua *1-(Divided)* | 2-Haztatze sistema *(2-Weighting system)* | 3-Bateratua *3-(Unified)*

Metodologia honek 3. aukera erabiltzearen alde egiten du apustu (**3-bateratua**). Honen bidez, haztatze sistemak saihestu eta inpaktuak zenbatzean oinarritutako hainbat adierazlerekin osatutako sistema bateratu baten bidez, birgaitze estrategia ezberdinen artean lehenesteko aukera eskainiko du metodologia honek.

CHAPTER 5 – Validation of the methodology

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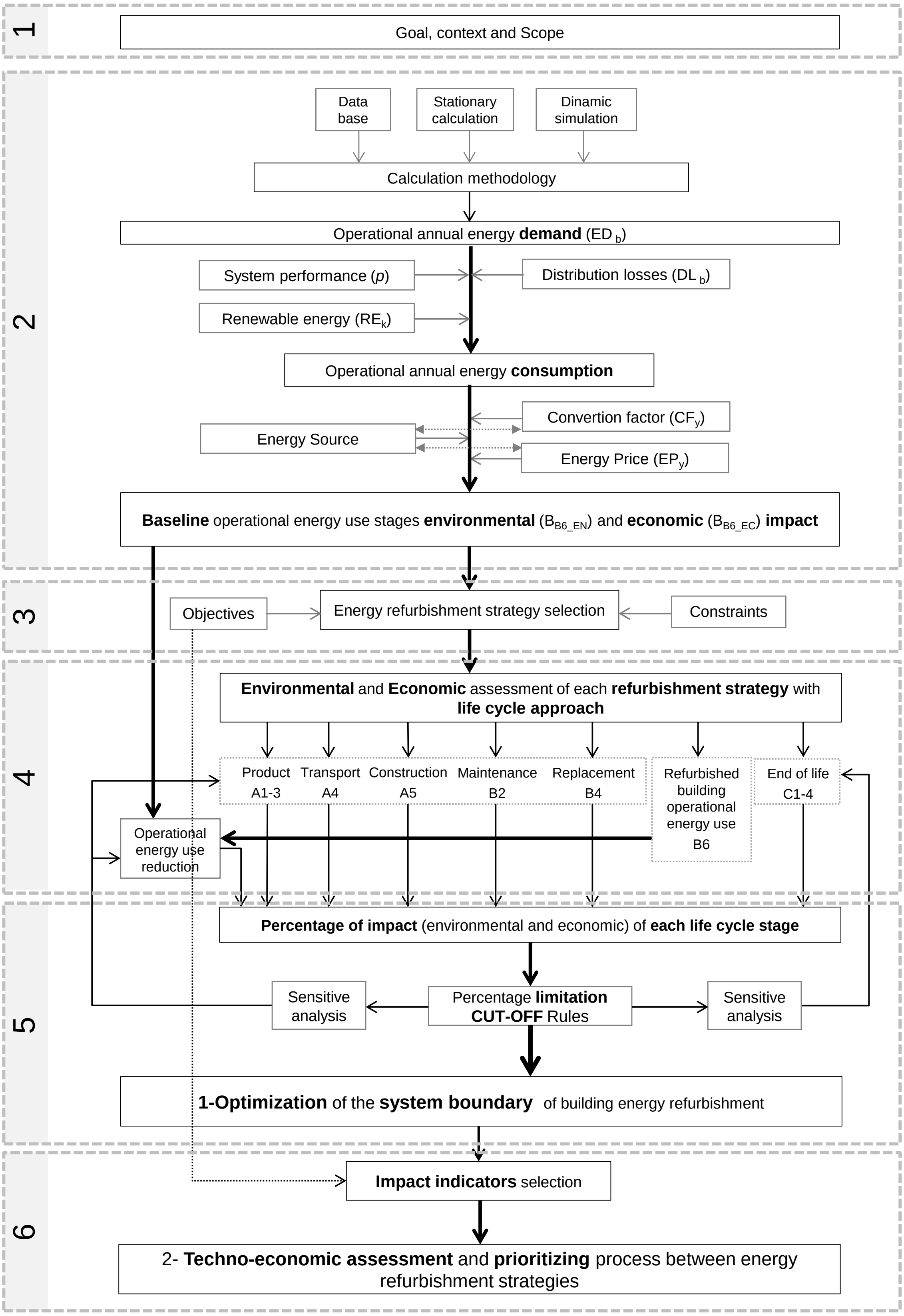
5 ATALA – Metodologiaren balioztatzea

5. Validation of the methodology



5.1. Goal, context and scope definition

5.1.1. Goal

This study is primarily aimed at validating the methodology suggested in section 4, thus proposing an optimal system that would allow for the prioritisation between different strategies for energy rehabilitation of buildings. In order for the results obtained in this validation to be replicated on existing buildings to a high extent, the **scope** of this study shall focus on evaluating a particular building type with high potential for energy rehabilitation: **residential buildings (multifamily) erected between the years of 1960 and 1980.** The selection of this building type as the one with the most energy rehabilitation and results replicability potential has been determined, among others, by three aspects or factors:

1- High percentage of residential buildings in the existing building sector.

2- High percentage of residential buildings located in consolidated urban spaces

3- High percentage of building sector erected between the years of 1960 and 1980, with a lack of insulation material and an inappropriate energy performance.

Buildings typology

It is estimated that there are 25 billion m^2 of useful floor space in the EU27 (*BPIE, 2011*). The residential stock is the biggest segment with an EU floor space of 75% of the building stock (see figure 43).

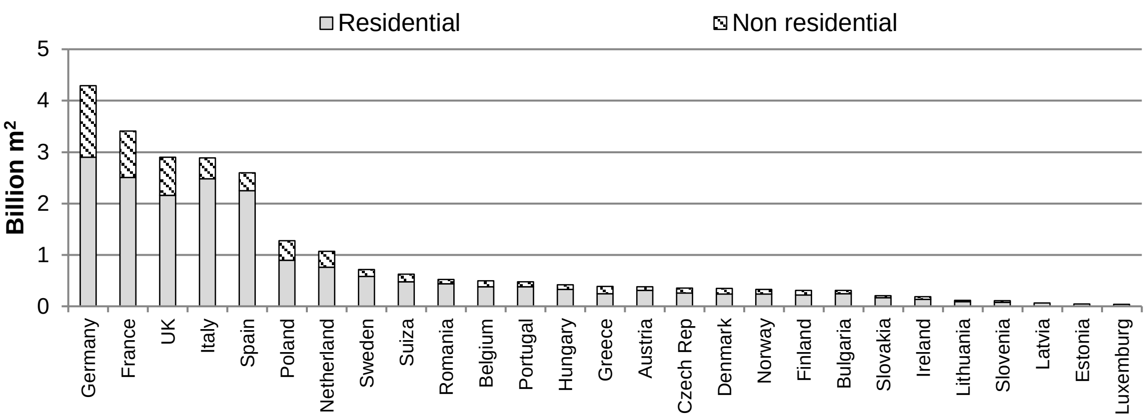


Figure 43 Floor space distribution per country. Source: Own elaboration with data from (*BPIE, 2011*).

Non-residential buildings account for 25% of the total stock in Europe and comprise a more complex and heterogeneous sector compared to the residential sector. The retail and wholesale buildings comprise the largest portion (28%) of the non-residential stock while office buildings are the second biggest category with a floor space corresponding to one quarter of the total non-residential floor space (23%). Variations in usage pattern, energy intensity, and construction techniques are some of the factors adding to the complexity of the sector.

Location

The location of buildings is of interest as typically the willingness and ability to take up renovation measures to improve energy performance can be affected by a number of factors including the location of a building. In the urban environment, economies of scale will come into play with large-scale renovation programmes able to act on streets, districts and localities: refurbishment with strategies such as district heating, seasonal thermal energy storages, large solar plants, cogeneration.... In rural environments, projects may be more widespread and hence benefit from economies of scale to a lesser extent while labour rates are often lower in these areas.

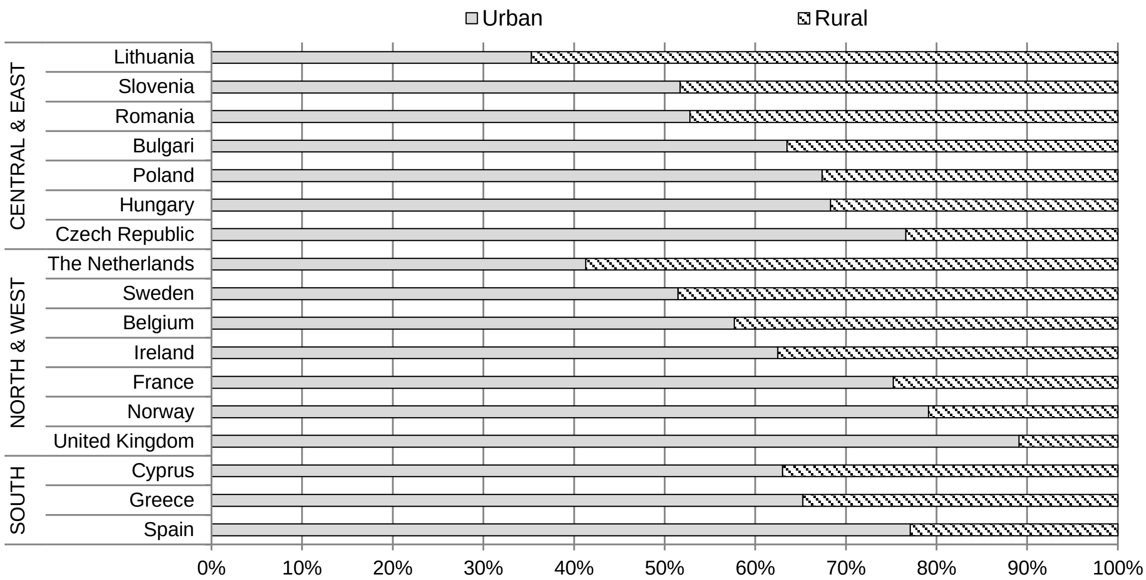


Figure 44 Location of residential buildings by number of dwellings. Source: Own elaboration with data from (*Nemry et al., 2008*).

As shown in figure 44, in the most populated European countries, including France, UK and Spain, 75%, 89% and 77% of the buildings respectively are located in consolidated urban areas, easing the implementation of new rehabilitation strategies and increasing the buildings' energy improvement potential.

Age

The age of a building is likely to be strongly linked to the level of energy use for the majority of buildings that have not undergone renovation to improve energy performance.

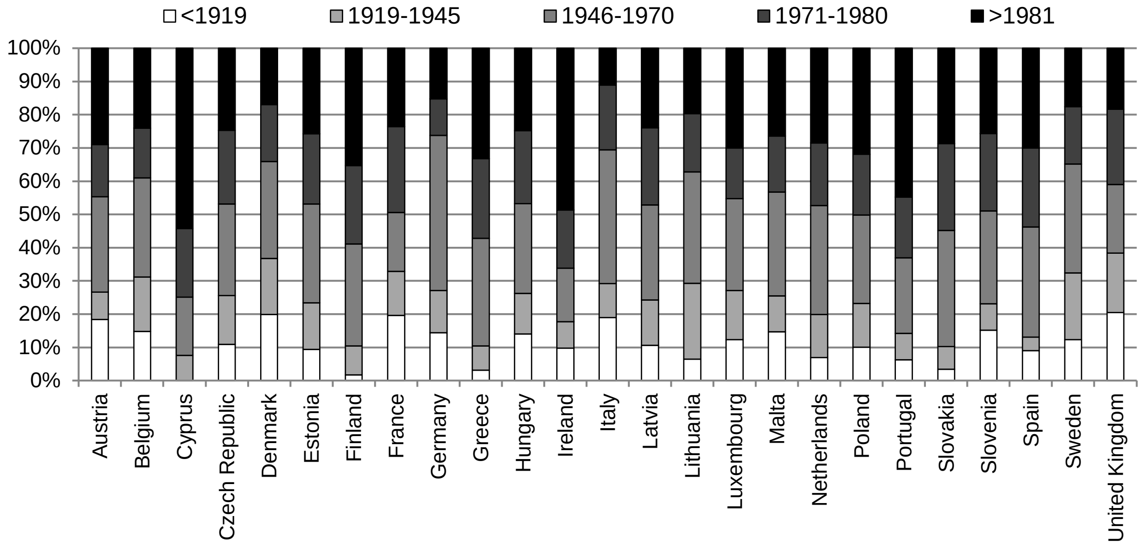


Figure 45 Age distribution of the housing stock. Source: Own elaboration with data from (*Boverket & MMR, 2005*)

The figure 45 shows that within the existing European stock, a large share (more than 50%) is built before 1970s: Germany (73%), France (50%), UK (59%), Italy (69%) and Spain (46%). That is, before there were few or no requirements for energy efficiency and only a small part of these have undergone major energy retrofits, meaning that, these have low insulation levels and their systems are old and inefficient.

One of the indicators that directly relates the age of the buildings with their energy performance is the thermal transmittance value (U value). As shown in figure 46, until the first oil stock of the 80s, thermal values of the elements that formed of the thermal envelope of buildings in the different European cities stayed constant, making the thermal behaviour of many of the buildings erected during that period inadequate.

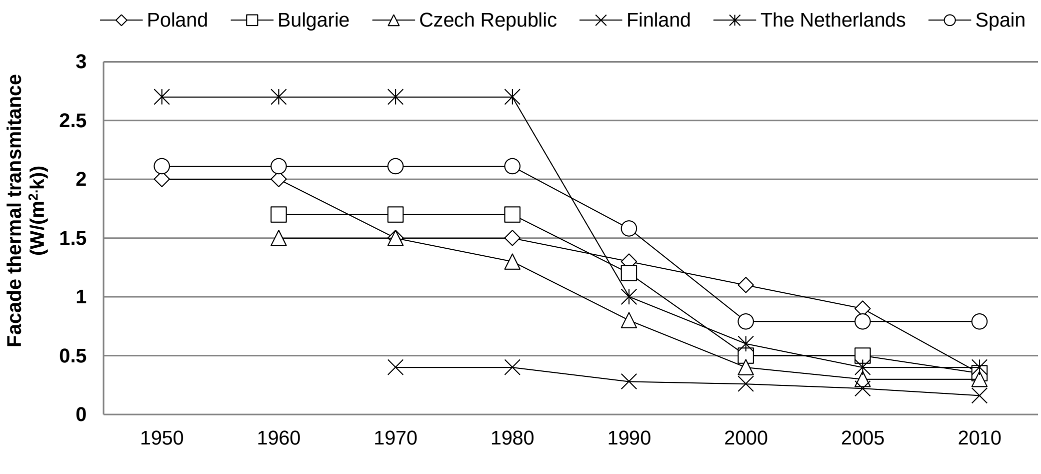


Figure 46 U values (W/(m^2·k)) for external walls in different countries for different construction periods. Source: Own elaboration with data from (*BPIE, 2011*)

From that date on, due to the growing concern about high dependence on fossil fuels and issues such as climate change, the European Commission began to propose and implement new policies and recommendations (see 2.3 section: *European building energy legislations*), integrating new requirements such as minimum values for the thermal transmittance of the different building's envelope elements. Along with this lack of thermal resistance of the building's envelope, power generation systems such as individual and central boilers and cooling systems of the vast majority of existing buildings, have inadequate characteristics, reason being their poor performance or distribution losses.

5.1.2. Context and need

This case study's selection process was carried out in order for the results to be extrapolated to other buildings, following the characteristics defined on the overall purpose of this study. After the evaluation of different buildings, the one selected for the validation of the proposed methodology is the residential block located in Isabel II Street (Amara neighbourhood, Donostia, Spain).

Before directly beginning to work on the building's environmental and economic evaluation and to suggest different rehabilitation strategies, first we should get to know the building's general context. In order to do so, there are two aspects that should be evaluated. All data obtained during this first stage is informative data that does not directly affect this thesis results nor its final conclusions. However, this type of initial context evaluation allows for detecting new needs, which shall avoid future problems for the building and the inhabitants themselves.

<u>Social context of the inhabitants of the building</u>

After conducting a survey among the building's inhabitants, the data obtained (see table 20) allowed for analysing aspects such as the inhabitants' social profile, their habits and environmental sensitivity, and their opinion on the structural condition of the whole building.

Table 20 Social context, environmental sensitivity and needs of the inhabitants of the building to assess

Social context	
Inhabitant per dwelling	1 (14%), 2 (47%), 3 (29%), 4 (8%) y 5 (2%).
Sex of inhabitants	Female (55%), male (45%)
Age of inhabitants	0-10 (3.4%), 10-30 (16%), 30-60 (32.6%), 60-80 (40.4%), >80 (7.6%)
Social profile	Student (11%), employee (31%), unemployed (12%), retired (46%)
Property	Property (90%), rent (10%)
Conclusions	High percentage of usable area of the dwellings unoccupied. 58.2% of inhabitants are retired or unemployment: economic limitations.

Habits and sensitivity to the environment	
Use of heating	Afternoon (64%), morning (26%), night (10%)
Ventilation	Morning (96%), everyday (92%)
Climate change	Concern 91.3%
Energy save	Important for 97.8% of the inhabitants
Dwelling orientation	They prefer: south (71%), west (12%), east (10%) and north (7%)
Conclusions	Appropriate habits to optimize the passive energy performance of the building High sensitivity on environmental and energy issues.
Conditions of the building and reforms carried out	
General conditions	Inadequate (52%), normal (42%) y adequate (6%).
Humidity	34% of dwellings
General refurbishment	61% considered necessary to reduce the energy consumption
Investment	62% of inhabitants were willing to assume spending to improve the general condition of the building
Reforms carried out	74% of inhabitant (78% change of windows)

Technical context of the building and its infrastructures

In the technical area, some other aspects that may have an influence on the rehabilitation strategy selected have been evaluated together with the constructive characteristics of the building.

- **Accessibility.** The accessibility of the building is adequate in its 3 levels: (1) approach to the building, (2) entrance to and movement inside the building; and (3) access to building services.

- **Internal building distribution.** The housing internal distribution is adequate, for all buildings have the necessary spaces and services to meet the inhabitant's needs in a healthy way. Therefore, no distribution performance within the building is suggested.

- **Lighting.** The lighting system of common areas, like stairs and entrance, are in very good condition (with integrated motion sensors) and all users have their own lighting elements in their houses.

- **Constructive characteristics.** With regards to the building's structural features, there are two types of studies which are carried out: visually and thermography. Visual evaluation allowed to detect that some houses had cracks and damp in a very advanced stage. Likewise, the outer envelope and the façade finish were in a very advanced stage of deterioration, which could lead to new problems to the users of such houses and to pedestrians. On the other hand, the envelope's thermographic analysis highlighted aspects such as high energy loss through the fronts of slabs and integrated pillars in the façade and the problematic heat loss through the heating system distribution pipes.

Figure 47 Image of a constructive problematic points of the current building and thermal bridges of front of slabs and integrated pillars in the facade. Source: Retegui & Altuna and Aurea Consulting

- Indoor thermal behaviour. According to the information provided by the building's inhabitants, the temperature of their homes was very low, especially in winter. Therefore, in order to be sure about the indoor thermal behaviour of each household, this study conducted a monitoring study by means of the installation of various air temperature measuring sensors. Therefore, sensors were installed in order to serve two objectives. On the one hand, a sensor was installed on the outside of the house, providing information about external temperature conditions. On the other hand, various air temperature sensors were installed inside homes that were located on different floors (preferably the top and ground floors, affected by the such heat loss through the floor and roof) and orientations (with different solar effect): house 1 (penthouse facing North), house 2 (middle floor facing Southeast), house 3 (middle floor facing North), house 4 (first floor facing West) and house 5 (first floor facing Southeast).

The internal temperature measurements on the existing building were taken between March and May 2011. The person responsible for this study states that these dates were not the most suitable for such measurement (winter time would have been preferable), but various project limitations made the choice of dates impossible.

Outdoor air temperature

As shown in figure 48, during the monitoring period, minimum outside temperatures never went lower than 8ºC and maximum outside temperatures almost reached 24ºC being 15.2ºC the average temperature for the evaluated period, which is a quite moderate temperature. That is, the evaluated period provides a quite moderate temperature scenario, with moments when the heating demand should be almost negligible.

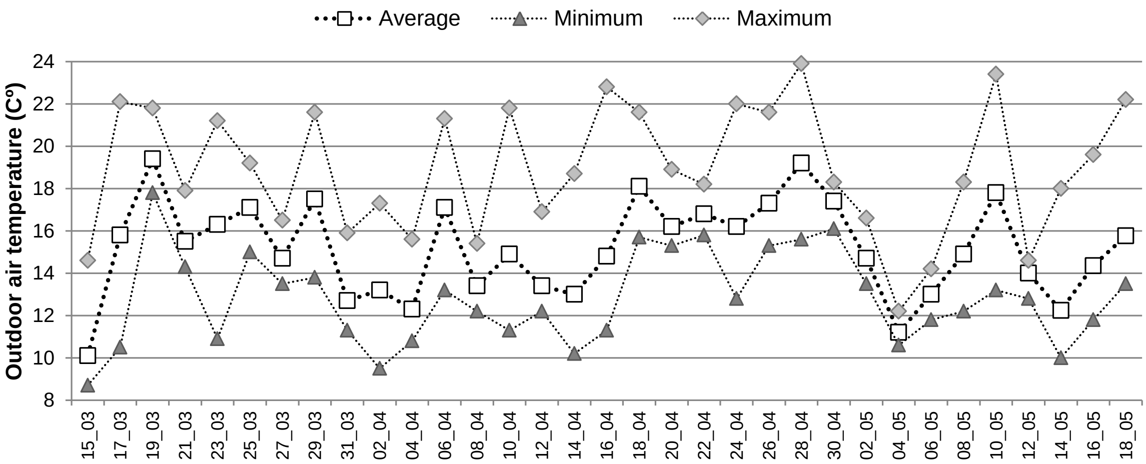


Figure 48 Outdoor dry bulb temperature (average, minimum and maximum) during the evaluation period.

<u>Indoor air temperature</u>

When evaluating the houses' room temperature, the study distinguished between three types of values: average, minimum and maximum indoor air temperatures, allowing for obtaining a bigger picture of the indoor air temperature. The first (see figure 49), shows the mean daily temperatures of the assessed houses, in order to obtain a primary estimate of the inhabitants' comfort degree in their homes (with regards to the air temperature parameter).

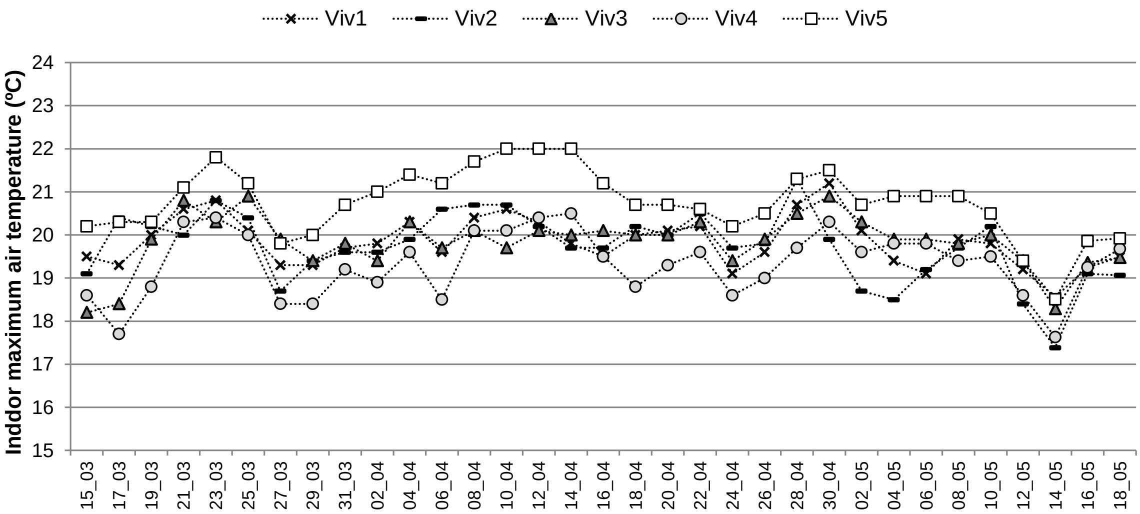


Figure 49 Daily average indoor air temperature of the evaluated dwellings.

This type of graph shows that:

- There is an average temperature difference of around 3-4ºC between the houses facing North and those facing South.

- Average temperatures of the houses located in lower and upper floors were around 2ºC lower than those located in intermediate floors.

- There were several homes in which the average indoor air temperature was never higher than 19ºC when outside temperatures did not exceed 10ºC.

The following section analyses minimum (see figure 50) and maximum (see figure 51) temperatures recorded in such houses during the evaluation period, in order to identify the most critical moments and their observable differences.

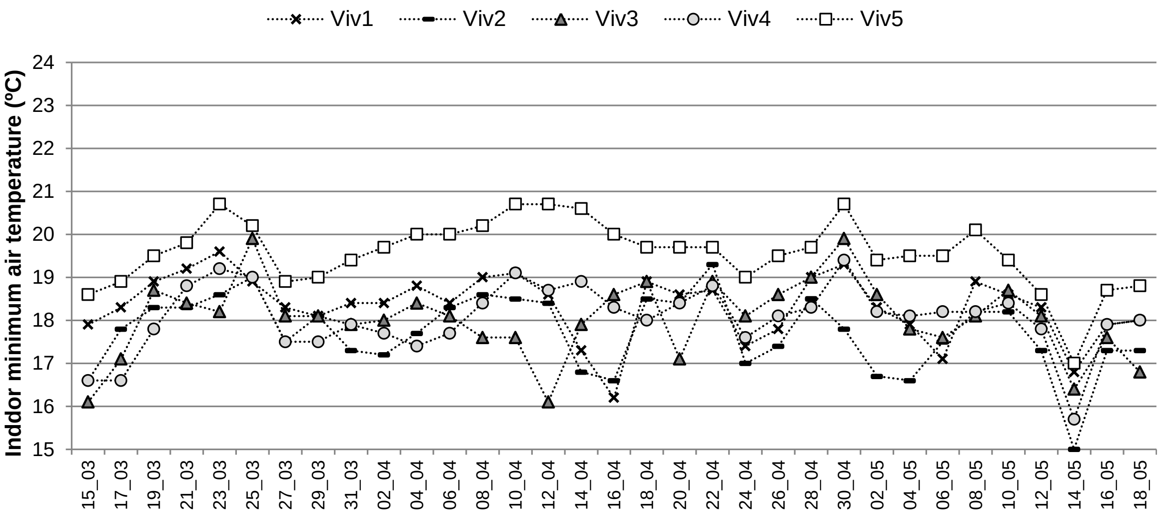


Figure 50 Indoor minimum air temperature of the evaluated dwellings.

The differences between the less-favoured dwellings, especially the attic that is most exposed to the North, in comparison with those with high solar incidence is remarkable, with differences of at least 4°C at the minimum daily temperatures.

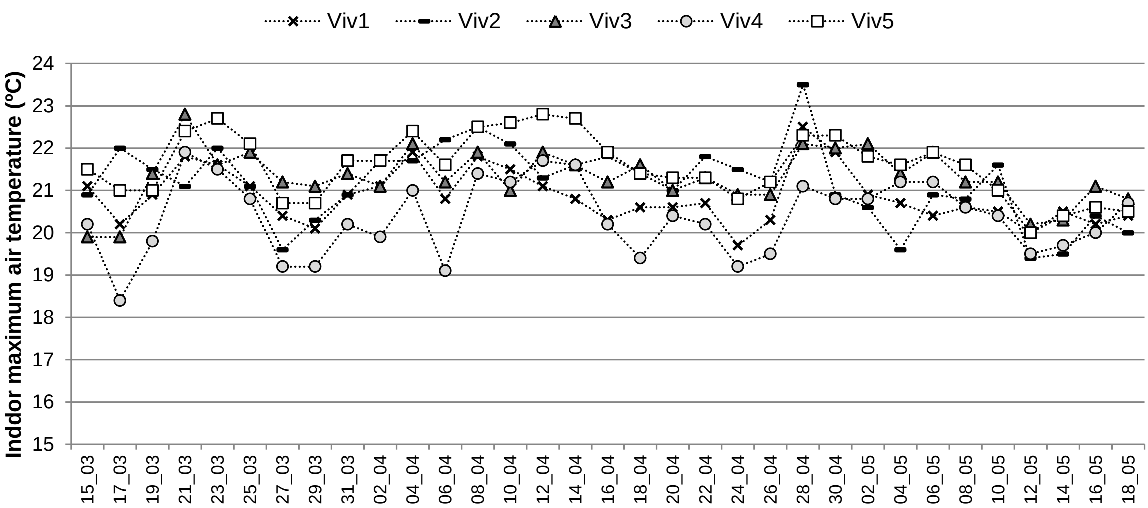


Figure 51 Indoor maximum air temperature of the evaluated dwellings.

With regards to maximum temperatures, figure 51 shows how one of the south-facing dwellings reached nearly 24°C (matching outside temperatures). Results of the studies carried out in other buildings during the monitoring period showed differences in maximum temperatures lower than 3ºC (except for some special points) and maximum room air temperatures within the range of 19-23ºC in most part of the points evaluated.

After evaluating the different temperature values monitored, it should be noted again that during the monitoring period, minimum outside air temperature was only below 10ºC in two occasions (which is not comparable to a winter day scenario). Because of the poor quality of the data obtained, it is very difficult to reach more objective conclusions with regards to the influence of each dwelling location or to the constructive characteristics of the existing building. In order to reach more detailed conclusions, it should be able to perform a 12-consecutive-month monitoring.

5.1.3. Scope

Functional unit

In the methodology's definition, table 9 shows how the different LCA and LCC studies performed on buildings have implemented numerous functional units, which were directly related to the purpose of each study. According to ISO 14040, "the functional unit is a measure of the function of the studied system". The main function of the dwelling building (residential) is certainly supplying a human habitation service, which can be directly correlated to the size of the living area (heated or cooled).

Therefore, during this study the functional equivalent used to compare the different refurbishment strategies is the building itself, analysed over its Reference Service Life (RSL_b) period and meeting the conditions of design requirements (thermal comfort, etc.). The results are expressed per year and per unit of living floor area. Other information:

- Occupancy schedule: based on the Spanish energy labelling. (*CTE, 2013)*
- Occupancy: 108 dwellings.

Refurbished building Reference Service Life (RSL_b)

A Reference Service Life (RSL_b) of 50 years from the date of refurbishment is considered, a value often used by default, since it is generally difficult to foresee the real life span of a building (*Malmqvist, 2011*).

System boundaries

Based on the methodology proposed during the section 4.1.3, following is defined the system boundary of a energy refurbishment evaluation with life cycle approach:

Baseline (existing building), option "A"	
B6	Operational energy use of the baseline.
Refurbished building	
A1-3	Production of refurbishment strategies product and systems
A4	Transportation of refurbishment strategies product and systems
A5	Construction process of refurbishment strategies.
B2	Maintenance of refurbishment strategies
B4	Replacement of refurbishment strategies product and systems
B6	Operational energy use of the refurbished building
C1-4	End of life of refurbishment strategies product and systems

Impact indicators

As shown by earlier literature reviews, (*Ramesh et al., 2010*), the operational energy use stage is the most environmental impact generating stage of a building's life-cycle, mainly because of the consumption of energy sources used to meet the comfort needs of the building's end users. This energy consumption is directly associated to the use of energy resources and the combustion of fossil fuels, leading to a higher CO_2 emissions impact.

Therefore, although the normative EN 15978 recommends the application of various impact indicators (see table 12), in order to focus this work on the building's scope and allow the end user to make decisions based on fewer indicators, this study shall only assess the environmental impacts (midpoint approach) of two of the most influential indicators of the building operational stage:

- "Use of Non-Renewable Primary Energy resources" (NRPE) in MJ-Eq/functional unit according to the CML method (*Guinée et al., 2001*).
- Glowal Warming Potential (GWP-100 years) in kgCO_2-eq/funtional unit according to the IPPC method (*IPCC, 2013*).
- Environmental impact assessment method: Midpoint approach.

For the economic assessment, this study is based on the evaluation of the economic indicator "Euro" (€). However, in order to prioritize between different refurbishment strategies, this methodology also applies other indicators such as the Internal Rate of Return – IRR (%) and Life Cycle Payback – LC_PB (years).

- Economic impact assessment method: Full Cost Accounting.

5.2. Baseline operational energy use stages environmental (B_{B6_EN}) and economic (B_{B6_EC}) diagnosis

With a total net floor area of 9484 m^2 and a heated surface of 8574 m^2 (living area), the building consists of a commercial ground floor and 9 residential floors (with 12 apartments on each floor), which are heated by a centralized natural gas heating system. All apartments are naturally ventilated and no cooling or renewable energy systems are installed. Since its construction (1963 year) and throughout its service life, the building has undergone two constructive-technological actions that have significantly improved its thermal-energy performance.

Figure 52 Reforms carried out: improve windows properties (a) and replacement of the heating generation centralized system (b)

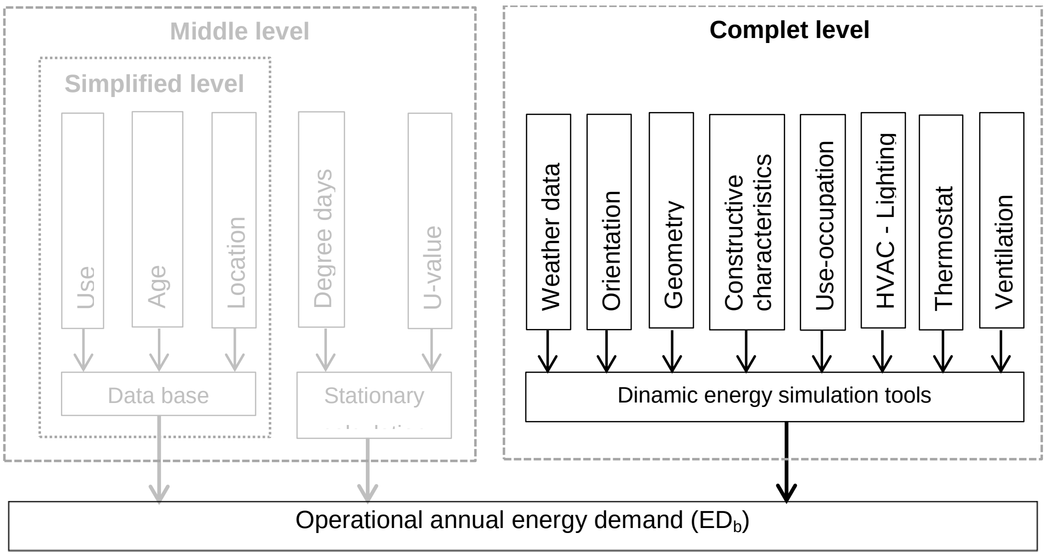
As mentioned in the questionnaire carried out to the building's inhabitants, the first action focused on the various renovations carried out in a great number of the original windows (about 40% of the windows have undergone some kind of improvement): some users replaced the entire window (installing a double glass and a new frame) whereas others opted for installing a double window (see figure 52a). The second action focused on the replacement of the communal oil boiler that supplied the entire heating system. During the years 2005-2006, the original boiler was replaced by a centralised installation of natural gas, which has a three section modular boiler with an 836.5 kW output (see figure 52b). In order to apply a scenario designed to be as realistic as possible, this work baseline shall reflect the "Current building", that is, the building with all its previous reforms.

5.2.1. Baseline operational annual energy demand (ED_b)

During their use phase, buildings require operational energy for meeting the demand for heating, cooling, hot water, ventilation, lighting and the use of appliances. Based on publications that show how energy consumption for heating is still one of the largest energy uses in residential buildings in Europe *(EEA, 2015)*, lots of studies focus all their efforts on evaluating the influence of energy rehabilitations in reducing the impact caused by heating consumption. However, due to this simplification, great part of the building's energy demand is outside the scope of studio. Therefore, in order to analyse the baseline's complete environmental and economic performance and to evaluate the influence of the different rehabilitation strategies application, this study evaluates all aspects that are associated with the building's energy demand and consumption.

	Heating	Cooling	DHW	Ventilation	Lighting	Appliances
Evaluated energy aspects	YES	YES	YES	YES	YES	YES

Due to all the information available with regards to the building, climatic zone, outdoor conditions, thermal performance, etc. this study's calculation process shall be based on the "Complete Level" calculation scheme that uses a dynamic energy simulation tool.



Using the Design Builder (*DB*) software and the International Weather for Energy Calculation (*ASHRAE*) file for the city of San Sebastian, final energy demand of the building before its refurbishment was estimated. Being an interface for Energy Plus, Design Builder is a dynamic energy simulation tool that generates detailed data about the energy performance of a building during 1 year by using real weather data as well as temporal aspects such as solar radiation, thermal mass or user occupancy. The building model developed replicates the real geometry (see figure 53), including overhangs, setbacks and the surrounding buildings. However, due to geometric approximations in the Design Builder model, the results could have an error or variation.

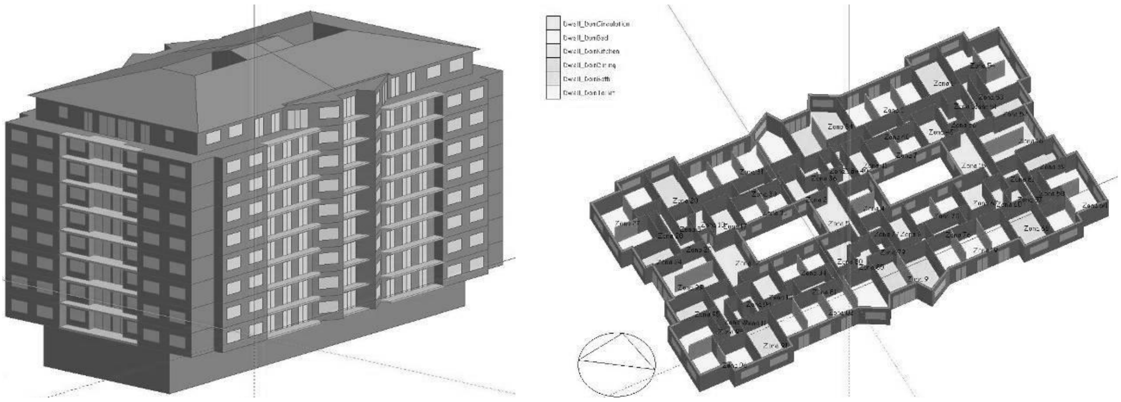
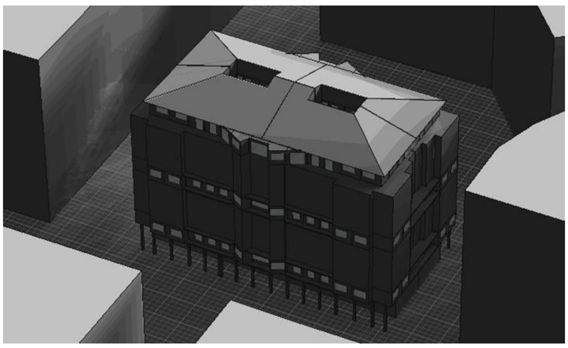


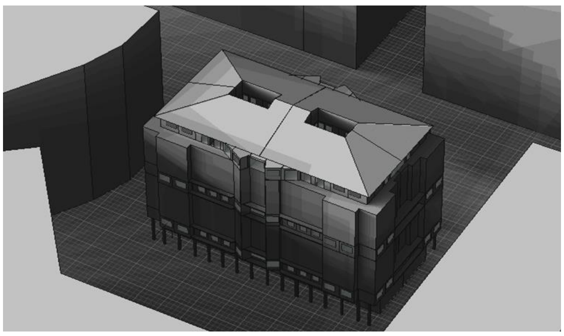
Figure 53 Render and floor distribution of the case study building in the Design Builder software. Source: (*Oregi et al., 2013*)

The building is located in Donostia-San Sebastian, where the annual average temperature is 14°C. In summer, the daily average temperature is below 20°C, so cooling systems are generally unnecessary, particularly if measures such as solar shading or night cooling are implemented. In winter, the daily average temperature is about 10°C, justifying the need for heating systems.

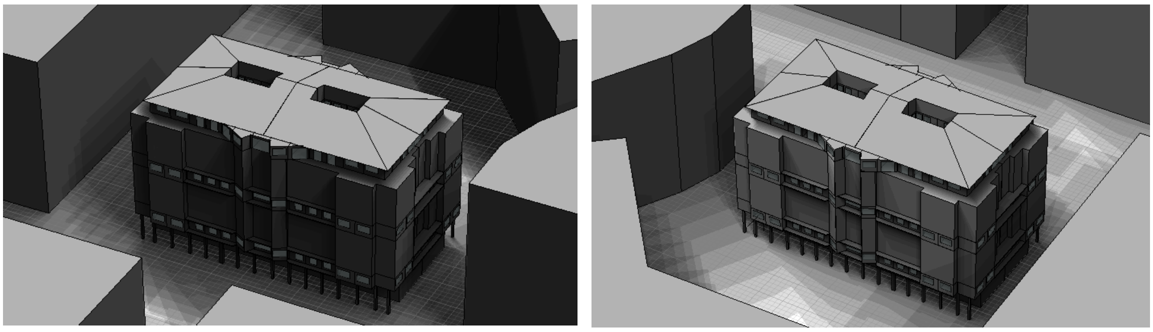
The building subject of the analysis is located in an urban area between 4 other buildings, so the shadows of adjacent buildings shall be considered to be a very important factor. As a result of the orientation of the studied building and the height of the adjacent buildings, only the houses located on the upper floors and southeast oriented receive a considerable direct solar radiation amount during the winter solstice. In summer, as it is to be expected, the two North facades barely receive any direct sunlight. On the contrary, the Southeast facade shall is exposed to such radiation, increasing the temperature difference between the different houses and reaching high room temperature values (as shown in the housing measurements section).



1 North and southwest facades, 21th December



2 North and southeast facades, 21 th December



3 North and southwest facades, 21 th June   4 North and southeast facades, 21 th June

Figure 54 Influence of the shadows by the surrounding buildings in the case study.

In order to determine the building's envelope constructive and thermal characteristics, this study has used the information obtained from the building's original plans and architectural memory. Table 21 shows the composition and the thermal transmittance value (U value) of the main elements of the baseline envelope, which do not meet the minimum requirements specified by current national (*CTE, 2013*) and local building regulations (*B.O. Gipuzkoa, 2009*).

Table 21 Composition and *U*-values (W/(m^2·K)) of the baseline building envelope. Source: (*Oregi et al., 2012*)

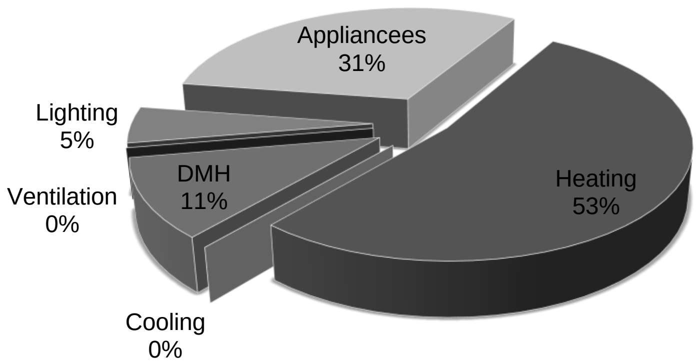
	Thickness (mm)	Density (kg/m^3)	Heat Conductivity (W/(m·k))	*U*-values (W/(m^2·K))
Cavity wall façade				
Exterior cement	10	1350	0.70	1.12
Double hollow brick partition	110	930	0.37	
Air layer	50	NA	Not Applicable (NA)	
Double hollow brick partition	110	930	0.37	
Gypsum plastering	10	825	0.25	
Reinforced concrete deck with ceramic finish				
Ceramic tile	20	2000	1.00	2.34
Air layer	50	NA	NA	
Reinforced concrete	200	2400	2.30	
Reinforced concrete first floor slab				
Reinforced concrete	250	2400	2.30	1.79
Air layer	500	NA	NA	
Gypsum plastering	15	825	0.25	
Window (68% of glazing and 32% of frame)				
Monolithic glazing (60%)	6	2450	*U-Value 5.7	4.71
Double glazing (40%)	10	2450	*U-Value 2.7	
Aluminium (Al) frame without Thermal Brake -TB (60%)	NA	NA	*U-Value 5.8	
Al frame with TB brake (40%)	NA	NA	*U-Value 4.2	

In order to develop the energy simulation by Design Builder, following current Spanish regulations (*CTE, 2013*), parameters like occupancy rate, schedules, and internal gains (see Table 22) have been estimated.

Table 22 Design Builder simulation parameters

Parameter	Unit	Value
Occupancy (dwellings)	People/m² (living area)	0.03
	Schedule	Until 07:00 (100%), Until 15:00 (25%), until 23:00 (50%), until 24:00 (100%)
Occupancy (ground floor)	People/m²	0
	Schedule	Until 24:00 (100%)
Heating system	Set point	21ºC
	Period	From 30 September to 31 May
	Schedule	Until 07:00 (Off), until 11:00 (On), until 18:00 (Off), until 23:00 (On), until 24:00 (Off).
Cooling system	Set point	25ºC
	Period	From 31 May to 30 September
	Schedule	Until 12:00 (Off), until 20:00 (On), until 24:00 (Off)
Domestic Hot Water	Quantity	50 liters/(person·day)
Ventilation (natural)	Air change per hour (r/h)	0.75
Ventilation (infiltrations)	Air change per hour (r/h)	0.1
Lighting (dwellings)	Illuminance level (lux)	300
	Installed power (W/m²)	7.5
	Schedule	Until: 07:00 (10%), until: 18:00 (30%), until: 19:00 (50%), until: 23:00 (100%), until: 24:00 (50%)
Lighting (common areas)	Illuminance level (lux)	100
	Installed power (W/m²)	3
	Schedule	Until 24:00 (On)
Lighting (ground floor)	Schedule	Off
Appliances	Installed power (W/m²)	4.4
	Schedule	Until: 07:00 (10%), until: 18:00 (30%), until: 19:00 (50%), until: 23:00 (100%), until: 24:00 (50%)

After introducing all the information in the Design Builder software, the baseline operational annual energy demand calculated according to these parameters are heating 240 MJ/(m^2·a), cooling 0 MJ/(m^2·a), Domestic Hot Water-DWH 50.2 MJ/(m^2·a), ventilation 0 MJ/(m^2·a), lighting 23.2 MJ/(m^2·a) and appliances 140.3 MJ/(m^2·a).



5.2.2. Energy efficiency of the energy generation system (ρ)

The heating thermal generation system is a centralised installation that works with natural gas and has a three section modular boiler with an 836.5 kW output. There are three independent heating circuits with a circulator pump and one only controller for the three circuits. Thanks to the regular maintenance and the proper adjustment of all the elements that define the system, the boiler combustion is appropriate, considering a nominal yield of 0.92.

With respect to the installation of thermal generators for DHW, each house has an electric thermos accumulator. In the case of individual systems, it is difficult to know the exact energy performance of each one of them. Therefore, this study suggests a nominal efficiency of 0.95 for all electric thermos accumulators (supposing that there is a 5% loss of efficiency due to the boiler aging and the houses' internal distribution).

Finally, regarding the lighting system and use of appliances, the building's electrical system performance is considered to be 100%.

5.2.3. Distribution losses (DL_b)

The heating system hot water distribution takes place inside the building's facade by means of an uninsulated duct system. As shown by figure 55 and due to such ducts and envelope's lack of insulation, this distribution system heat loss is huge. Therefore, even if the length of the distribution was reduced, 10% of the heat from the heating system is estimated to be wasted due to the inadequate insulation level of the distribution system.

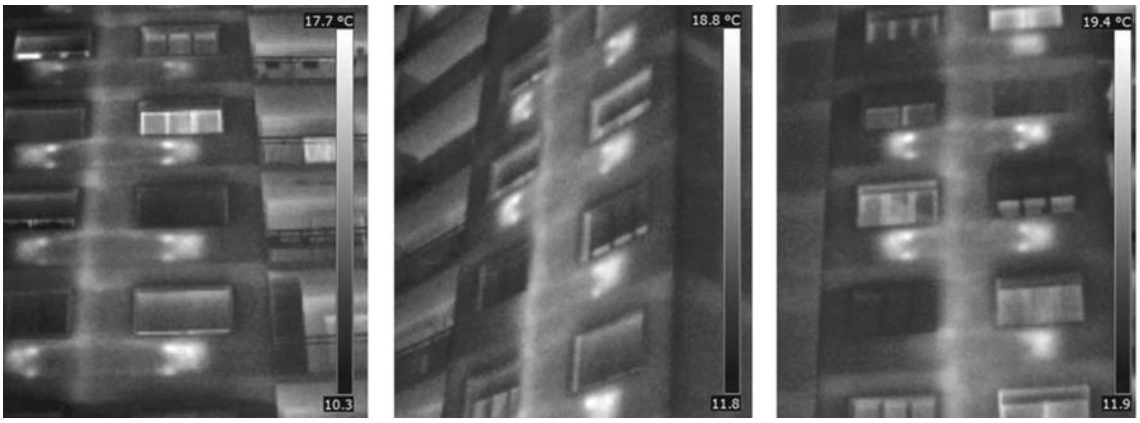


Figure 55 Energetic losses during the distribution circuit of the heating system of the case study

5.2.4. Renewable energy generated on the building site (RE_k)

The current building does not have any system of energy generation through renewable sources.

5.2.5. Baseline operational annual energy consumption

The baseline diagnosis was carried out with the help of a dynamic energy simulation tool and real energy consumption values of this case study are unknown.

5.2.6. Conversion factor (CF_y)

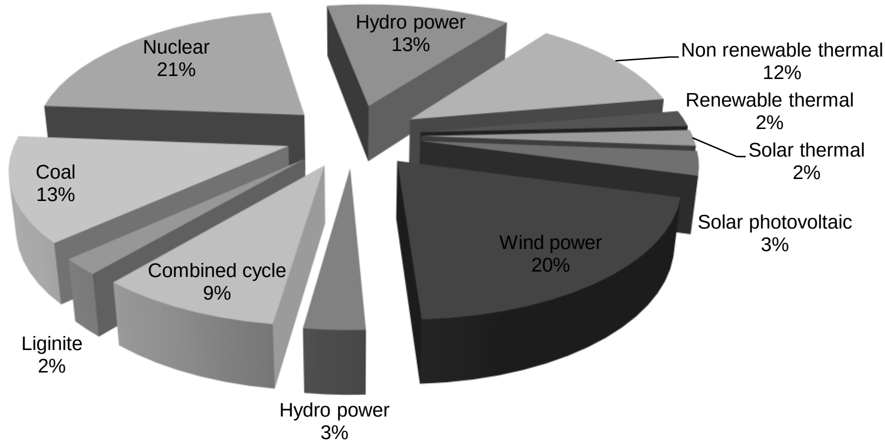
Through the correct definition of "conversion factor" values, the energy consumption, being for heating space or water, for cooling or for lighting is transformed into environmental impact. For the natural gas source (heating systems energy source), the related impacts were deduced from Ecoinvent database, applying the process "Heat production, natural gas, at boiler modulating (Europe without Switzerland), which has an energetic performance of 95.9%. The conversion factor from natural gas applied during this case study to Non-Renewable Primary Energy use (NRPE) will be 1.23E+00 (MJ/MJ) and to Global Warming Potential (GWP) will be 6.89E-02 (kg CO_2-eq/MJ).

However, in the case of the electricity mix (energy source for cooling, DHW, lighting and appliances), the calculation is more complicated; due to each Member State has a different electricity mix scheme. Electricity can come from various sources such as hydropower, nuclear power, coal, combined cycle, oil, wind etc, meaning that first we must find out what makes up the electricity supply is in each country. Therefore, the environmental loads assigned to electricity supply have been adapted respectively to the Spanish electricity mix for 2014 taking into account the data originated from "Red Eléctrica Española" (*REE*) (see table 23).

Table 23 Current electricity generation scenario in Spain (2014).

	Electric balance (GWh)	Percentage (%)	1 Kwh/1kwh electric*
Ordinary regime			
Hydropower	33,970	12.74	0.1396
Nuclear	56,827	21.32	0.2336
Coal (Coal 90% and lignite 10%)	39,807	14.93	0.1636
Combined cycle	25,091	9.41	0.1031
Special regime			
Hydropower	7,099	2.66	0.0292
Wind	54,344	20.38	0.2234
Solar photovoltaic	7,918	2.97	0.0325
Solar thermal	4,442	1.67	0.0183
Renewable thermal (co-generation)	5,066	1.90	0.0208
Non-renewable thermal	32,037	12.02	0.1317
TOTAL	266,601	100%	109.593

** The study has considered the different distribution losses of each energy source.*



After defining the scenario of the Spanish electricity mix, it is calculated the environmental impact of each of the different electricity generation processes (see table 24). For this purpose, this study has used the Ecoinvent v3.0 inventories, which consider the efficiency of the energy supply chain and the infrastructures (from cradle to grave).

Table 24 Ecoinvent processes of the different electricity generation scenarios.

	Process	Source	Electricity Allocation
Hydropower	Electricity production, hydro, reservoir, non-alpine región (Spain)	Ecoinvent v3.0	100%
Nuclear	Electricity production nuclear pressure water reactor (Spain). 75%	Ecoinvent v3.0	100%
	Electricity production, nuclear, boiling water reactor (Spain). 25%	Ecoinvent v3.0	100%
Coal	Electricity production, hard coal	Ecoinvent v3.0	100%
Lignite	Electricity production, lignite (Rest Of the World - ROW)	Ecoinvent v3.0	100%
Combined cycle	Electricity production, natural gas, combined cycle power plant (ROW)	Ecoinvent v3.0	100%
Hydro power	Electricity production, hydro, run-of-river (Spain)	Ecoinvent v3.0	100%
Wind	Electricity production, wind < 1MW turbine, onshore (Spain). 60%	Ecoinvent v3.0	100%
	Electricity production, wind, 1-3MW turbine, onshore (Spain). 40%	Ecoinvent v3.0	100%
Solar photovoltaic	Electricity production, photovoltaic, 570kWp open ground installation, multi-Si (Spain)	Ecoinvent v3.0	100%
Solar thermal	Electricity production, wind, 1-3MW turbine, onshore. GWP impact based on the study of Burkhardt (*Burkhardt et al.,2012*)	Ecoinvent v3.0	100%
Renewable thermal	Electricity, heat and power co-generation, wood chips, 6400kw thermal (Spain). 70%	Ecoinvent v3.0	25%
	Electricity, heat and power co-generation, biogas, gas engine (Spain). 19.2%	Ecoinvent v3.0	25%
	Electricity, treatment of municipal solid waste, incineration (Spain). 10.8%	Ecoinvent v3.0	25%
Non-renewable thermal	Electricity production, hard coal (Spain). 0.5%	Ecoinvent v3.0	36%
	Heat and power co-generation, natural gas, 1MW electrical, lean burn (Europe). 90.5%	Ecoinvent v3.0	38.2%
	Electricity production, oil (Spain). 9%	Ecoinvent v3.0	39%

After applying each of the different energy processes and consider the amount of energy of each process that is applied to generate 1 kWh of electricity (see annex 7.5.2), the conversion factor from electricity (Spain 2014) applied during this case study to Non-Renewable Primary Energy use (NRPE) will be 1.74E+00 (MJ/MJ) and to Global Warming Potential (GWP) will be 6.32E-02 (kg CO_2-eq/MJ).

5.2.7. Energy Price (EP_y)

As seen in section 4.2.7, each Member State sets its own prices and rates for the different energy sources. Based on the information from Eurostat (see figure 53 and figure 34), this work has applied the values (all taxes and levies included) for the final energy cost of the country of this case study. (Spain).

- Natural gas:0.0209 €/MJ
- Electricity: 0.0625 €/MJ

5.2.8. Energy Price Increment (EPI_y)

Projects such as "Concerto" proposed to use the increase rate of approximately 5% per year (*Capros et al., 2010*), while other studies (*Vrijders & Wastiels, 2013*) applied an increase of 2.25%. Due to the uncertainty and the different scenarios of evolution of energy price, based on the information defined in section 4.2.8, this case study determines that household electricity prices will rise 4% a year and natural gas 3% a year.

5.2.9. Results

Table 25 shows the baseline operational energy use stages environmental and economic impact value obtained by the application of equations 1 and 2.

Table 25 Results of the baseline operational energy use stages environmental and economic diagnosis

	Impact indicator	**Impact values** (per $m^2 \cdot a$)				
		Heating	**DHW**	**Lighting**	**Appliances**	**Total**
Environmental	GWP (kg CO_2-eq)	1.9E+01	3.3E+00	1.5E+00	8.8E+00	3.3E+01
	NRPE (MJ)	3.5E+02	9.2E+01	4.1E+01	2.4E+02	7.3E+02
Economic	Euro (€) (50years)	13.53	10.08	4.43	26.77	54.81

The calculation results show how the main point of impact of the two environmental impact indicators defined above, is heating consumption, which accounts for 59% (GWP) and 49% (NRPE) of the overall impact. Regarding the other points of energy consumption, DHW is responsible for 10% (GWP) and 13% (NRPE); lighting for 4%

(GWP) and 6% (NRPE); and the use of appliances reaches up to 27% (GWP) and 33% (NRPE) of the overall building's impact. Economic impact readings reflect that heating is responsible for 31% of the economic impact during the building's use stage, whereas DHW, lighting and the appliances use are responsible for 17%, 7% and 45% respectively.

Example for calculating the environmental and economic impact

$$B_{B6\_EN} = \sum_{n=1}^{RSL_b} \left(\sum_{m=1}^{m=k} \left[\left(\frac{ED_b}{\rho_m} + DL_b - RE_y \right) \times CF_x \right] \right) \Big/ FU \quad (1)$$

$$B_{B6\_EC} = \sum_{n=1}^{RSL_b} \left(\sum_{m=1}^{m=k} \left[\left(\frac{ED_b}{\rho_m} + DL_b - RE_y \right) \times EP_y \right] \times \left[1 + EPI_y^n \right] \right) \Big/ FU \quad (2)$$

Table 26 Summary of the different parameters that allow to assess the baseline environmental and economic impact calculation

	ED_b (MJ/(m^2·a))	*p* (%)	DL_b (%)	RE_k (MJ/(m^2·a))	Energy source	Price increment (%)
Heating	240	92	10	0	Natural gas	3
Cooling	0	-	-	-	-	-
DHW	50.2	95	0	0	Electricity	4
Ventilation	0	-	-	-	-	-
Lighting	23.2	100	0	0	Electricity	4
Appliances	140.3	100	0	0	Electricity	4
Reference Service Life period (RSL_b) = 50 years						

$$B_{B6\_EN} = \frac{\sum_{n=1}^{n=50} \left(\left(\frac{240}{0.92} + \left(\frac{240}{0.92} \times 0.1 \right) \right) \times 1.23 \right) + \left(\left(\frac{50.2}{0.9} + \frac{23.2}{1} + \frac{140.3}{1} \right) \times 1.74 \right)}{50} = \mathbf{729}\ MJ/(m^2 \cdot \mathrm{a})$$

$$B_{B6\_EC(b)} = \frac{\sum_{n=1}^{n=50} \left(\left(\left(\frac{240}{0.92} + \left(\frac{240}{0.92} \times 0.1 \right) \right) \times 0.02 \right) \times (1 + 0.03^n) \right) + \left(\left(\left(\frac{50.2}{0.9} + \frac{23.2}{1} + \frac{140.3}{1} \right) \times 0.06 \right) \times (1 + 0.04^n) \right)}{50} = \mathbf{54}\ €/(m^2 \cdot \mathrm{a})$$

5.3. Energy refurbishment strategies selection

Once the baseline impact is evaluated, this study aims to define the initial objectives, assess limitations and thus suggest different strategies for energy rehabilitation that would reduce the environmental and economic impact of the current building.

5.3.1. Objectives

Along with addressing the building's current constructive deficiencies, the different energy rehabilitation strategies shall be aimed at reducing the environmental and economic impact of the baseline during its life cycle.

5.3.2. Constraints

In accordance with the methodology's suggested scheme, 5 shall be the aspects allowing for this case study's limitations evaluation.

- **Municipal regulations / ordinances.** In accordance with the Land-use planning of the municipality of San Sebastian, this building does not have any degree of conservation. The building Isabel II 21-23-25 is not registered and has a low degree of architectural value, so there are no limits when it comes to replacing the image (colours and finishes) of the existing building. On the contrary, governing laws establish that the overall composition of the building shall be kept intact, keeping the size, arrangement and geometry of the envelope's windows and balconies.

- **Geographic.** There are no geographical limitations when it comes to rehabilitating the elements of the building envelope.

- **Technologic and refurbishment strategies.** When defining technological limitations, it is noteworthy that this is an isolated energy rehabilitation study, making it impossible for the implementation of other types of strategies such as district heating, waste heat recovery or o seasonal thermal storage systems. In this case study, thanks to the adequate performance of the thermal generation systems (the boiler was renovated during the years 2005-2006), an overall system replacement is not considered pertinent, unless it's being replaced for a bioenergy system.

- **Economic.** Due to uncertainty and casuistry in each Member State, the provision of financial aid by each administration shall not be considered for this case study. However, it should be mentioned that currently (in Spain) there are economic aids, tax deductions, 0% interest credits, etc. that may foster the implementation of different energy rehabilitation strategies. Moreover, being a theoretical study, no limit value on the on return period and return on investment has been defined.

- **Social**. No social group put up against the energy rehabilitation performance of this case study.

5.3.3. Building energy refurbishment strategies

In order to reduce the environmental and economic impact related to the building's heating, DHW, lighting and appliances energy use, different energy refurbishment strategies have been evaluated during this study, taking into account that the area where the case study is located shows no historic, urban or architectonic restrictions, allowing direct refurbishment actions on all the envelope elements. As shown in table 27, the reduction of each energy aspect is directly linked to one or more actors: inhabitant behaviour (1), refurbishment designer or technician (2), and industry or technology producer (3).

Table 27 Different strategies to reduce the environmental and economic impact generated during the use stage of the building and the actors involved in them

	Refurbishment Strategy	**1**	**2**	**3**
Heating - Cooling	Improve the thermal characteristics of the envelope		x	x
	Reduce the air infiltrations (adequate construction process)		x	
	Application of new and innovative systems and materials to improve the thermal performance of the envelope and reduce the degree of infiltration.			x
	Application of new energy generation systems with better performance.		x	x
	Application of power generation systems through renewable systems.		x	x
	Regulation of energy systems.	x	x	
	Reasonable use of the dwelling by the inhabitant	x		
DHW	Application of new energy generation systems with better performance		x	x
	Application of power generation systems through renewable systems.		x	x
	Application of reductiono systems	x	x	x
	Reasonable use of the DHW by the inhabitants	x		
Lighting	Reasonable use of the lighting by the inhabitants	x		
	Strategies to increase the use of natural lighting		x	
	Application of new luminaires with better performance	x		x
Applianc es	Application of new appliances with better performance (directly related to Energy policies and Eco-Label regulations			x
	Reasonable use of the appliances by the inhabitants	x		

It should not be forgotten that the building's inhabitants sensible use and personal decisions (fully linked to their social status, economic capacity, sensitivity, training, health, demographic profile, etc.) shall be taken into consideration at all times (1) for they are essential for the improvement of a property's environmental and economic performance. However, the difficulty in evaluating such a subjective aspect as the inhabitants' behaviour makes it difficult to technically quantify the influence of these strategies with respect to the baseline building. Therefore, this work does not conceive the possibility of integrating strategies based on aspects such as the influence of the inhabitant's awareness increase in the reduction of the final energy consumption.

Refurbishment strategies will be applied to the case study in there efficiency levels. The basic efficiency level is based on restoration strategies that enforce the minimum thermal requirements determined by the existing regulations and standards. The efficient efficiency level is based on restoration strategies that improve the thermal properties and renewable generation minimum requirements determined by the existing regulations in a 30%. Finally, the advanced efficiency level strategies improve the thermal properties and renewable energy generation quantities, adding insulation to very high values such as those used in standards like the Passive House (*IPHA*) and increasing the renewable energy generation in 50% respect the mínimum requirements.

Another variable considered for defining refurbishment strategies has been the type of material used, which is important for the life cycle performance particularly in relation to their embodied environmental impact. The strategies have been subsequently divided also by the employment of low and high embodied environmental impact materials (insulation materials). Table 29 details the strategies chosen.

The first strategy focuses on the replacement of all existing windows with a new frame and glazing. The windows for the basic energy efficiency level (1b) consist of a double glazing (2.7 W/(m^2·K)) and aluminum frame (2.9 W/(m^2·K)), meeting the minimum thermal requirements for refurbishments in Spain. The windows for efficient level (1e) consist of a low-emissivity coated glazing (2.0 W/(m^2·K)) and PVC frames (2.0 W/(m^2·K)). Finally, the windows for advanced level (1a) consist of a low-emissivity coated glazing (1.4 W/(m^2·K)) and wooden frames (1.2 W/(m^2·K)).

The second solution is a ventilated facade system, which is composed of an aluminum substructure, a layer of insulation and a ceramic outlayer. The third strategy is an external insulation system composed of an insulation layer and mortar outlayer. The fourth strategy is an indoor thermal improvement solution consisting of a layer of insulation and plasterboard. Finally, the fifht strategy is an air chamber insulation injection solution composed of an insulation layer (see more information in table 28).

According to the efficiency level parameter, different insulation thicknesses are proposed for basic, efficient and advanced levels. The projected insulation thicknesses for the basic efficiency energy level are 5 cm for the façade, 8 cm for the deck and 6 cm for the first floor slab. The thicknesses proposed for the efficient and advanced energy efficiency level are 9(e)-25(a), 13(e)-30(a) and 10(e)-15(a) cm, respectively. Regarding the aluminum profile of the ventilated façade, 10.2 cm^2 of aluminum per m^2 is projected for the basic level, 20.3 cm^2 for the efficient level and 49.6 cm^2 for the advanced level. Strategies with low embodied energy insulation apply wooden fiber and high embodied energy strategies apply Extruded Polystyrene (XPS) insulation. Regarding the other products that make up the three systems (outlayer, mortar and plasterboard), their properties and quantities are maintained in all cases. It should also be highlighted that secondary products that form part of these strategies, such as screws, sealants, glues are not considered within the scope of the study.

Table 28 Main characteristics of the different energy refurbishment strategies of the building envelope

Ventilated facade (2) and External insulation systems (“3”)	
Strengths	It allows to work when the interior of the dwelling is inaccessible It allows to the change in appearance of the facade. It does not reduce the indoor usable space. It increases the life and value of the building It reduces the effect of thermal bridges It minimizes the risk of interstitial condensation It optimizes the use of the thermal inertia It fixes cracks and fissures, preventing possible leaks
Weaknesses	The thickness of the envelope is increased, creating possible problems with regulations fficult to apply in buildings with a degree of protection
Indoor thermal improvement (“4”)	
Strengths	It allows to realize partial refurbishments No scaffolding systems are required It maintains exterior aesthetics It solves thermal bridges integrated into the facade
Weaknesses	Decreases interior space It does not solve all the thermal bridges High risk of possibility of condensation forming
Air chamber insulation injections (“5”)	
Strengths	It provides thermal insulation and rigidity to the façade Very useful in façades of double brick
Weaknesses	Waterproofing of the envelope is not guaranteed Need to use a thermal camera to ensure its adequate implementation Necesidad de usar una cámara termográfica para asegurar su adecuada aplicación

Along with energy conservation refurbishment systems, this work evaluated different strategies based on the use of energy from renewable sources. The first renewable strategy focused on designing a solar thermal system on the roof of the building, which uses solar energy to generate heat that is then used to produce hot water for Dwelling Hot Water (DHW), allowing for directly reducing the electric consumption of current thermos accumulators. Due to the physical limitations for the placement of any additional storage tank, this case study established the condition under which the DHW fraction covered by the solar thermal panel system shall not exceed 95% of the demand of any month. According to the efficiency level parameter, different thermal generation requirements are proposed for basic, efficient and advanced levels. The percentage of generated energy for the basic efficiency energy level is 30% of the DHW demand (mínimum requirement defined by the current regulations), while for the efficient level is proposed to generate enough energy to meet 45% of demand for DHW. For the advanced level it is proposed to increase the surface area of the solar panels to the defined limit for the proposal: 95% maximum generation. Once all calculations had been made (see annex 7.5.1), this study designed a system made up from 75, 110 and 140 m^2 thermal solar panels for the basic, efficient and advanced efficiency levels respectively.

The second renewable strategy aimed to integrate photovoltaic panels on the roof of the building, generating and exporting electricity from a renewable source to the national grid. Thus, the implementation of this strategy reduced the power consumption from non-renewable source, decreasing the environmental and economic impact of the whole building. According to the efficiency level parameter, different photovoltaic panel areas are proposed for basic, efficient and advanced levels. The implementation of power generation systems in energy rehabilitation performances is not mandatory. Therefore, this study does do not suggest any photovoltaic panel system for this basic level study. The projected photovoltaic panels' area for the efficient energy level are 120 m^2, while for the advance level are 400 m^2.

** Due to Spanish electric policies, this study does not suggests self-consumption of the generated electricity*

Finally, the last refurbishment strategy is focussed on the changing of the heating generation system, where this study proposed to replace the existing natural gas boiler by a biomass boiler with a power of 180kW (it is proposed to maintain one module of the gas boiler for peak periods).

Bearing in mind the building's use (residential) and the direct influence of each inhabitant's behaviour, this work does not suggest any strategy to reduce the impact generated by lighting or appliances use. However, if the building was intended for tertiary use, the end user's influence on the building's energy control would be lower. Thus, this type of building allows for suggesting strategies such as the integration of lighting systems with natural light control or the replacement existing lights and appliances by others with better features.

Table 29 Set of energy refurbishment strategies applied in this case study

Strategy	Efficiency level	Embodied environmental impact of products	Strategy ID
Window replacement (1)	Basic (b)		1b
	Efficient (e)		1e
	Advanced (a)		1a
Ventilated façade (2)	Basic	Low (l)	2bl
		High (h)	2bh
	Efficient	Low	2el
		High	2eh
	Advanced	Low	2al
		High	2ah
External Insulation System (3)	Basic	Low	3bl
		High	3bh
	Efficient	Low	3el
		High	3eh
	Advanced	Low	3al
		High	3ah
Internal (4)	Basic	Low	4bl
		High	4bh
	Efficient	Low	4el
		High	4eh
	Advanced	Low	4al
		High	4ah
Air chamber (5)	Basic	Low	5bl
		High	5bh
	Efficient	Low	5el
		High	5eh
	Advanced	Due to the air chamber dimensions, not applicable	
Solar thermal panels (6)	Basic	-	6b
	Efficient	-	6e
	Advanced	-	6a
Photovoltaic panels (7)	Efficient	-	7e
	Advanced	-	7a
Biomass boiler (8)	-	-	8

5.4. Environmental and economic assessment of each refurbishment strategy with life cycle approach

After obtaining the baseline environmental and economic impact and determining the different energy rehabilitation strategies, this section of the methodology shall evaluate the impact (environmental and economic) of each life cycle stage of the refurbished building. On the one hand the (negative) impact generated by each rehabilitation strategy shall be evaluated and, on the other hand, the new impact of the rehabilitated building's operational energy use stage shall be quantified by each of these strategies.

5.4.1. R_{A1-3}. Initial Embodied Environmental Impact (IEE_{A1-3}) and Initial economic Cost (IC_{A1-3})

The initial embodied environmental impact associated with the production phase of each product and system has been calculated applying Equation 4a and using process data from Ecoinvent and GaBi databases as well as Environmental Product Declarations (EPD) issued by manufacturers (see table 30).

Table 30 Processes and EPDs used to quantify the environmental impact of each product and process included in the life cycle assessment. More information in annex 7.5.2

Product / process	Source	Unit
Double glazed	INIES – FDES SGG Climaplus (Saint-Gobain, 2011a)	m^2
Double glazed low-e	INIES – FDES SGG Climaplus	m^2
Triple glazed	INIES – FDES SGG Climatop (Saint-Gobain, 2011b)	m^2
Aluminium frame	Ecoinvent. Window frame, aluminium, at plant	m^2
PVC frame	Ecoinvent. Window frame, plastic (PVC), at plant	m^2
Wood frame	Ecoinvent. Window frame, wood, U=1.5 W/m^2·K, at plant	m^2
Aluminium sub-structure	CERTIFIED. Extruded aluminium industry-average	kg
Insulation (high)	IBU. FPX - Fachvereinigung Polystyrol-Extruderschaumstoff (*IBU, 2014a*)	m^2
Insulation (low)	IBU. GUTEX Holzfaserplattenwerk H. Henselmann GmbH + Co KG (*IBU, 2015*)	m^3
Outlayer	GaBi. Ceramic façade panels – NBK Ceramic PE (2008)	m^2
Mortar	Ecoinvent. Cement mortar, at plant	kg
Plasterboard	Ecoinvent. Gypsum plaster board, at plant	kg
Solar thermal panel	Ecoinvent. Flat plate collector, at plant	m^2
Photovoltaic panel	Ecoinvent. Photovoltaic panel, mono-Si, at plant	m^2
Boiler	Ecoinvent. Gas boiler, RER	unit
Transport-truck	GaBi. Articulated lorry (40t) incl. fuel ELCD (2005)	t·km
Landfill	GaBi. Landfill for inert matter (construction waste) (2010)	kg
Disposal, hazardous waste	Ecoinvent. Disposal, hazardous waste, 0% water, to underground deposit	kg

The initial economic cost associated with the production phase (A1-3) has been calculated applying Equation 4b and using data from different sources (see table 31).

When it comes to defining the economic cost of window refurbishment, there are many studies that evaluate this rehabilitation strategy and each one of them offer different window replacement costs values (€/m^2): VFF 221-390 (*VFF, 2014)*, EURIMA 116-316 (*Eurima, 2005*) or EPIQR 231-274 (*EPIQR, 1996*). This studio shall apply the values published by VFF. With respect to rehabilitation strategies on the building's envelope, works performed by ECOFYS 2005, EPIQR or IMPRO-Building (*Nemry, 2008*) define different cost data from various strategies or values such as incremental costs (€/(cm·m^2)) per centimetre insulation.

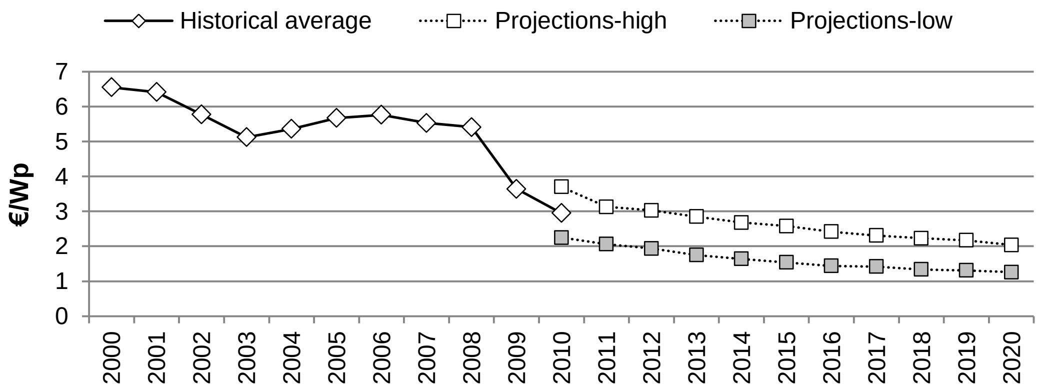


Figure 56 Costs of a Wp generated by photovoltaic technologies. Source: own elaboration with data from (EPIA, 2011)

Finally, due to the greater use of renewable energy in the construction sector, there are numerous studies that evaluate the economic cost reduction of these technologies. According to the study conducted by the International Energy Agency, compared to 2010, the cost of thermal solar panels production could go down by 43% (*IEA, 2014*), making it difficult to define a real economic cost in each and every temporary scenario during their life cycle. The investment cost for PV systems was high in 2010, but is expected to decrease during the next years (see figure 56) with the increasing penetration in the market of thin film modules, with the development of the production processes and with the mass-scale integration in building that will reduce costs related to mounting structures. The studies developed by European Photovoltaic Industry Association suggest that the PV prices will decrease through to 2020 with average prices falling by around 3-5% each year (*EPIA, 2011*).

Table 31 Economic data for products and processes included in the analysis. Including VAT.

Strategy ID	Source	Unit	A1-3 (€/unit)	A5 (€/unit)	B2 (€/unit·a)
1b			198.0	104.0	0.3
1e	VFF	m^2	217.0	104.0	0.3
1a			380.0	104.0	0.3
2bl			154.2	46.7	0.4
2el	ECOFYS & Generador de precios	m^2	157.4	46.7	0.4
2al			202.3	51.2	0.4
2bh			143.4	46.7	0.4
2eh	ECOFYS & Generador de precios	m^2	148.2	46.7	0.4
2ah			185.3	51.2	0.4
3bl			83.2	26.4	0.6
3el	ECOFYS & Generador de precios	m^2	92.7	26.4	0.6
3al			143.5	29.7	0.6
3bh			75.4	26.4	0.6
3eh	ECOFYS & Generador de precios	m^2	85.6	26.4	0.6
3ah			130.9	29.7	0.6
4bl	ECOFYS &Generador de precios	m^2	37.8	11.0	0.1
4el			42.5	11.0	0.1

4al			61.1	11.0	0.1
4bh	ECOFYS & Generador de precios	m^2	34.3	11.0	0.1
4eh			38.5	11.0	0.1
4ah			53.2	11.0	0.1
5bl	ECOFYS & Generador de precios	m^2	29.8	14.8	-
5el			33.2	14.8	-
5bh	ECOFYS & Generador de precios	m^2	8.1	14.8	-
5eh			11.3	14.8	-
6b-e-a	(*SDH, 2012*).	m^2	437.2	113	59.7
7b-e-a	(*Smestad, 2008*).	m^2	265.3	13.6	2.2
8	*(Hergon, 2014)*	Unit	22300	780-	322.7*

Annex 0 shows the IEE $_{A1-3}$ y IC_{A1-3} impact of each and every one of the rehabilitation strategies applied.

5.4.2. R_{A4}. Initial transportation environmental (ITE_{A4}) and economic (ITC_{A4}) impact associated to each refurbishment strategy

The initial environmental and economic impact associated with the transportation phase of each product and system has been calculated applying Equations 5a and 5b. The transportation of building materials to construction sites involves a variety of transportation modes. In this study, the transport system is based on road transportation by truck. Due to the lack of exact transportation information for each material, this study proposes three different distances (D_m) for products and systems that will be part of the refurbishment strategies: 50 km (distribution within the province), 120 km (distribution within the region) and 300 km (distribution within the same member state). Regarding the economic cost of the transport process (EC_t), based on the information of the Spanish data base “Presto”, is defined the value of 0.13€ per each t·km.

Product	**D_m (km)**	**Product**	**D_m (km)**	**Product**	**D_m (km)**
Double glazed	120	Wood frame	300	Mortar	50
Double glazed low-e	120	Aluminium sub-structure	50	Plasterboard	120
Triple glazed	300	Insulation (high)	50	Solar thermal panel	300
Aluminium frame	120	Insulation (low)	300	Photovoltaic panel	300
PVC frame	120	Outlayer	120		

The value of 300 km resembles the average value of 293 km identified in the IMPRO-Building study and the 260 km (median value) or 341 km (mean value) identified as average values reported in the French EPDs for transportation to the building site (Lasvaux, 2010). The transportation is realized by truck (to calculate the process environmental impact - IA_t, refer to table 30).

Annex 0 shows the ITE $_{A4}$ and ITC_{A4} impact of each and every one of the rehabilitation strategies applied.

5.4.3. R_{A5}. Initial environmental (ICE_{A5}) and economic (ICC_{A5}) impact associated to the construction stage of each refurbishment strategy

The initial environmental and economic impact associated with the construction process phase of each product and system has been calculated applying Equations 6a and 6b. Following the guidelines of the methodology, the waste generated during the construction stage and its treatment for end of life (transport and disposal) are considered. 3% of all the products or materials used in each rehabilitation strategy are considered to become waste (WP_m). For this case study, road transportation (IA_t - EC_t) during 50 km (DW_m) to the landfill (ENW_m - ECW_m) for inert and non-hazardous waste (Ecoinvent, "Landfill for inert matter, construction waste" process) is considered, except for the renewable systems, which will be deposited in a facility management of hazardous waste (Ecoinvent, "disposal, hazardous waste, 0% water, to underground deposit" process) that is located at a distance from the building to 250 km (DW_m). Being beyond the scope of the study, potential recycling or reuse of the aluminium used in the frame of the windows ("1b") and in the ventilated facade sub-structure ("2") is not included.

Along with the impact generated by transport and the waste management, this stage considered the economic impact of each rehabilitation strategy implementation or construction process (CC_m). To do so, this study applied the values defined table 31. With respect to the economic impact on waste treatment, based on the research project SOFIAS (*Oregi et al, 2014*), this study has established a value of 0.075 € per kg of waste managed.

Annex 0 shows the ICE_{A5} and ICC_{A5} impact of each and every one of the rehabilitation strategies applied.

5.4.4. R_{B2}. Economic impact associated to maintenance process of each refurbishment strategy (MC_{B2})

The economic impact associated with the maintenance phase of each product and system has been calculated applying Equation 7.

Each rehabilitation strategy's maintenance costs (MC_m) and periodicity (EMP_m) are different in each case. The annualised economic cost values (EMP_m concept being integrated) of each strategy have been defined by table 31. With respect to the inflation rate (IR_n), and based on the different values applied on different national and international studies, this study applies a 1.5% inflation value. It should be emphasised that, as shown in figure 38, this value may change significantly depending on the case study's location or the evaluation period.

Annex 0 shows the MC_{B2} impact of each and every one of the rehabilitation strategies applied.

5.4.5. R_{B4}. Environmental and economic impact associated to the replacement stage of each refurbishment strategy.

The recurrent environmental and economic impact associated with the replacement phase of each product and system has been calculated applying Equations 8a, 8b, 8d, 8e, 8f and 8g. Along with the 50 years RSL_b value defined above, table 32 shows the Estimated Service Life (ESL_m) values of each product and system that are part of the different rehabilitation strategies.

Table 32 Information about each product and system that participate in different refurbishment strategies

Product	ESLm		Product	ESLm	
	Years	Source		Years	Source
Double glazed	30	Environmental Product Declaration (EPD)	Insulation (high)	50	NAHB
Double glazed low-e	30	EPD	Insulation (low)	50	NAHB
Triple glazed	30	EPD	Outlayer	50	NAHB
Aluminium frame	20	National Association of Home Builders (*NAHB, 2007*)	Mortar	35	NAHB
PVC frame	30	NAHB	Plasterboard	30	NAHB
Wood frame	30	NAHB	Solar thermal panel	30	(*Fthenakis et al., 2009*)
Aluminium sub-structure	50	NAHB	Photovoltaic panel	30	Fthenakis
Biomass boiler	30	NAHB			

In order to evaluate the economic impact each product, system or process shall have on the different sub-stages of the replacement stage (production, transport or construction process), the 1.5% inflation value shall apply. Thus, inflation shall determine each product or process cost variation during the case study's service life period. Due to this inflation rate value, economic impacts or initial investments shall grow by 34%, 56%, 68% and 81% on all rehabilitation strategies that have been replaced over a period of 20, 30, 35 and 40 years respectively (IR_{ESLm}).

Annex 0 shows the recurrent environmental and economic impact values of each and every one of the rehabilitation strategies applied.

5.4.6. R_{B6}. Refurbished building operational energy use stages environmental (R_{B6_EN}) and economic (R_{B6_EC}) impact.

The environmental and economic impact associated with the operational energy use phase of the refurbished building has been calculated applying Equation 9a and 9b. In this case, option “A” was the calculation methodology applied (see 4.1.3), the baseline being the comparison scenario for all strategies. If the user is interested in optimising the efficiency level of each rehabilitation strategy, the application of option "B" would then be suggested.

The new energy demands (ED_b) of the refurbished building scenarios have been calculated with the same methodology as the baseline operational energy use, i.e., through building energy simulations with Design Builder software.

In those rehabilitation strategies performed on the outside of the building’s envelope (“2 - 3”), and due to the thermal resistance increase of the ducts’ exterior, the heating system hot water distribution energy losses (DL_b) are reduced. This case study considered three different scenarios for distribution losses reduction: by 30% (basic), 40% (efficient) and 45% (advanced). With regards to other rehabilitation strategies, the 10% distribution loss value has been maintained.

Rehabilitation strategies "6" and "7" suggest the implementation of energy generation systems from renewable sources. Annex 7.5.1 shows the calculation criteria and parameters used when performing such calculations, allowing for the quantification of thermal (“6”) and electrical (“7”) energy generated by each system for the different efficiency levels proposed in this study.

	Strategy ID	Generated final energy	
		MJ/year	**MJ/(m^2·a)**
Solar thermal	6b	130,694	15.2
	6e	191,686	22.3
	6a	243,961	28.4
Photovoltaic	7e	57,754	6.7
	7a	192,521	222.4

System performance (*p*), conversion factors and energy prices have remained intact with regards to the natural gas boiler and thermoelectric system. However, strategy "8" aims to integrate a new biomass energy generation system on the heating system. For the biomass source (heating systems energy source), the related impacts were deduced from Ecoinvent database, applying the process “heat production, wood pellet, at furnace 25kW” (Rest-of-the-World), which has an energy performance of 85% (*p*). The conversion factor (CF_y) for the biomass that this study applies is going to be

1.98E-01 MJ/MJ (NRPE) and 1.16E-02 kg CO_2-eq/MJ (GWP). Regarding the price of biomass energy (PE_y), based on information published by AFIB (area of timber harvesting and biomass) and CTFC (Forest Technology Centre of Catalonia), this study has determined the value of 0.016 € / MJ.

Finally, given the energy prices' variability and the life-cycle assessment object, this case study established that household electricity prices shall rise by 4% a year, whereas natural gas and biomass shall rise by 3% and 2.7% a year respectively.

Annex 0 shows the R_{B6_EN} and R_{B6_EC} impact of each and every one of the rehabilitation strategies applied.

5.4.7. R_{C1-4}. Environmental (EL_{C1-4_EN}) and economic (EL_{C1-4_EC}) impact associated to the end of life stage of each refurbishment strategy

The environmental and economic impact associated with the end of life phase of the refurbished building has been calculated applying Equation 10a and 10b.

Environmental impact of the end-of-life stage is usually not considered since it typically represents less than 1% of the life cycle energy of buildings (*Winistorfer et al., 2007*). However, in order to assess all building phases, during this study the environmental and economic impacts generated during the transportation of the products (initial and recurrent) to the waste treatment facility and their management are evaluated. For this case study, road transportation (IA_t - EC_t) during 50 km (DW_m) to the landfill (ENW_m - ECW_m) for inert and non-hazardous waste (Ecoinvet, "Landfill for inert matter construction waste" process) is considered, except for the renewable systems, which will be deposited in a facility management of hazardous waste (Ecoinvent, "disposal, hazardous waste, 0% water, to underground deposit" process) that is located at a distance from the building to 250 km (DW_m). Being beyond the scope of the study, potential recycling or reuse of the aluminium used in the frame of the windows ("1b") and in the ventilated facade sub-structure ("2") is not included.

Annex 0 shows the EL_{C1-4_EN} and EL_{C1-4_EC} impact of each and every one of the rehabilitation strategies applied.

5.4.8. Sample Calculation of NRPE use and economic impact for the refurbished building with one of the energy refurbishment strategies

As an example, the environmental and economic calculation of a proposed rehabilitation strategy ("2ah") is explained. This strategy focuses on improving the current thermal properties of the façade with a ventilated façade system, which consists of 5581 m^2 of 25 cm XPS insulation for the facade, 1127 m^2 of 30 cm XPS insulation for the deck, 948 m^2 of 15 cm XPS insulation for the first floor slab, aluminium sub-structure with a section of 49.6 cm^2 and 4409 m^2 of ceramic façade panels. Through this information, the values of the table 33 and the values previously defined, the authors have performed the calculation of the NRPE use and the economic impact (€) per functional unit (1m^2 of the building living area over a 1 year) of each of the life cycle phases of this strategy.

Table 33 Inputs values of the "2ah" refurbishment strategy

	Nomenclature	Aluminium sub-structure	XPS insulation	Ceramic panel
Embodied environmental impact	EE_m	71.3 MJ/kg	335 MJ/m^2	256 MJ/m^2
Economic cost (€/m^2)-System	EC_m		185.3 €/m^2	
Quantity	Q_m	48,569 kg	7,656 m^2	4,409 m^2
Transport distance (km)	D_m	50	50	120
Transport quantity (t)	Q_{mt}	48.6	42.5	36.4
Transportation system	IA_t - EC_t	Truck	Truck	Truck
Percentage of waste generated	WP_m	3%	3%	3%
Transport distance to waste management (km)	DW_m	50	50	50
Waste treatment	ENW_m - ECW_m	Landfill	Landfill	Landfill
Installation process cost - System	CC_m		51.2 €/m^2	
Maintenance cost - System	MC_m		0.41 €/m^2·a	
Refurbished building energy demand	ED_b		Heating (146 MJ/(m^2·a)), DHW (53 MJ/(m^2·a)), Lighting (23 MJ/(m^2·a)), Appliances(140 MJ/(m^2·a)).	

Initial Embodied Environmental Impact ($IEE_{A1\text{-}3}$) and Initial economic Cost ($IC_{A1\text{-}3}$)

$$IEE_{A1-3} = \sum_{m=1}^{m=k} EE_m \times Q_m \Big/ FU \qquad (4a)$$

$$IC_{A1-3} = \sum_{m=1}^{m=k} EC_m \times Q_m \Big/ FU \qquad (4b)$$

$$IEE_{A1-3} = \frac{(71.3 \times 48569) + (335 \times 7656) + (256 \times 4409)}{8574 \times 50} = \mathbf{1.6E01}\ \boldsymbol{MJ}/(\boldsymbol{m^2} \cdot \boldsymbol{a})$$

$$IC_{A1-3} = \frac{(185.3 \times 4409) + (41.3 \times 2075)}{8574 \times 50} = \mathbf{2.3}\ €/(\boldsymbol{m^2} \cdot \boldsymbol{a})$$

Initial transportation environmental (ITE_{A4}) and economic (ITC_{A4}) impact

$$ITE_{A4} = \sum_{m=1}^{m=k} D_m \times Q_{mt} \times IA_t \Big/ FU \qquad (5a) \qquad ITC_{A4} = \sum_{m=1}^{m=k} D_m \times Q_{mt} \times EC_t \Big/ FU \qquad (5b)$$

$$ITE_{A4} = \frac{\big((50 \times 48.6) + (50 \times 42.5) + (120 \times 36.4)\big) \times 0.84}{8574 \times 50} = \mathbf{2.4E-02}\ \boldsymbol{MJ}/(\boldsymbol{m^2} \cdot \boldsymbol{a})$$

$$ITC_{A4} = \frac{\big((50 \times 48.6) + (50 \times 42.5) + (120 \times 36.4)\big) \times 0.13}{8574 \times 50} = \mathbf{0.0046}\ \boldsymbol{€}/(\boldsymbol{m^2} \cdot \boldsymbol{a})$$

Initial environmental (ICE_{A5}) and economic (ICC_{A5}) impact associated to the construction stage

$$ICE_{A5} = \sum_{m=1}^{m=k} ([(Q_{mt} \times WP_m) \times DW_m \times IA_t] + [(Q_{mt} \times WP_m) \times ENW_m]) \Big/ FU \qquad (6a)$$

$$ICC_{A5} = \sum_{m=1}^{m=k} ([(Q_{mt} \times WP_m) \times DW_m \times EC_t] + [(Q_{mt} \times WP_m) \times ECW_m] + [Q_m \times CC_m])/FU \qquad (6b)$$

$$ICE_{A5} = \frac{\big((48.6 + 42.5 + 36.4) \times 0.03 \times 50 \times 0.84\big) + \big((48.6 + 42.5 + 36.4) \times 0.03 \times 186\big)}{8574 \times 50} = \mathbf{2.1E-03}\ \boldsymbol{MJ}/(\boldsymbol{m^2} \cdot \boldsymbol{a})$$

$$ICC_{A5} = \frac{\big((48.6 + 42.5 + 36.4) \times 0.03 \times 50 \times 0.13\big) + \big((48.6 + 42.5 + 36.4) \times 0.03 \times 75\big) + (4409 \times 51.2)}{8574 \times 50} = \mathbf{0.64}\ \boldsymbol{€}/(\boldsymbol{m^2} \cdot \boldsymbol{a})$$

Economic impact associated to maintenance process

$$MC_{B2} = \sum_{n=1}^{RSL_b} \left(\sum_{m=1}^{m=k} \frac{MC_m \times Q_m}{EMP_m} \right) \times (1 + IR_n) \Big/ FU \qquad (7)$$

$$MC_{B2} = \frac{\sum_{n=1}^{n=50} \big((0.41 \times 4409) \times (1 + 0.015^n)\big)}{8574 \times 50} = \mathbf{0.38}\ €/(\boldsymbol{m^2} \cdot \mathbf{a})$$

Environmental and economic impact generated during the Replacement stage

Due to the service life value (ESL_m) defined for each of the elements of the ventilated facade system, no replacement shall take place during the RSL_b of the rehabilitated building.

If the ESL_m value of a product that is part of the system was lower than its RSL_b value ($ESL_m < RSL_b$), the calculation of how many times each product has to be replaced during the rehabilitated building's life-cycle shall be deemed necessary, allowing for the evaluation of the replacement stage. With regards to the economic calculation, the ESL_m value, together with the number of substitutions, shall be fully linked to the current price increase of each rehabilitation strategy on the building's life-cycle. Therefore, as a result of the equations suggested by this methodology (8b, 8e and 8g), the application of the inflation value shall be deemed necessary.

Refurbished building operational energy use stages impact

$$R_{B6\_EN} = \sum_{n=1}^{RSL_b} \left(\sum_{m=1}^{m=k} \left[\left(\frac{ED_b}{\rho_m} + DL_b - RE_k \right) \times CF_y \right] \right) \Big/ FU \qquad (9a)$$

$$R_{B6\_EC} = \sum_{n=1}^{RSL_b} \left(\sum_{m=1}^{m=k} \left[\left(\frac{ED_b}{\rho_m} + DL_b - RE_y \right) \times EP_y \right] \times \left[1 + EPI_y^n \right] \right) \Big/ FU \qquad (9b)$$

$$R_{B6_{EN}} = \frac{\sum_{n=1}^{n=50} \left(\left(\frac{146}{0.92} + \left(\frac{146}{0.92} \times 0.045 \right) \right) \times 1.23 \right) + \left(\left(\frac{50.2}{0.9} + \frac{23.2}{1} + \frac{140.3}{1} \right) \times 1.74 \right)}{50} = \mathbf{581\ MJ/(m^2 \cdot a)}$$

$$R_{B6_{EC}} = \frac{\sum_{n=1}^{n=50} \left(\left(\left(\frac{146}{0.92} + \left(\frac{146}{0.92} \times 0.045 \right) \right) \times 0.02 \right) \times (1+0.03^n) \right) + \left(\left(\left(\frac{50.2}{0.9} + \frac{23.2}{1} + \frac{140.3}{1} \right) \times 0.06 \right) \times (1+0.04^n) \right)}{50} = \mathbf{49\ €/(m^2 \cdot a)}$$

End of life

$$EL_{C1-4\_EN} = \sum_{m=1}^{m=k} ([Q_{mt} \times DW_m \times IA_t] + [Q_{mt} \times ENW_m]) \times (RSL_b/ESL_m) \Big/ FU \qquad (10a)$$

$$EL_{C1-4\_EC} = \sum_{m=1}^{m=k} ([Q_{mt} \times DW_m \times EC_t] + [Q_{mt} \times ECW_m]) \times (RSL_b/ESL_m) \Big/ FU \qquad (10b)$$

$$EL_{C1-4\_EN} = \frac{\left(\left((48.6+42.5+36.4) \times 50 \times 0.84 \right) + \left((48.6+42.5+36.4) \times 186 \right) \right) \times 1}{8574 \times 50} = \mathbf{6.8E-02\ MJ/(m2 \cdot a)}$$

$$EL_{C1-4\_EC} = \frac{\left(\left((48.6+42.5+36.4) \times 50 \times 0.13 \right) + \left((48.6+42.5+36.4) \times 75 \right) \right) \times 1}{8574 \times 50} = \mathbf{0.024\ €/(m2 \cdot a)}$$

Summary scheme

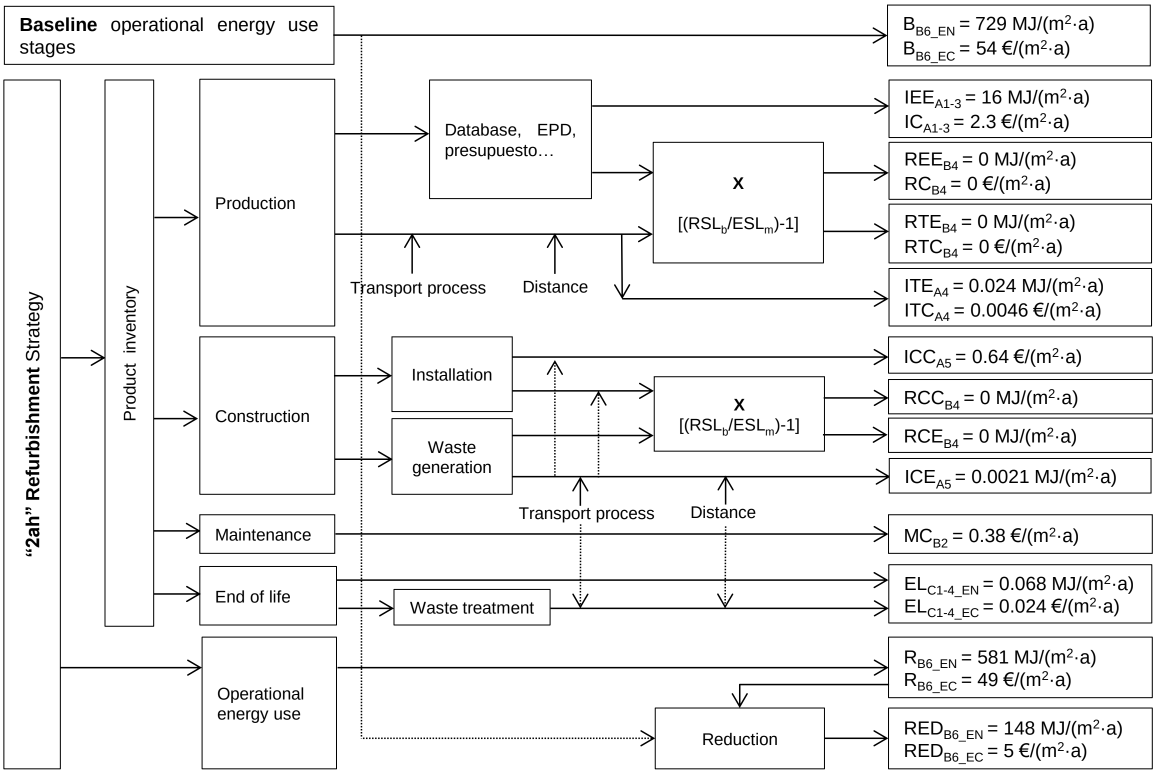


Figure 57 Scheme of Non Renewable Primary Energy (NRPE) use and economic (€) impact per functional unit of each life cycle phase due to the application of the "2ah" energy refurbishment strategy.

Figure 57 shows that the NRPE use of the building after applying the refurbishment strategy "2ah" is reduced from 729 MJ/(m^2·a) to 597 MJ/(m^2·a), reaching a reduction of 22.1%, which is mostly due to the operational energy use phase reduction (148 MJ/(m^2·a)). With respect to the economic evaluation, after applying the refurbishment strategy "2ah", the impact is reduced by 5 €/(m^2·a) during the operational stage. However, the initial investment of this type of rehabilitation strategy is also very high (2.3 €/(m^2·a)).

5.4.9. Summary of results

Applying the same calculation procedure for all energy rehabilitation strategies, the environmental (NRPE use) and economic impact (€) of each phase was obtained (results of the environmental impact indicator GWP are available on the annex 0). Figure 58 and figure 59 show, in comparison with the baseline scenario, the decrease on the environmental and economic impact during the operational stage (positive values) and the increase of environmental and economic impact derived from the production, transportation, construction, replacement and end of life phases (negative values) of the products and systems applied in each refurbishment strategy.

For the particular building studied, table 34 shows that the refurbishment option with the highest NRPE use reduction (*i.e.*, 68%) calculated with the LCA methodology is strategy “8”, which is based on the replacement of the existing natural gas boiler by a biomass thermal generation. Regarding the other conservation and renewable strategies, the refurbishment option with highest NRPE use reduction (*i.e.*, 25.5%) calculated with the LCA methodology is strategy “3al”, which increases the building envelope insulation level by the application of an external insulation system. Results show that the influence of the constructive characteristics and embodied energy parameters is very low (in some cases less than 1%), being the advanced level refurbishment strategies the most effective and efficient to reduce the baseline NRPE use.

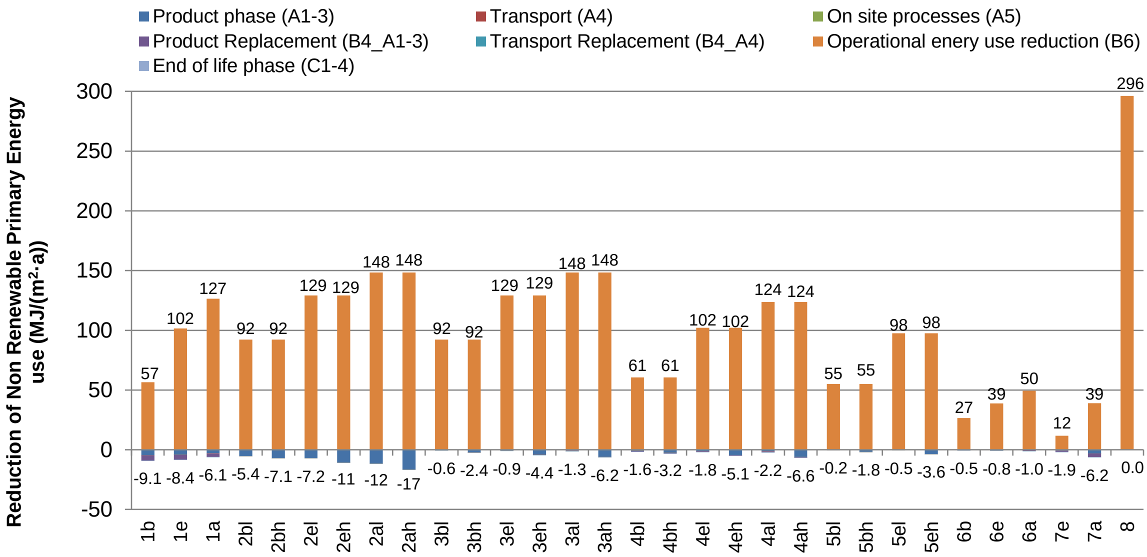


Figure 58 Reduction of Non Renewable Primary Energy use (MJ/(m^2·a)) from each refurbishment strategy in relation to the baseline. Values of this figure are available in annex 0.

As expected the reduction of life cycle NRPE use is much larger than the energy consumed by the different refurbishment strategies. The ratio between the increase and decrease on NRPE use reach up to 11%, for strategies using products with higher embodied energy (*i.e.*, “2ah”) and for photovoltaic strategies (16%). Consequently, the ratio has lower values (up to 0.43%) when the products applied have lower embodied energy (*i.e.*, “5bl”).

Table 34 NRPE reduction (MJ/(m^2·a)) of the refurbished building during its Reference Service Life period.

Strategy ID		**Strategy ID**		**Strategy ID**	
1b	47.43	**3bh**	89.77	**4ah**	117.02
1e	93.22	**3el**	128.34	**5bl**	54.91
1a	120.47	**3eh**	124.85	**5bh**	53.34
2bl	86.77	**3al**	147.09	**5el**	97.03
2bh	85.03	**3ah**	142.18	**5eh**	93.89

2el	122.00	**4bl**	58.98	**6b**	25.97
2eh	118.51	**4bh**	57.41	**6e**	38.09
2al	136.70	**4el**	100.33	**6a**	48.47
2ah	131.79	**4eh**	97.18	**7e**	9.83
3bl	91.51	**4al**	121.44	**7a**	32.78
				8	296.24

Regarding the economic assessment, for the particular building studied, table 35 shows that the refurbishment option with the highest annual economic reduction per square meter of living area calculated with the LCA methodology is strategy “6a” (4.26 €/(m^2·a)), which is based on the projection of a solar thermal system. Nevertheless, in other rehabilitation strategies, the annual global balance is negative. Meaning that, after applying a rehabilitation strategy, the economic impact reduction during the operational stage of the refurbished building is lower than the negative impact or the investment made during the other stages of the building’s life-cycle. Rehabilitation strategy “3” (rehabilitation of the envelope by the application of an external insulation system) should be especially noted because, despite the great impact reduction of its operational stage (“3al - 3ah”), the overall balance for the proposed period of analysis shows a negative value, due to the high impact of its replacement stage (directly related to the relation between the ESL_m value of this system and the building RLS_b value).

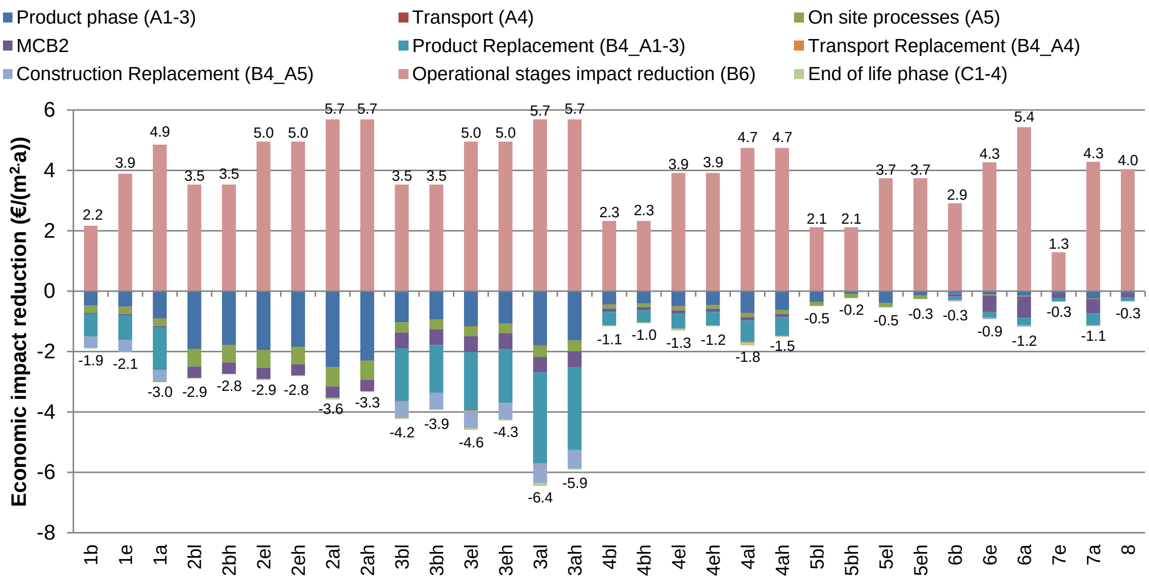


Figure 59 Economic reduction (€/(m^2·a)) from each refurbishment strategy in relation to the baseline. Values of this figure are available in annex 0.

With respect to the other passive and renewable strategies, it should be noted that the economic cost of the strategies "4" and "5" is very low, mainly due to their lack of maintenance, construction process simplicity and lack of replacement. Although the impact reduction during the operational stage is lower in these cases, the overall economic impact is far more positive than on strategies such as the installation of ventilated façades (“2) or external insulation systems (“3”).

** Strategies "3" and "4" do not solve hot spots such as thermal bridges' slabs, integrated pillars nor do they improve the performance of the existing building's envelope. Therefore, when prioritising between different strategies, together with the economic performance, these aspects that can significantly influence the generation of future diseases or reduce the inhabitants' health should be taken into consideration.*

Table 35 Economic reduction (€/(m^2·a)) of the refurbished building during its Reference Service Life period.

Strategy ID		Strategy ID		Strategy ID	
1b	0.27	**3bh**	-0.41	**4ah**	3.23
1e	1.87	**3el**	0.36	**5bl**	1.62
1a	1.83	**3eh**	0.67	**5bh**	1.89
2bl	0.64	**3al**	-0.77	**5el**	3.19
2bh	0.78	**3ah**	-0.22	**5eh**	3.47
2el	2.00	**4bl**	1.15	**6b**	2.57
2eh	2.14	**4bh**	1.26	**6e**	3.34
2al	2.10	**4el**	2.61	**6a**	4.26
2ah	2.35	**4eh**	2.75	**7e**	0.94
3bl	-0.71	**4al**	2.94	**7a**	3.14
				8	3.71

5.5. Optimization of the system boundary. Cut-off rules

Once the environmental and economic impacts of each rehabilitated building's life-cycle stage has been quantified, this fifth section shall achieve this thesis' first goal: to evaluate the impact percentage of each life-cycle stage with respect to the global impact reduction of the refurbished building during its life cycle. These new values shall allow for suggesting different scenarios for the simplification of the evaluation system boundary based on the life-cycle methodology without actually reducing the accuracy of the results and maintaining the study's rigour. In order to do so, this study defines different percentage limits or cut-off rules:

- **1%**. When the influence of a building's life-cycle stage is less than 1% of the overall impact, the study may manage without the evaluation of such stage.
- **5%**. When the influence of a building's life-cycle stage is less than 5% of the overall impact and the quality of the data is low (lack of EPDs of actual manufacturers, unitemised economic budgets, etc.), the study may manage without the evaluation of such stage

- **10%.**Even if the quality of the data is low, when the influence of a building's life-cycle stage is higher than 10% of the overall impact, the evaluation of such stage shall be deemed necessary.

As an example, in this section, the environmental and economic impact percentage calculation of a proposed rehabilitation strategy ("2ah") is explained. Based on the values obtained in section 5.4, the technician shall obtain the generated or reduced impact value of each life-cycle stage of the building that has been rehabilitated by the selected strategy.

Life Cycle Stage		Environmental		Economic	
		(MJ/(m^2·a))	%	(€/(m^2·a))	%
Product	A1-3	16	**10.035**	2.3	**25.48**
Transport	A4	0.024	**0.014**	0.0046	**0.05**
Construction	A5	0.0021	**0.001**	0.64	**7.04**
Maintenance	B2	-	**-**	0.38	**4.15**
Replacement	B4	0	**0**	0	**0**
Operational energy use reduction	B6	148	**89.908**	5.7	**63.00**
End of life	C1-4	0.068	**0.041**	0.024	**0.27**
Total	Life Cycle	165	100	9.03	100

The following are the environmental and economic impact percentages resulting from the application of such calculation on all the rehabilitation scenarios.

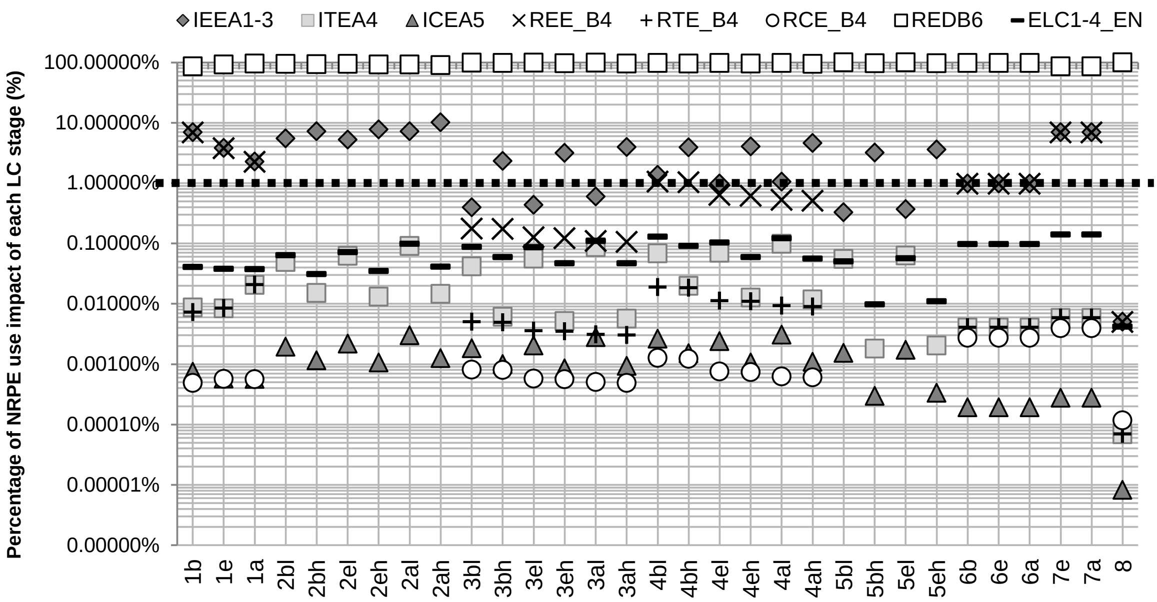


Figure 60 Percentage of NRPE use (MJ) impact of each life cycle stage with respect to the overall NRPE use impact reduction of the refurbished building during its life cycle. Values of this figure and values of the environmental indicator GWP are available in annex 7.5.4.

Figure 60 shows the percentage value of each environmental assessment stage for the impact indicator "NRPE use per functional unit". These values clearly show that the influence of initial and recurrent impacts of the stages of transport (A4), construction process (A5) and end of life (C1-C4) with respect to the reduced overall impact of the refurbished building during its life cycle is less than 0.1% in all rehabilitation strategies evaluated. That is, for this case study's environmental assessment (as defined by the aforementioned parameters), these life-cycle stages could be left out when analysing and prioritising between the different rehabilitation strategies, for this simplification shall not risk the quality of the final resulting information.

Regarding the stages that evaluate the initial products' embodied energy impact (A1-A3), such value ranges from 0.32% (when low energy absorption materials are used) to 10.03% (when the rehabilitation strategy consists of high embodied energy products, "2ah"). Therefore, at first glance, this stage shall not be simplified, especially when the user applies databases' values with a low detail level or accuracy.

The results of the stage that quantifies the embodied energy impact of the replaced products' ($REE_{B4\_(A1-3)}$), the interpretation is quite more complex, for it is necessary to consider the relationship between the Estimated Service Life (ESL_m) value for each product that composes each rehabilitation strategy and the rehabilitated building's Reference Service Life period (RSL_b) value, along with each product or system's embodied energy value. In this case study, regarding the defined ESL_m y RSL_b values, the strategies with greater impact percentage for this stage are the "1b" (window with aluminium frame) and "7" (photovoltaic panels). Regarding the other rehabilitation strategies ("2-3-4-5-6-8"), the impact percentage for this stage is less than 1% the overall NRPE use impact reduction, due to their low embodied energy or lack of need for replacement during the study's $RSL_{b.}$

Finally, as shown by figure 60, reducing the NRPE use during the operational stage of the building is still the most influencing stage, since its global NRPE use impact percentage ranges from 86.1% ("1b") to 99.6% ("5bl").

Regarding the economic evaluation, figure 61 shows each life-cycle's stage percentage (%) value for the "euro (€) per functional unit" impact indicator. These values show that, except for one strategy ("4al") in which the impact percentage of the end of life stage is 1.4%, the influence of transport (A4) and end-of-life (C1-C4) stages' initial and recurrent impact with respect to global economic impact reduction during its life cycle is less than 1% in all other rehabilitation strategies. That is, for the economic evaluation of this case study (as defined by the aforementioned parameters), these life-cycle stages could be left out when analysing and prioritising between the different rehabilitation strategies, for this simplification shall not risk the quality of the final resulting information

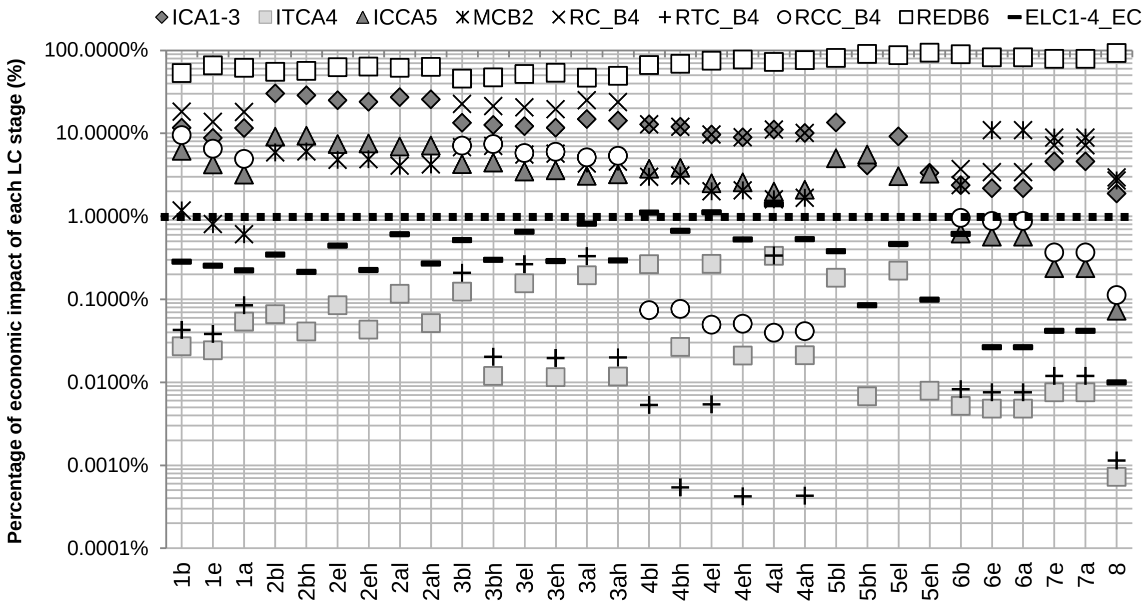


Figure 61 Percentage of economic impact (€) of each life cycle stage with respect to the overall economic impact reduction of the refurbished building during its life cycle. Values of this figure are available in annex 7.5.4.

The results show that the products and system's initial cost stage (IC_{A1-3}) is quite important, reaching values of 29.8% in strategies such as "2bl". On the contrary, the influence of strategies that use renewable energy is greatly reduced, since the proportion of the economic impact of such stage does not exceed 5% of the overall economic impact reduction.

The construction process impact (ICC_{A5}) increases considerably with regards to the environmental study, reaching the 9.2% percentage value in strategies such as the "2bh". On the contrary, in other rehabilitation strategies ("3-4-5-6-7-8"), such value is less than 5%.

With regards to the economic impact of the maintenance stage (B2), the results show completely opposite scenarios. In rehabilitation strategies on windows ("1") and ventilated facade systems ("2"), as well as in rehabilitations inside ("4") or on the air chamber ("5"), the maintenance stage impact percentage is 5% lower than the overall economic impact reduction, suggesting that this maintenance stage should be left out of this type of economic evaluations scope. However, in strategies such as the external insulation system ("3") or renewable systems ("6-7"), due to their sensitivity to climate "attacks" or the need to carry out periodic adjustments, the impact of such stage reaches 10% of the overall economic impact reduction, being subject to consideration in life-cycle economic studies.

Regarding the stage that assesses the economic impact generated by products and systems that have been replaced ($RC_{B4\_(A1-3)}$ and $RCC_{B4\_(A5)}$) during the renovated building's life-cycle, results show that strategies in which ESL_m is lower than the established RSL_b value, such impact can reach 24.7% ("3al") values in the production sub-stage and 9.5% ("1b") in the construction sub-stage with respect to the overall economic impact reduction. On the contrary, those strategies in which the ESL_m is equal to or greater than the RSL_b defined for this case study ("2-5"), such stage percentage value is 0%. That is, the simplification of such stage shall depend directly on a proper definition of the RSL_b and ESL_m parameters.

Furthermore, when assessing the economic impact reduction during the operational stage of the renovated building, results show that their percentage value may range from 45% (strategy "3bl" in which the impact of the steps A1-A3 or B4 is quite high) to 93% (strategy "5eh" in which the impact of the other life-cycle stages is very low), being the life-cycle stage with greater economic influence in this case study.

5.5.1. Sensitivity and Uncertainty Evaluation

Previous studies show that the constructive characteristics of this type of buildings and the strategies applied to this type of energy rehabilitation projects could be similar in all EU member states. However, there are numerous parameters that directly influence the variation of the aforementioned results and conclusions. Therefore, with the aim of drawing a general conclusion that offers an overview of residential building refurbishment actions, a sensitivity analysis tackling different relevant aspects is conducted in this section.

Reference Service Life of the Building (RSL_b)

This methodology shows the way different studies and publications apply different RSL_b values to their case studies, in which the value can range from 25 to 100 years. Because of the direct relationship between the building's assessment period and the assessed building's life-cycle impact (environmental and economic), this study suggests two new scenarios: reducing the Reference Service Life of the building to 25 years and increasing this value up to 100 years.

Estimated Service Life of the Products (ESL_m)

ESL_m values for each product and system where defined for the baseline scenario (see table 32). However, depending on the real use and maintenance practices, these values may be reduced or increased. Therefore, two additional ESL_m scenarios are assessed: reducing the lifetime of all products by half and increasing their life by up to 50 years.

Transportation Distance (D_m)

There are many cases where it is very difficult to determine the actual distance from where each product or system that makes up the different rehabilitation strategies for each case study is transported. Therefore, transportation distance values from the production gate to the building site have been changed to 50, 300, 1000 and 5000 km.

Climate Zone

In accordance with the climatic characteristics of the city where the studied building is located (radiation, outdoor temperature, humidity…), energy demand and energy generated through renewable systems such as thermal and photovoltaic solar panels, parameters shall vary, changing the results of the impact percentage of each life-cycle stage. Therefore, in order to check the influence of applying the same refurbishment strategies in other climate zones, three additional climate zones are evaluated: warm climate (south of Italy, Palermo), EU average (Stuttgart, Germany) and cold climate (Norway, Oslo).

Range Heating Degree Days	**City**	**Heating Degree Days (HDD)** ***(Knoema)***
>4000	Oslo	4448
2500-HDD-4000	Stuttgart	3076
1500-HDD-2500	Donostia	1974
<1500	Palermo	1347

Due to the relevance of cooling consumption in warm climates (Palermo), in this case the operational energy includes energy consumption for cooling indoor spaces (see Equations 1-2). The cooling system consists of individual air-air electric installations with a nominal performance of 3 (ρ*m* value). Thermostats are set at 25 °C from 12 a.m. until 8 p.m. for the cooling period (from 31 May to 30 September). The values from the solar radiation of the different cities (necessary to solar thermal and PV strategies) are obtained by the web site “Photovoltaic Geographical Information System” (*PVGIS*).

Uncertainty on Data on Embodied Energy of Products (EE)

Most current studies, including the present one, use environmental data from LCI databases and/or environmental product declarations, which are based on the LCA methodology for calculating the environmental inputs and outputs of each process involved in the corresponding supply chain (bottom-up technique). This process based

LCA approach may conduct to a large associated uncertainty (*Treloar, 1997*) due to the truncation error derived from data scarcity at a certain point of the upstream supply chain. Crawford (*Crawford, 2008*) has shown that this error can be up to 87% of the embodied energy of building products, and has proposed the use of input-output LCA analysis, a top-down technique that establishes a link between economic transactions and the energy intensity of economic sectors, or hybrid LCA analysis, combining process and input-output analysis, to capture all the upstream processes. Other studies (*Crawford, 2011*; *Crawford & Stephan, 2013*; *Stephan & Stephan, 2014*) have shown that input-output-based hybrid analysis can produce embodied energy figures around four times higher than process analysis, for the same building. In order to assess the effect of a potential underestimation of the embodied energy values, a new scenario has been calculated multiplying the energy values by an average coefficient of 4.03 (*Stephan & Stephan, 2014*).

Uncertainty in relation to Occupancy Schedules and User Behavior (OE)

Occupancy schedules may significantly vary the results of operational energy use. This parameter adds a remarkable uncertainty to the results, as it has a critical role when estimating energy loads in residential buildings, as shown for example by Topouzi (*Topouzi, 2011*).

Raaij and Verhallen proposed a comprehensive model of residential energy use that relates personal, environmental (e.g. building and climate) and behavioural factors (*Raaij & Verhallen, 1983*). The factors influencing residential energy use are divided in three types of energy-related behaviour: purchase, usage and maintenance. Purchase-related behaviour considers purchase of household appliances, heating and cooling equipment including ventilators. Usage-related behaviour comprises day-to-day usage of appliances and the building itself. Maintenance-related behaviour refers to appliances and HVAC-system servicing and small repairs as well as small home improvements. An extensive list of specific and important factors was presented and discussed: lifestyle; characteristics of home and appliances; socio-demographic factors; energy-related attitudes; responsibility, effectiveness and knowledge; cost-benefit trade-off; energy prices; feedback information and social reference and community approach.

Lutzenhiser investigated the prospects for a cultural model of household energy consumption (*Lutzenhiser, 1992*). The cultural analysis focuses on the group instead of the individual. Taking a starting point in existing models that focus mainly on physical, economic, psychological and social factors the cultural perspective was discussed including its ecological foundations.

Hitchcock presented an integrated framework for energy use and behaviour in the domestic sector (*Hitchcock, 1993*). It is stated that energy consumption patterns are a complex technical and social phenomenon that must be viewed from both engineering and social perspectives to be fully understood. The model suggests the main components of the technical and social perspectives, respectively, as well as the important interaction between the perspectives. For most other models “occupant behaviour” expresses the two-way interaction between the physical and human spheres, whereas this study defines “occupant behaviour” as the one-way link from the human system to the physical system and the so-called “dwelling behaviour” as the opposite one-way link from the physical system to the human system. The social perspective comprises the human system together with the two environmental factors: economic system and cultural system. The engineering perspective comprises the physical system together with the climate system as an environmental factor.

Some studies *(Pettersen, 1994*) show that the influence from inhabitants is much more significant than variation from climate, since in the case where the inhabitants' behaviour is unknown, it is impossible to predict the total energy consumption more accurately than ±15–20% compared with the consumption found with traditional energy calculation methods. Other works (*Larsen et al., 2010*) determinate that que user behaviour and lifestyle means that energy consumption in otherwise identical homes can vary by a factor 2 – 3. Indeed, Pettersen and Juodis have shown in their studies that user behaviour could vary the primary operational energy associated with space heating by ±15% - 20% (*Crowther, 1999; Juodis et al., 2009*).

Therefore, two new scenarios have been added to take these issues into account, assuming that the energy demand of the baseline scenario can be 20% higher and 20% lower than initially calculated due to occupancy and behavioural issues.

<u>Temporal evolution of the Conversion Factors for electricity and natural gas (CF)</u>

In the base case scenario, the primary energy and GWP conversion factor for electricity is assumed to remain constant over a period of 50 years (RSL_b). This assumption is probably unrealistic, even if the electricity sector has not significantly changed. It is probable that renewable energy plants will be installed in this coming period and therefore, the primary energy and GWP conversion factors for electricity are very likely to decrease. However, it is not known which will be the energy policies for the following decades, since there are other macro-parameters that influence this kind of global decisions.

Therefore, two new scenarios have been added to take these issues into account, assuming that the conversion factors of the baseline scenario can be 20% higher and 20% lower than initially calculated due to energy police issues.

Energy Price Increment (EPI)

Although during the last years the evolution of European natural gas and electricity prices for household Consumers (*Eurostat, 2014*) has been quite linear (see figure 62), it is very difficult to estimate what will be the scenario in a short or medium period. Therefore, two new scenarios have been added to take this issue into account, assuming that the energy prince increment defined to the baseline scenario can be zero percent (0%) or double than initially calculated (double %).

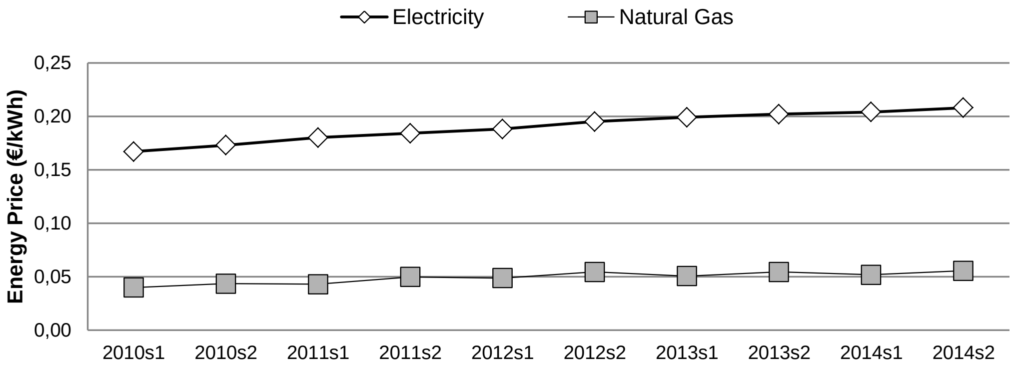


Figure 62 Evolution of EU-28 electricity and natural gas prices (taxes and levies included) for household consumers.

Inflation Rate (IR)

As shown in the section 4.4.4, due to the complexity of European markets, nowadays it is very difficult to determine a specific inflation value in order to assess the increase or decrease of the monetary value for the rehabilitated building's life-cycle. Therefore, two new scenarios have been added to take this issue into account, assuming that the inflation value can be 0% and 3%.

Combination of Different Factors (C)

Finally, in order to explore additional potential situations, 8 new refurbishment scenarios are assessed by combining extreme values for the different parameters defined separately previously. Taking into account the low influence of the material transportation distance (less than 0.01%), this parameter was not included in the combination of different factors.

Strategy ID		C1	C2	C3	C4	C5	C6	C7	C8
RSL_b	100	X	X			X	X		
	25			X	X			X	X
ESL_m	Half	X	X			X	X		
	Double			X	X			X	X
Climate	Palermo	X	X	X	X				
	Oslo					X	X	X	X
EE	Hybrid	X		X		X		X	
	Process		X		X		X		X
ED_b	-20%	X	X	X	X				
	20%					X	X	X	X
CF_x	-20%	X	X	X	X				
	20%					X	X	X	X
EPI_y	0%	X	X	X	X				
	Double					X	X	X	X
Inflation	0%	X	X	X	X				
	3%					X	X	X	X

Other combinations such as increasing energy demand in warm climates, applying materials with 50 ESL_m years in buildings with values of RSL_b of 50 years or reducing inflation when energy demand has been increased, have been discarded since none of these combinations produce new extreme scenarios that provide new critical values.

5.5.2. Results - Discussion. Simplification proposal for the system boundary of the life cycle methodology

The exercise previously developed, and especially the results obtained from this sensitivity analysis, allows analysing what should be the criterion of simplification of the refurbishment strategies evaluation system boundary (determinate by the building life cycle methodology standards EN15978 and FprEN 16627:2014) without jeopardizing the rigor of the results and the resulting decisions.

This end, on the basis of the method of calculation used in sections 5.4 and 5.5, the same study is performed for each of the new scenarios generated after proposing new parameters during the sensitivity analysis, making it possible to gain an overall idea of the influence of each stage in the life cycle on the buildings within the scope of the analysis proposed in the aims of the thesis. To do this, the indicator used for the results remains the percentage of impact (NRPE use and economic impact) respect to the overall impact reduction of the refurbished building during its life cycle.

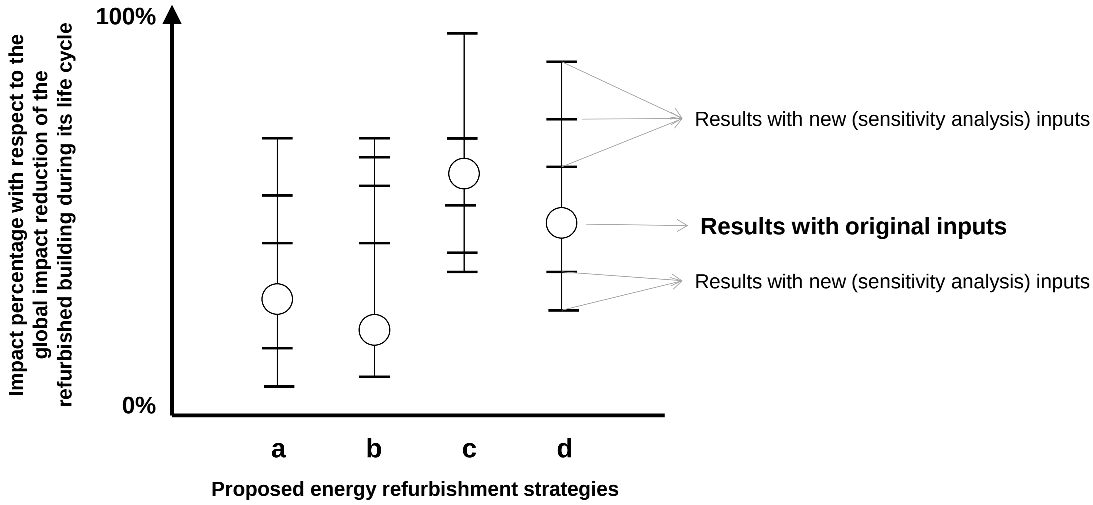


Figure 63 Scheme of the methodology applied to show the variation of the impact percentage of each refurbishment strategy according to each sensitivity assessment

The results will be assessed in detail for each of the stages in the life cycle and for each of the retrofitting strategies proposed, giving a detailed analysis of the influence of the different parameters on each of the different aspects of the study.

> ** All percentage impact values with respect to the global impact reduction of the refurbished building during its life cycle reflected in the graphs of this section shall be defined in annex 7.5.5.*

Environmental assessment

The results show that in most of the evaluated scenarios, the percentage of the environmental impact of each life cycle stage is same or similar for Non Renewable Primary Energy (NRPE) use and Global Warming Potential (GWP) impact indicators (see annex 7.5.5). Therefore, all the discussion and conclusions have focused on evaluating and interpreting the results for the NRPE use impact indicator.

Product Stage (IEE_{A1-3})

The results of this study reflect that in 70% of the evaluated scenarios (case of colder climates or situations with drastic reductions on operational energy use due to a refurbishment strategy) the percentage of the NRPE use impact of the product stage is less than 5% with respect to the overall NRPE use impact reduction of the refurbished building during its life cycle, allowing the omission of this stage (see figure 70). For moderate climates and where products with low embodied energy are used, the omission of this stage might be of sufficient accuracy, focusing the study on the assessment of the reduction on energy use during the operational stage of the building, might be of sufficient accuracy. Of course, it should then be decided and benchmarked which materials are considered low embodied energy. For warm climates and ambitious goals for reducing the energy consumption of buildings by using materials and systems with a high energy embodied values, the omission of the quantification of impacts produced during the production stage (IEE_{A1-3}) can mislead the decision making for choosing solutions with the best life cycle environmental performance. Although if products with low embodied energy are used, it is necessary to quantify this stage in buildings located in warm climates or with low operational energy demand. For example, it is worth noting scenario "C3", in which a building located in a warm climate and with a reduced RSL_b value, being the hybrid system applied when performing embodied energy calculations, the NRPE use impact of the product stage reaches 63% of the overall NRPE use impact reduction (see figure 64).

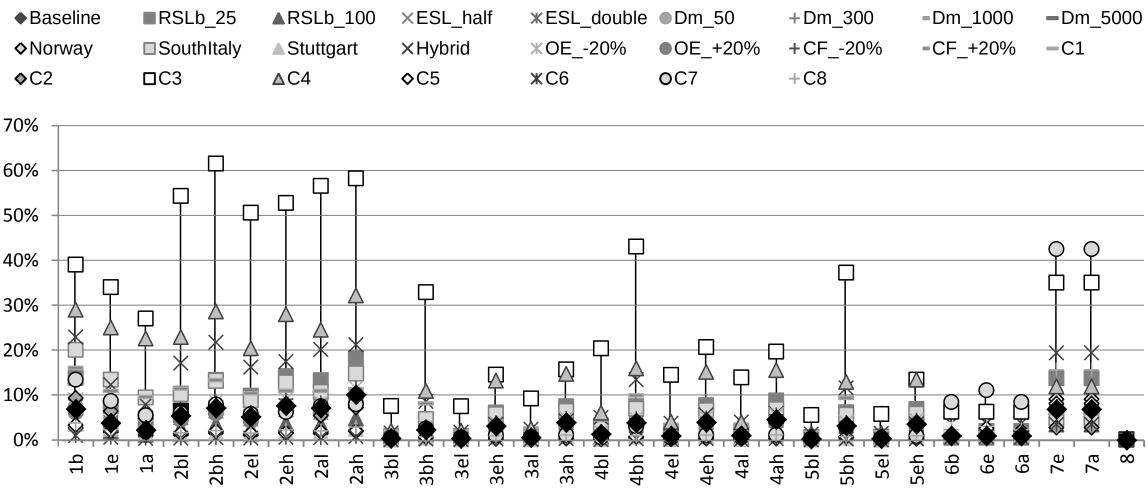


Figure 64 Percentage of NRPE use impact of the product stage with respect to the global NRPE use impact reduction of the refurbished building during its life cycle.

The source of data used in the LCA has a remarkable influence increasing the uncertainty of the results, as significant differences exist in the calculations using data derived from process inventories (e.g., from Ecoinvent and GaBi databases, for instance, or from EPDs) or from hybrid Input-Output analysis. This observation is in line with previous studies (*Crawford, 2008; Stephan et al., 2013*) which have demonstrated that the truncation error associated to process-based life cycle inventories may significantly affect the final results.

Transportation Stage (ITE_{A4})

The results show that in the 98.7% of the scenarios evaluated (see figure 70), el percentage of the NRPE use impact of this stage is less than 1% of the overall NRPE use impact reduction of the refurbished building during its life cycle, allowing the omission of this stage. Only when all products are transported from 5,000 km (very difficult scenario to take into account within the EU), the NRPE use impact of such stage increases, getting to reflect a 1.83% ("4al") maximum value of the overall NRPE use impact reduction during its life cycle (see figure 65).

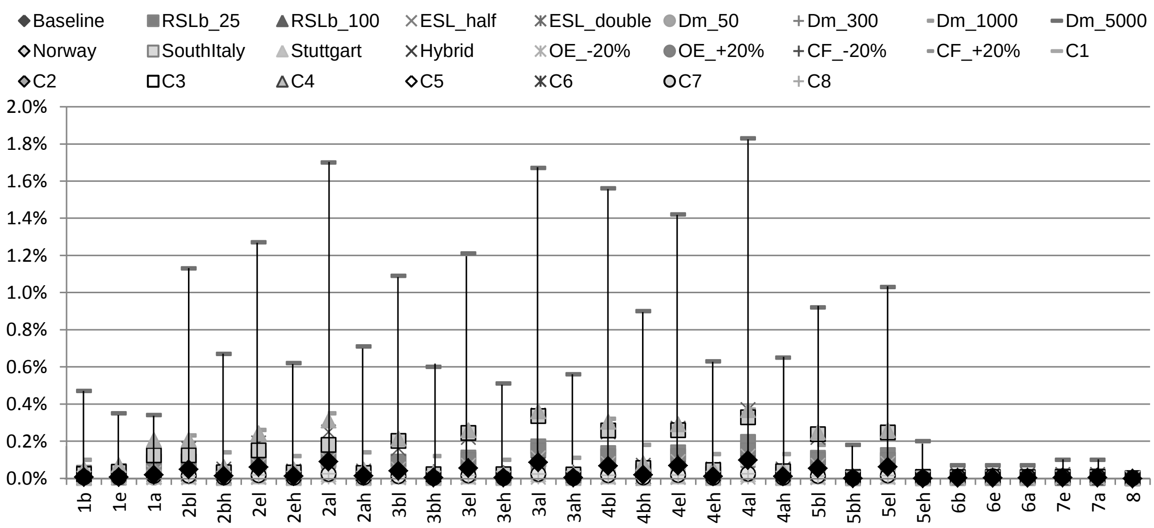


Figure 65 Percentage of NRPE use impact of the transportation stage with respect to the global NRPE use impact reduction of the refurbished building during its life cycle.

Although these results reflect that transport distance is practically irrelevant for reducing the NRPE use, it is worth noting that transport may have remarkable contributions to other environmental impact categories related to air quality or noise. In addition, regarding data associated to the transportation stage (ITE_{A4}), technicians usually have information on the exact location of the distributor of the product or system applied in the refurbishment project, but in many cases the manufacturing location is unknown, being the impacts associated to transport from manufacturer to distributor difficult to calculate.

Construction process Stage (ICE_{A5})

According to the defined environmental assessment scope for this methodology (omitting aspects such as the impact generated by the transport of the employers to the construction site), on no scenario shall the construction process NRPE use impact exceed 1% of the overall NRPE use impact reduction of the refurbished building during its life cycle (see figure 66 and figure 70), allowing the omission of this stage.

However, as for data associated for construction stage (ICE_{A5}), the main barrier is related to the lack and uncertainty of environmental information, which largely depends on project specific parameters and are difficult to assess for a set of different strategies.

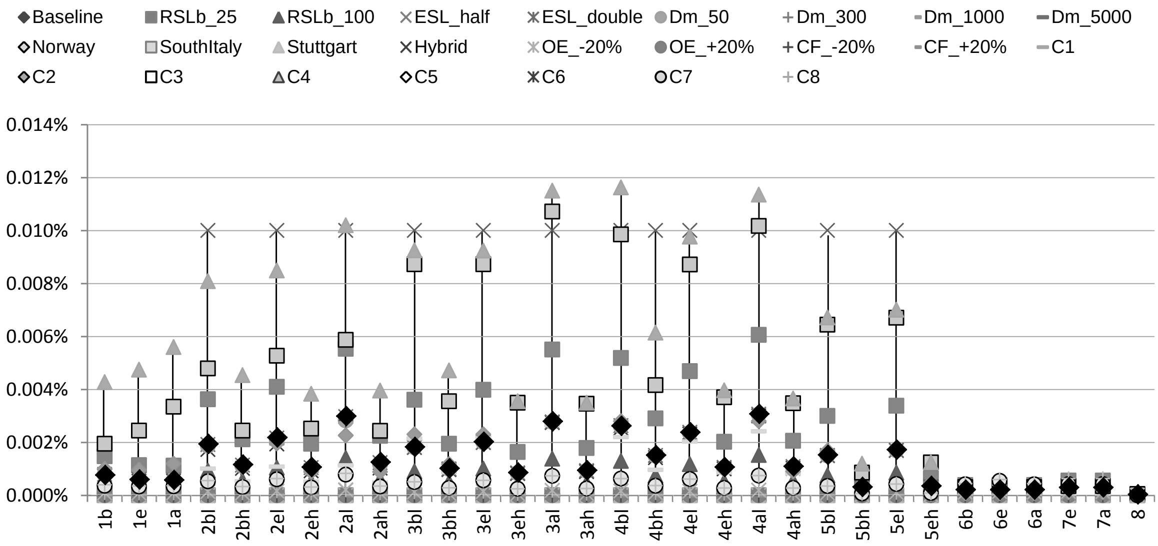


Figure 66 Percentage of NRPE use impact of the product stage with respect to the global NRPE use impact reduction of the refurbished building during its life cycle.

Replacement Stage: product (REE_{B4}), transportation (RTE_{B4}) and construction stages (RCE_{B4})

When assessing the replacement stage (B4), results are divided into three sub-stages: impact generated during the production, transport and construction process of the replaced refurbishment strategies. It should be noted that the impact of such stage shall be directly linked to the relationship between RSL_b and ESL_m values. The greater the difference between these two values, the greater the importance of such stage and vice versa. Therefore, it is very important to emphasize that the inadequate definition of the RSL_b and ESL_m values increases the uncertainty of the results. In fact, the difficulty of determining with certainty these two values (influence of climatic conditions or other alterations that make necessary the replacement of the refurbishment strategy) may significantly affect the final results.

The results of this study reflect that in 83% of the evaluated scenarios (case of colder climates, situations with drastic reductions on operational energy use due to a refurbishment strategy or similar ESL_m and RSL_b values) the percentage of the NRPE use impact of the replacement-product stage is less than 5% of the overall NRPE use impact reduction of the refurbished building during its life cycle (see figure 70). Therefore, in this type of scenario, omitting this stage ($REE_{B4\_(A1\text{-}3)}$) shall not change the final value of the results (again consider the problem of the source of data in the LCA and its influence). However, when the evaluated stage is located in warm climates (situations with little reductions on operational energy use due to a refurbishment strategy) or when the rehabilitation strategies' service life value (ESL_m) is less than the service life (RSL_b) of the building to be rehabilitated, the impact of such stage can generate 56% of the overall NRPE use impact reduction during its life cycle. It is worth noting that this high impact percentage is considerably reduced when the source of data used in the LCA is derived from "process inventories" ("C2"), reducing its value from 56% to 32% (see figure 67).

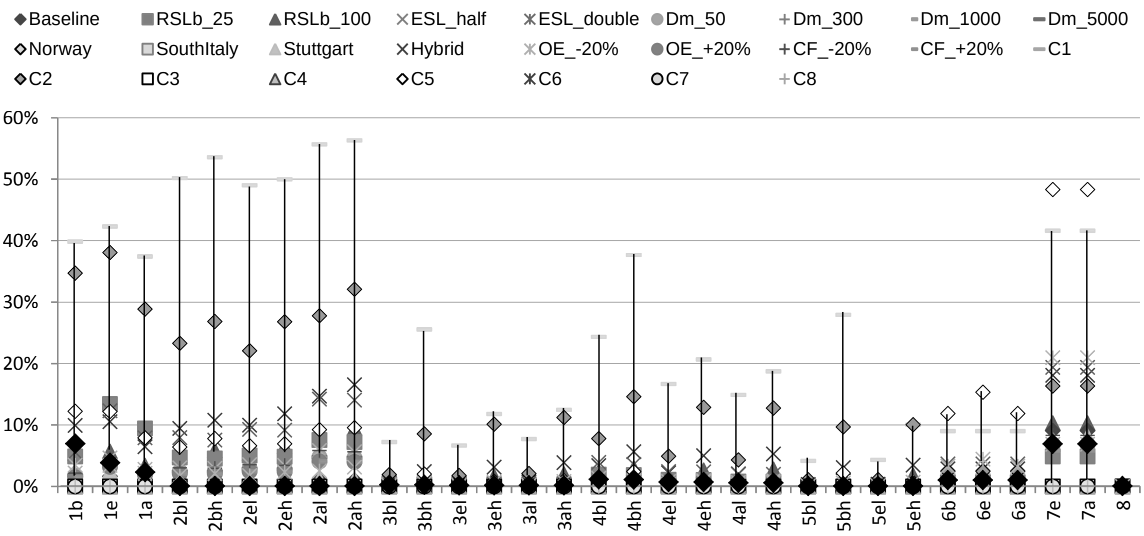


Figure 67 Percentage of NRPE use impact of the product replacement stage with respect to the global NRPE use impact reduction of the refurbished building during its life cycle.

Regarding the sub-stage of transportation of products ($RTE_{B4\_(A4)}$) and construction processes ($RCE_{B4\_(A5)}$), the results show that in the 100% of the evaluated scenarios the percentages of NRPE use impact are less than 1% of the overall NRPE use impact reduction of the refurbished building during its life cycle, allowing the omission of these stage (consider the problem of the lack or uncertainty of the environmental information). In some rehabilitation strategies, in which the scenario suggests that all products replaced are transported from 5,000 km, the transportation stage ($RTE_{B4\_(A4)}$) NRPE use impact percentage approached 0.8% of the overall NRPE use impact reduction, but none of the scenarios exceeded the 1% barrier. The same applies to the construction process stage ($RCE_{B4\_(A5)}$), in which the greatest NRPE use impact percentage is 0.125%.

Operational energy use stages NRPE use impact reduction (RED_{B6_EN})

The results reflect that in most of the evaluated scenarios (more than 90%), the percentage of the NRPE use impact of this stage is higher than 80% of the overall NRPE use impact reduction of the refurbished building during its life cycle (see figure 70), where in 74% of the cases, its impact percentage is greater than 90%. Namely, this stage correct assessment shall be one of the foundations of the evaluation of many of the energy rehabilitation projects on buildings with similar characteristics. For example, in scenarios like "C8", where its location fosters situations with drastic reductions on operational energy use due to a refurbishment strategy and to the fact that the relationship between ESL_m and RSL_b values eliminates the need for replacing any of the strategies ($RSL_b \leq ESL_m$), this stages' NRPE use impact percentage with respect to the overall NRPE use impact reduction during its life cycle can reach 99.8% values ("3el"). In these cases, results might justify the implementation of those evaluation systems that only evaluate this life-cycle stage. However, for warm climates or situation with low reduction on operational energy use, the NRPE use percentage impact of this stage reduces, reaching minimum values of 27% (applying the strategy "1b" in the "C3" scenario).

Therefore, this 99.8% to 27% variation (see figure 68) in the results makes it difficult to apply the results of such stage indiscriminately, for in some scenarios this shall be the only influencing life-cycle stage when prioritising between different rehabilitation strategies and, in other cases, its influence on decision-making processes shall be much smaller. In addition, the uncertainty in relation to occupancy schedules, user behaviour and the correct calculation of the energy demand/consumption reduction has a remarkable influence increasing the uncertainty of the results related to this life cycle stage.

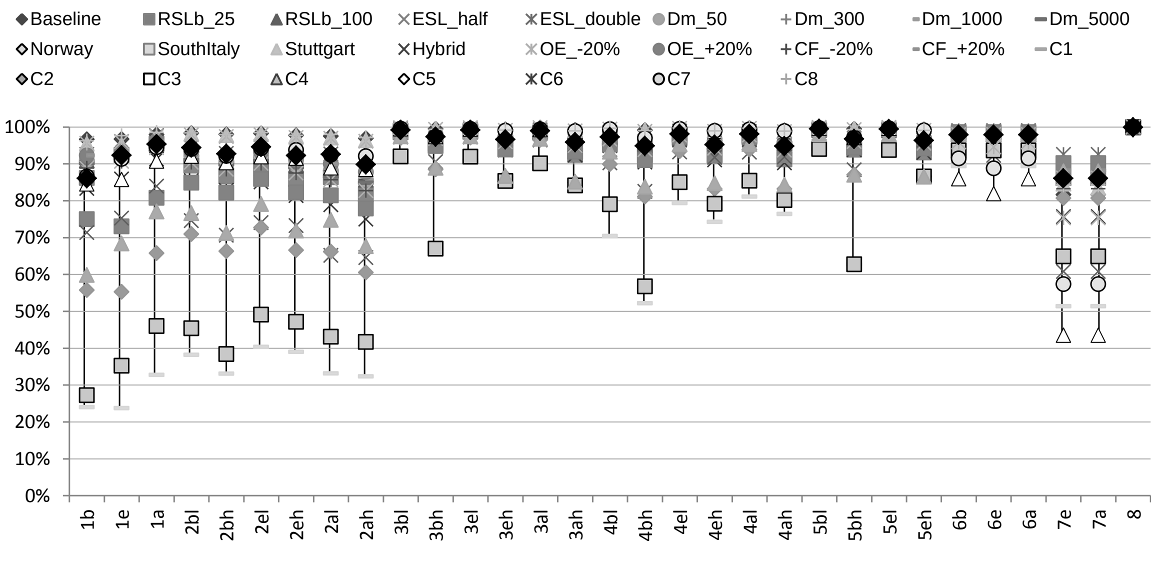


Figure 68 Percentage of NRPE use impact of the operational Energy use stage with respect to the global NRPE use impact reduction of the refurbished building during its life cycle.

With regards to renewable strategies such as photovoltaic systems ("7"), results show that the values of this phase might vary considerably due to aspects such as solar incidence on different climates or the system's ESL_m value. For example, in scenarios like "C5", where the case study is located in Oslo and photovoltaic panels ESL_m is reduced by half, the NRPE use impact percentage of such stage reflects 43.5% of the overall NRPE use impact reduction. Whereas in other scenario in which the building is located in San Sebastian and the values defined for the ESL_m and RSL_b parameters avoid all replacements, the NRPE use impact percentage shall increase to reach the 92.5% overall impact value.

End of life Stage ($EL_{C1\text{-}4\_EN}$)

Finally, the results reflect that in most of the evaluated scenarios (100% in NRPE use and more tan 92% in GWP), the percentage of the environmental impact of the end of life stage ($EL_{C1\text{-}4\_EN}$) is less than 1% of the overall NRPE use impact reduction of the refurbished building during its life cycle, allowing the omission of this stage in all of the scenarios. However, due to the lack of information about future waste management processes, the uncertainty of the end of life stage is also very large.

Summary

After considering the results, the values obtained make it possible to give a detailed view of the importance of each stage in terms of the impact reduction of the retrofitted building during its life cycle. Finally, to conclude the consideration of the environmental results and show the general conclusions drawn during the process of optimising of the system boundary, this study will take as a basis the scheme proposed in figure 69.

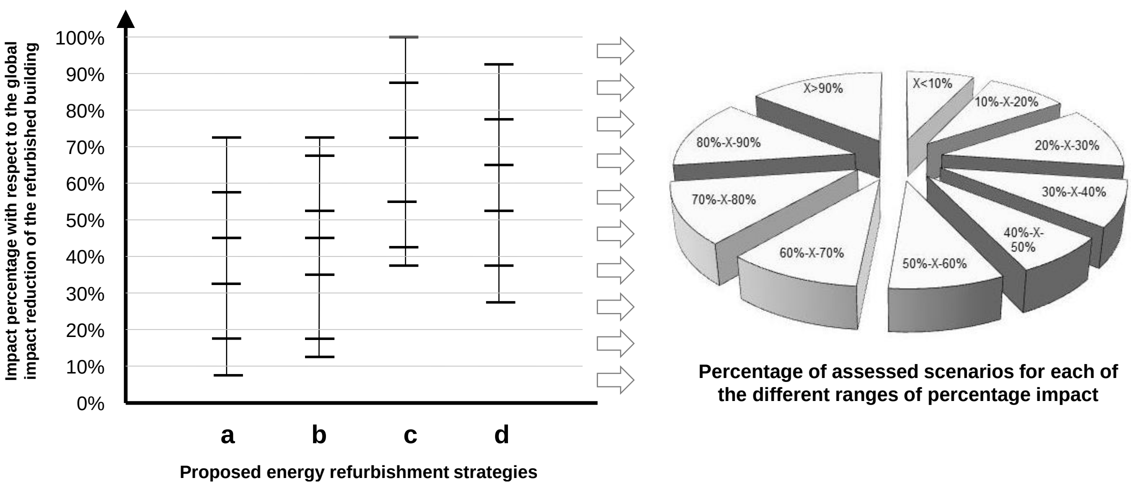


Figure 69 Scheme of the methodology applied to show the percentage of scenarios for each of the different ranges of percentage impact

On the basis of this scheme, the results obtained in the whole environmental analysis section will be grouped according to their impact percentage value, showing how many of the 775 environmental scenarios assessed reflect each percentage range in each of the stages in the life cycle.

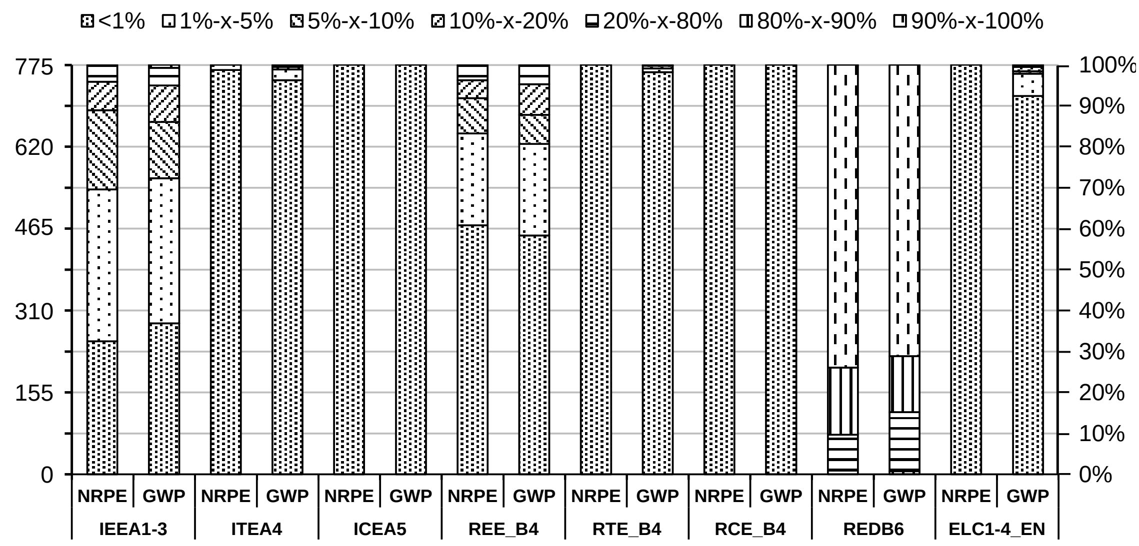


Figure 70 Summary of the percentage of assessed scenarios for each of the different ranges of environmental percentage impacts per each life cycle stage

<u>Economic assessment</u>

In accordance with the work line established by the environmental evaluation and in order to analyse what criteria to apply when simplifying the refurbished buildings' economic evaluation system boundary, the economic impact percentage generated during each of the rehabilitated building's life-cycle stages is then quantified and evaluated.

** The source of data used in the LCA of products and systems (process or hybrid) has no influence on economic calculations. Therefore, it is proposed to make the following simplifying the previously defined combinations: C1 = C2, C3 = C4, C5 and C6 = C7 = C8.*

Product Stage ($IC_{A1\text{-}3}$)

For situations with drastic reductions on operational energy use due to a refurbishment strategy and RSL_b values higher than 70 years (32% of the evaluated cases), the percentage of the economic impact of the product stage ($IC_{A1\text{-}3}$) is less than 5% of the overall economic impact reduction of the refurbished building during its life cycle (see figure 78), allowing the omission of this stage in this scenarios. In addition, due to the different renewable systems' energy generation potential (directly related to economic savings for the operational energy use stage), the impact percentage of such stage in almost all scenarios shall be less than 5%.

However, for moderate - warm climates and other scenarios, the omission of the quantification of economic impacts produced during this stage can mislead the decision making for choosing solutions with the best life cycle economic performance. For example, it is worth mentioning scenario "C3" (situations with little reductions on operational energy use due to a refurbishment strategy), in which the RSL_b value is low (less than 30 years) and the economic scenario does not suggest any increase in energy prices, the product stage economic impact exceeds 40% of the of the overall economic impact reduction of the refurbished building during its life cycle (see figure 71), reaching values of 59% (“3al”). Meaning that, with regards to one of the economic analysis foundations of the building subject to rehabilitation, such stage’s impact can reach very significant values during its life-cycle.

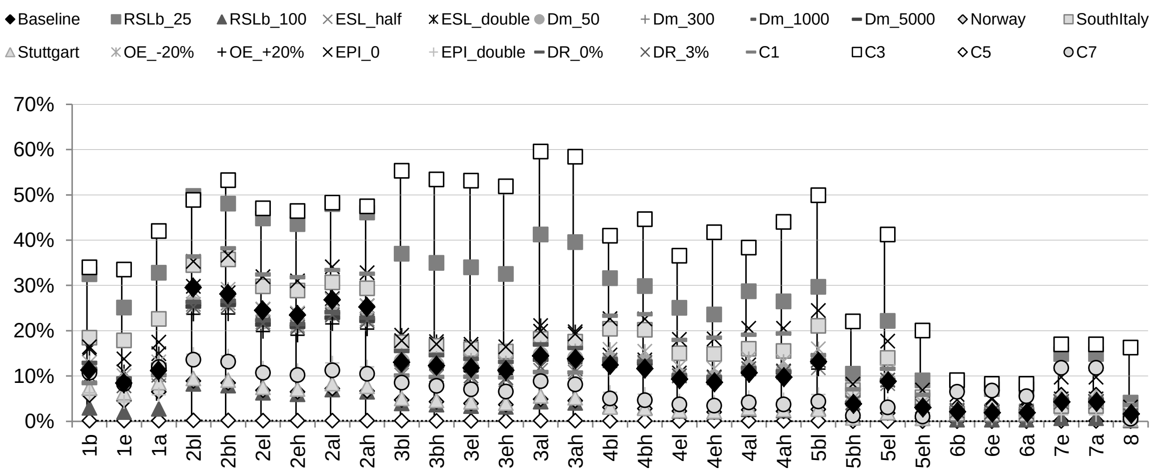


Figure 71 Percentage of economic impact of the product stage with respect to the global economic impact reduction of the refurbished building during its life cycle.

Finally, the economic source of data used in the LCC has a remarkable influence increasing the uncertainty of the results, as significant differences exist in the calculations using data derived from different inventories or different state members (*BKI, 2009*). Therefore, this uncertainty may significantly affect the final results.

Transportation Stage (ITC_{A4})

Results show that, except for those scenarios in which all products are transported from a 5,000 km distance (3.7% of the evaluated scenarios), the impact of all the other evaluated scenarios is less than 1% of the overall economic impact reduction of the refurbished building during its life cycle, allowing the omission of this stage (see figure 72 and figure 78). In the event that all products are transported from 5,000 km distances, such stages direct economic impact percentage increases, reaching up to 5.5% (“4al”) of the overall economic impact reduction during its life cycle.

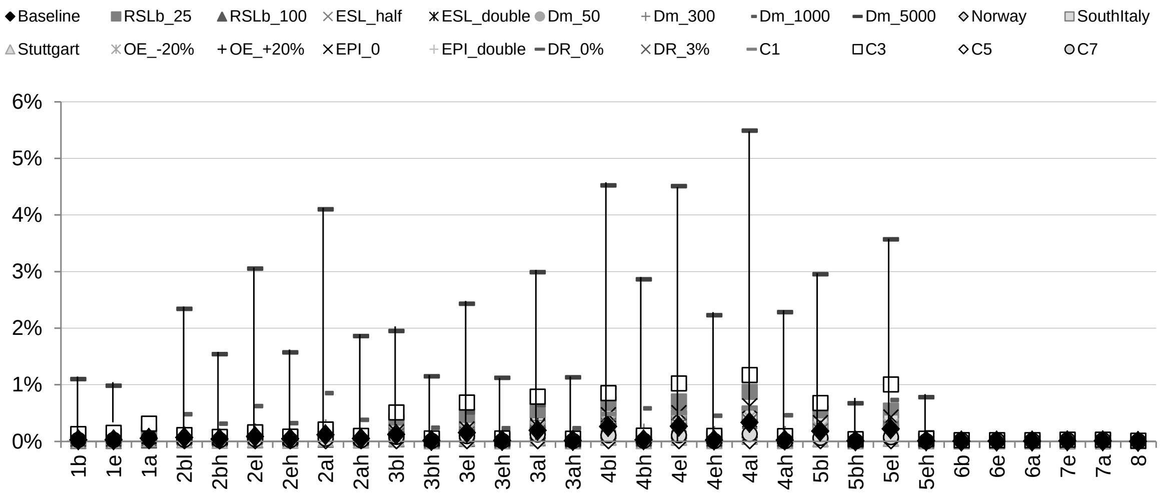


Figure 72 Percentage of economic impact of the transportation stage with respect to the global economic impact reduction of the refurbished building during its life cycle.

Construction process Stage (ICC_{A5})

In accordance with the economic evaluation scope defined by this methodology for the construction process stage (omitting aspects such as the impact generated by the transport of the employers to the construction site or the workers wage economic impact), such stage's impact percentage with respect to the overall economic impact reduction is less than 5% in 72% of the scenarios evaluated during this study. Scenario "C5" is noteworthy scenario for its economic impact percentage value after the implementation of all rehabilitation strategies evaluated in this work shall be less than 1 % of the overall economic impact reduction during its life cycle due to the economic influence of other life-cycle stages.

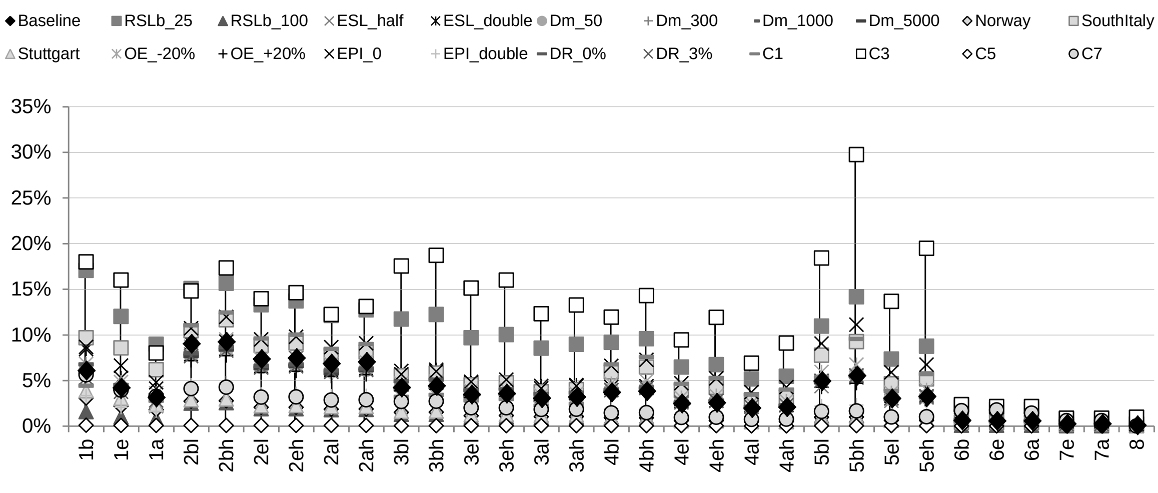


Figure 73 Percentage of economic impact of the construction process stage with respect to the global economic impact reduction of the refurbished building during its life cycle.

The same applies to photovoltaic systems ("7") and biomass boiler ("8"), in which their construction process impact percentage shall be less than 1% in all scenarios. On the contrary, in scenarios with similar characteristics to those of "C3", in which the importance of stages such as the operational energy use is reduced, the impact percentage of such stage shall exceed 10% of the overall economic impact reduction of the refurbished building during its life cycle (see figure 73), reaching values of 29.7% ("5bh").

Maintenance Stage (MC_{B2})

Results show that maintenance-stage-related economic costs are responsible for less than 5% of the overall economic impact reduction of the refurbished building during its life cycle in 27% of the scenarios evaluated (see figure 78). For example, in all strategies applied for the "C5" combination, the impact percentage associated with such stage shall be less than 1% of the overall economic impact reduction (see figure 74). The same applies to strategies by which windows are replaced ("1") or insulation is injected into the building's air-chamber ("5"), which demand for reduced maintenance economic costs.

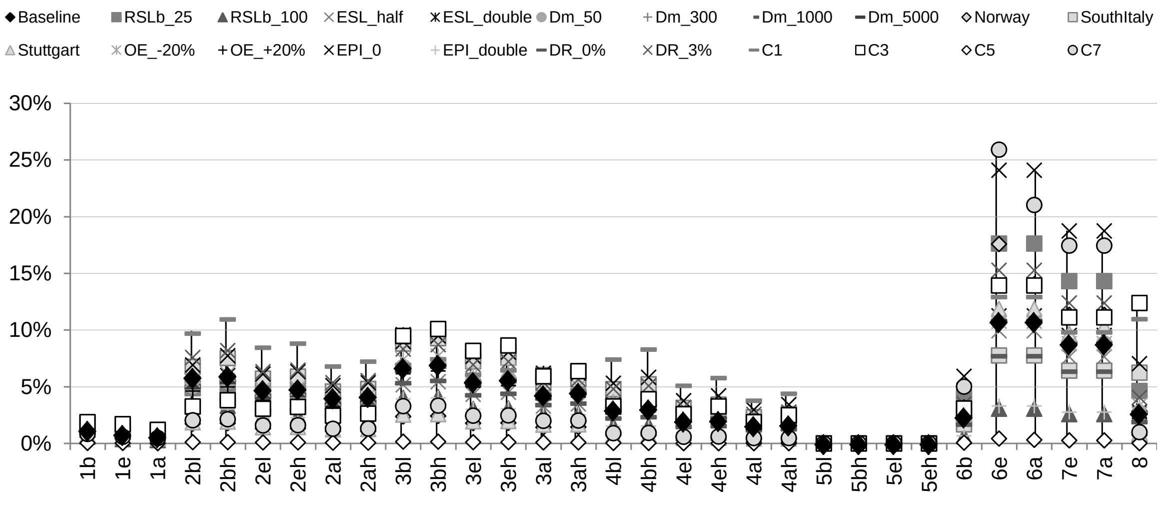


Figure 74 Percentage of economic impact of the maintenance stage with respect to the global economic impact reduction of the refurbished building during its life cycle.

However, in many of the other strategies, the impact exceeds the 5% threshold. For those scenarios in which the characteristics of the building subject to rehabilitation are similar to those of scenarios "C1" and "C3", in which the impact percentage might exceed values of 10% ("2bh") of the overall economic impact reduction of the refurbished building during its life cycle, due to aspects such as the building's service life, the relationship between RSL_b-ESL_m values or low reductions on operational energy use due to a refurbishment strategy. In addition, when installing photovoltaic ("7") or solar thermal ("6") systems, their maintenance cost increases considerably, especially in scenarios with low RSL_b values, reducing the building's life-cycle renewable energy generation potential. For example, as shown in figure 74, a solar thermal system ("6e") installed in a scenario "C7" (climates with low solar radiation incidence and buildings with periods of service life lower than 30 years), such stage's impact percentage might reach 26.1% of the of the overall economic impact reduction. Therefore, the omission of the quantification of impacts produced during the maintenance stage (MC_{B2}) can mislead the decision making for choosing solutions with the best life cycle environmental performance.

Replacement Stage: product (RC_{B4}), transportation (RTC_{B4}) and construction stages (RCC_{B4})

The results of this study reflect that in 51% of the evaluated scenarios (case of colder climates, situations with drastic reductions on operational energy use due to a refurbishment strategy, when ESL_m values are similar or equal to RSL_b ones or when the need for a replacement is reduced or eliminated thanks to factors such as good maintenance and proper installation) the percentage of the economic impact of the replacement-product stage is less than 5% of the of the overall economic impact reduction of the refurbished building during its life cycle (see figure 78). Therefore, in this kind of scenarios, omitting this stage ($RC_{B4\_(A1-3)}$) shall not alter the final value of the results. However, when the scenario subject to evaluation is located in warm-moderate climates (situations with little or moderate reductions on operational energy use due to a refurbishment strategy), the rehabilitation strategies service life (ESL_m) value is lower than the reference service life of the refurbished building (RSL_b) or when the scenario suggested has a high inflation value, increasing the cost for rehabilitation products and systems to be applied during the replacement stage, such stage's impact percentage might exceed 30% of the of the overall economic impact reduction during its life cycle.

Take the case of scenario "C1", in which the building is located in a warm climate, the RSL_b of the building subject to rehabilitation is 100 years, whereas, due to various reasons such as climate severity, inadequate construction process, lack of maintenance, etc. the refurbishment strategy's ESL_m has been halved and the energy price has not increase (directly related to the operational energy use stages impact reduction), such stage's impact percentage might reach 54.3% ("3al") of the overall economic impact reduction of the refurbished building during its life cycle (see figure 75). Therefore, whenever the ESL_m value is minor than RSL_b value and the potential of the operational energy use reduction is not high (moderate to warm climates), the omission of the quantification of impacts produced during the replacement -product stage ($RC_{B4\_(A1-3)}$) can mislead the decision making for choosing solutions with the best life cycle economic performance.

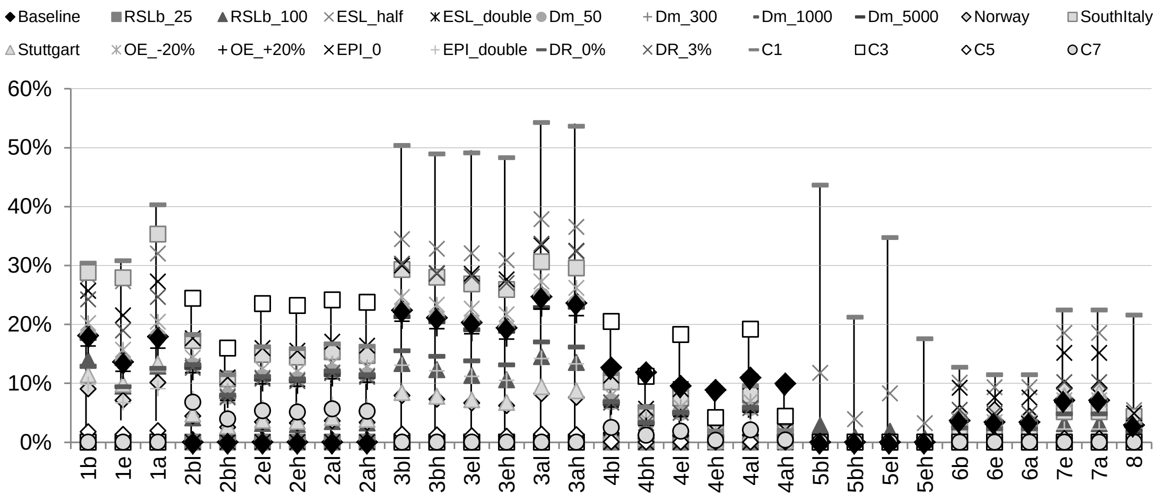


Figure 75 Percentage of economic impact of the product replacement stage with respect to the global economic impact reduction of the refurbished building during its life cycle.

With respect to the product transport sub-stage ($RTC_{B4\_(A4)}$), results show that in 98.5% of the scenarios evaluated, such stage's economic impact percentage is less than 1% of the overall economic impact reduction of the refurbished building during its life cycle, allowing the omission of this stage. Only in extreme scenarios in which all products are transported from 5,000 km distances, this sub-stage's direct economic impact percentage reaches values of 5.1% ("3al").

Regarding the construction process sub-stage ($RCC_{B4\_(A5)}$), because of the relationship between the RSL_b-ESL_m values, results show that in 85% of the scenarios evaluated such stage's impact percentage is less than 5% of the overall economic impact reduction of the refurbished building during its life cycle. Furthermore, the impact of buildings with low RSL_b values or rehabilitation strategies in which the ESL_m values are equal to or higher than the RSL_b ones shall be null. This way, omitting such stage shall not change the study's outcome. On the contrary, as shown in figure 76, when applying rehabilitation strategies such as "3" (strategy with low ESL_m value) on scenarios like the "C1" (RSL_b value of 100 years and situations with little reductions on operational energy use due to a refurbishment strategy), such stage's impact percentage value might increase considerably with respect to the overall economic impact reduction of the refurbished building during its life cycle, exceeding values of 17% ("3bh"). Therefore, whenever the ESL_m value is lower than the RSL_b one and the reduction on operational energy use potential is not drastic, such stage's economic impact shall need to be evaluated.

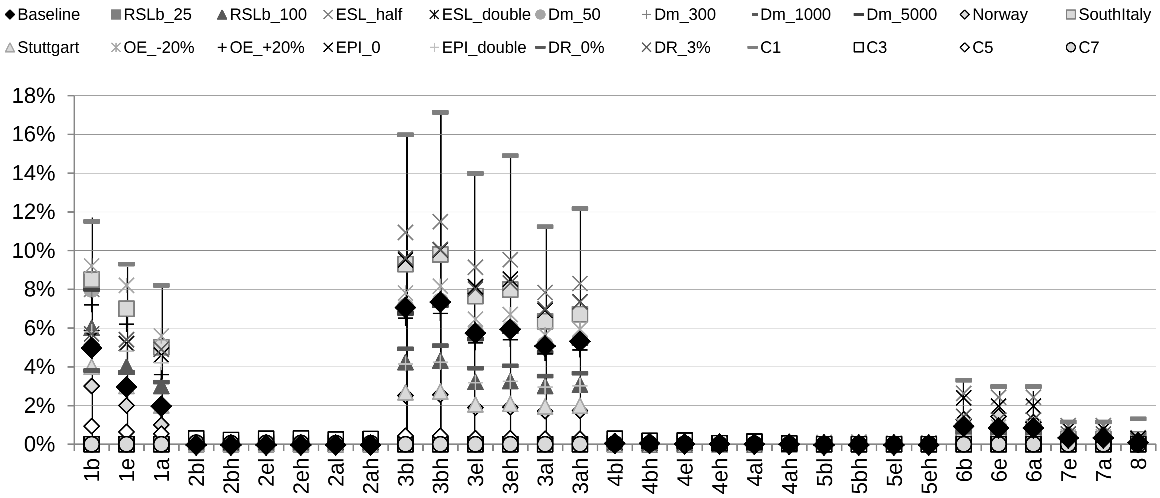


Figure 76 Percentage of economic impact of the construction process - replacement stage with respect to the global economic impact reduction of the refurbished building during its life cycle.

The lack of information about aspect such as the manufacturing location, the difficulty to determinate correctly the values of RSL_b and ESL_m, and the inflation data used in the Life Cycle Cost assessment have a remarkable influence increasing the uncertainty of the results.

Operational energy use stages economic impact reduction (RED_{B6_EC})

After applying different rehabilitation strategies on each one of the scenarios suggested during the sensitivity analysis, in comparison with environmental results, economic results (see figure 77) show that depending on the applied strategy or the building's service life (RSL_b) value, such stage's impact percentage might represent from 7.5% to 99.9% of the overall economic impact reduction of the refurbished building during its life cycle. Therefore, the omission of the quantification of impacts produced during the operational stage (RED_{B6_EC}) can mislead the decision making for choosing solutions with the best life cycle economic performance.

The results reflect that in most of the evaluated scenarios (more than 79%), the percentage of the economic impact of this stage is higher than 50% of the overall economic impact reduction of the refurbished building during its life cycle (see figure 78), where in 39% of the cases, its impact percentage is greater than 80%. That is to say, such stage's correct assessment is one of the key factors when assessing many of the energy rehabilitation projects in buildings in which decisions are taken according to the economic impact reduction. For example, in scenarios like "C5", in which the

RSL_b value is high (>50 years) and energy prices increase is higher than in the current scenario, such stage's impact percentage might reach 99.9% of the overall economic impact reduction ("4el", "4eh", "4ah", "5bh" and "5eh"). In these cases, results may justify the application of evaluation systems that only quantify the impact generated during this life-cycle stage. On de contrary, such stage's impact percentage is less than 30% of the overall impact in extreme scenarios. For example, in those such as "C3" in which the building is located in climate zones with little reduction on operational energy use potential and energy prices do not increase (0%), their impact percentage can be reduced reaching 7.7% ("2bl") of the overall economic impact reduction of the refurbished building during its life cycle.

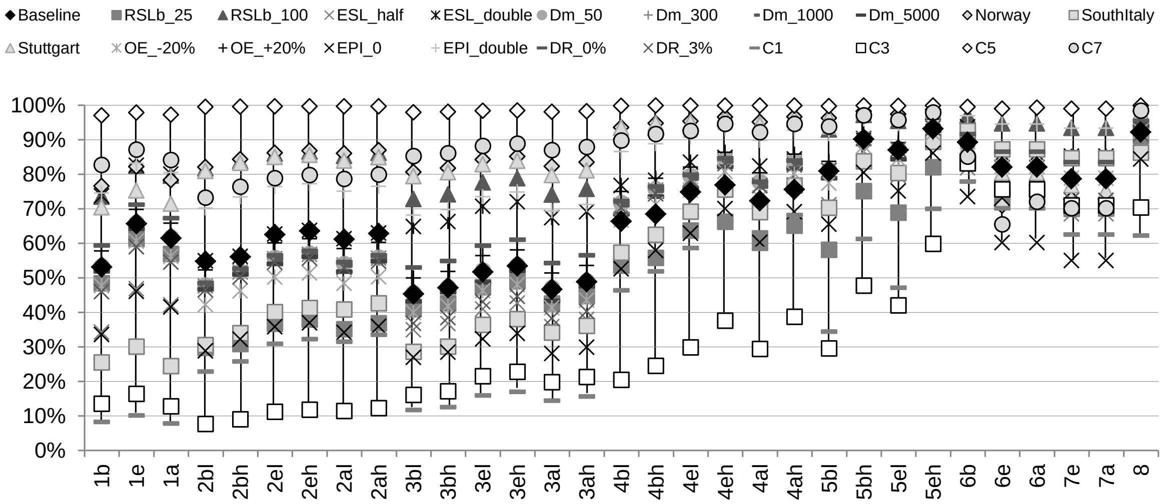


Figure 77 Percentage of economic impact of the operational energy use stage with respect to the global economic impact reduction of the refurbished building during its life cycle.

The uncertainty in relation to the correct calculation of the energy demand/consumption reduction (direct relation with inhabitants behaviour) and to the energy price increment values have a remarkable influence, increasing the uncertainty of the results.

End of life Stage (EL_{C1-4_EC})

Finally, the results reflect that in most of the evaluated scenarios (92.5%), the percentage of the economic impact of the end of life stage (EL_{C1-4_EC}) is less than 1% of the overall economic impact reduction of the refurbished building during its life cycle, allowing the omission of this stage in all of the scenarios. However, due to the lack of information about future waste management processes, the uncertainty of the end of life stage is also very large.

Summary

Based on the same criterion for calculating and representing the results set forth in the environmental section, the results obtained in the whole economic analysis section will be grouped according to their impact percentage value (see figure 78), showing how many of the 662 economic scenarios assessed reflect each percentage range in each of the stages in the life cycle.

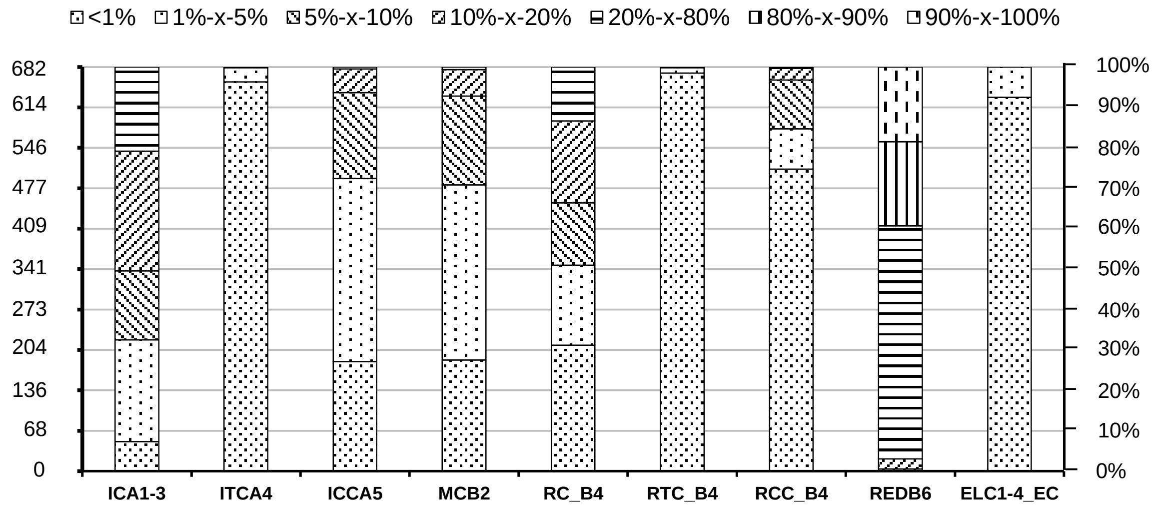


Figure 78 Summary of the percentage of assessed scenarios for each of the different ranges of economic percentage impacts per each life cycle stage

5.6. Techno-economic assessment and prioritizing process between energy refurbishment strategies

In order to end the debate on the level of complexity and rigor that the system evaluation should have when prioritising between the different energy rehabilitation performances, the last stage of the methodology shall focus on making a critical reading of the environmental-economic results obtained and on evaluating the influence of some of the parameters that define this decision-making methodology.

The impact indicators results' reading shall be made by means of the "Unified system" (see 4.6 section), allowing for making unified decisions pursuant to environmental and economic results.

- **Graphic 1**: NRPE use reduction (MJ/m^2·a), NRPE use reduction (%) and IRR (%)
- **Graphic 2**: NRPE use reduction (MJ/(m^2·a)), NRPE use reduction (%) and LC-PB (years)
- **Graphic 3**: NER and IRR (%)
- **Graphic 4**: NER and LC-PB (years)

** All values reflected in the graphs of this section shall be defined in annex 7.5.6.*

Along with the rehabilitation strategies suggested (see 5.3.3) and analysed during this case study, this last stage of the work shall also evaluate the **efficiency level increase** influence of the different strategies (see figure 79). That is, so far, this study has focused on comparing each rehabilitated building with regards to its baseline (option "A", see figure 27). However, this parameterised evaluation system (option "B"), shall assess the environmental and economic performance thanks to each strategy's efficiency level, optimising between decisions such as optimum thickness of the new envelope's isolation or the photovoltaic panels surface.

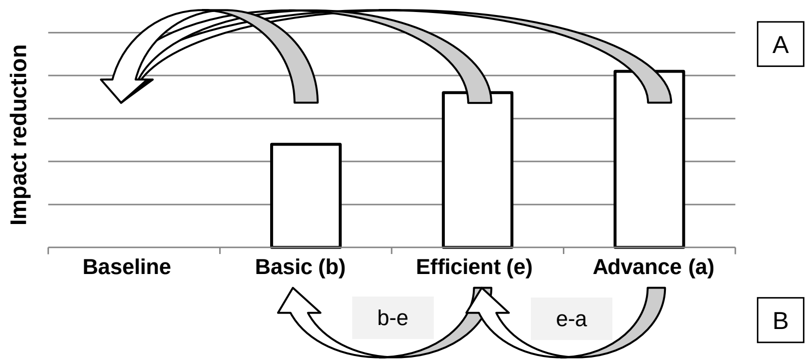


Figure 79 Scheme of the refurbishment efficiency level optimization

Table 36 shows how each rehabilitation strategy's parameterised evaluation shall generate new sub-strategies that shall be evaluated during this last stage.

Table 36 New rehabilitation scenarios created from the efficiency optimization

Strategy	"1"	"2"	"3"	"4"	"5"	"6"	"7"
New scenarios	1b-1e 1e-1a	2bl-2el 2el-2al 2bh-2eh 2eh-2ah	3bl-3el 3el-3al 3bh-3eh 3eh-3ah	4bl-4el 4el-4al 4bh-4eh 4eh-4ah	5bl-5el 5bh-5eh	6b-6e 6e-6a	7e-7a

Finally, before showing the results, the first phase focuses on determining the new assessment methodology system boundary. To do so, based on various simplifications, it is possible to reduce the life-cycle methodology evaluation complexity and obtain final results without ceasing to be rigorous in the calculations and being certain that the values' quality is not be reduced. In this case, this study shall only leave out those life-cycle stages in which the impact percentage (either environmental or economic) are less than 1% of the building's overall impact in more than 90% of the scenarios evaluated. According to this "percentage limitation" or cut-off rule and each life-cycle stage's impact percentage results obtained in the study of section 5.5, following is defined the system boundary to be applied for the assessment of this case study.

	A1-3	A4	A5	B2	B4			B6	C1-4
					A1-3	A4	A5		
Environment	X	Omitted	Omitted	-	X	Omitted	Omitted	X	Omitted
Economic	X	Omitted	X	X	X	Omitted	X	X	Omitted

5.6.1. Summary of results of the case study

Once all stages that shall be integrated into the final calculations have been decided and all calculations for each and every one of the impact indicators have been made (see section 4.6), the following are 4 graphics that reflect the results that shall be applied when prioritising and making decisions between different energy rehabilitation strategies.

First overall reading of the results (see figure 80) shows how in those rehabilitation strategies with higher reduction rate of NRPE use, their Internal Rate of Return (IRR) value is very low (even negative in many cases) and their Life Cycle PayBack (LC-PB) value is very high (see figure 81), in some cases, even higher than the RSL_b value of the building to be rehabilitated. When evaluating the results in further detail, different conclusions and considerations can be determined.

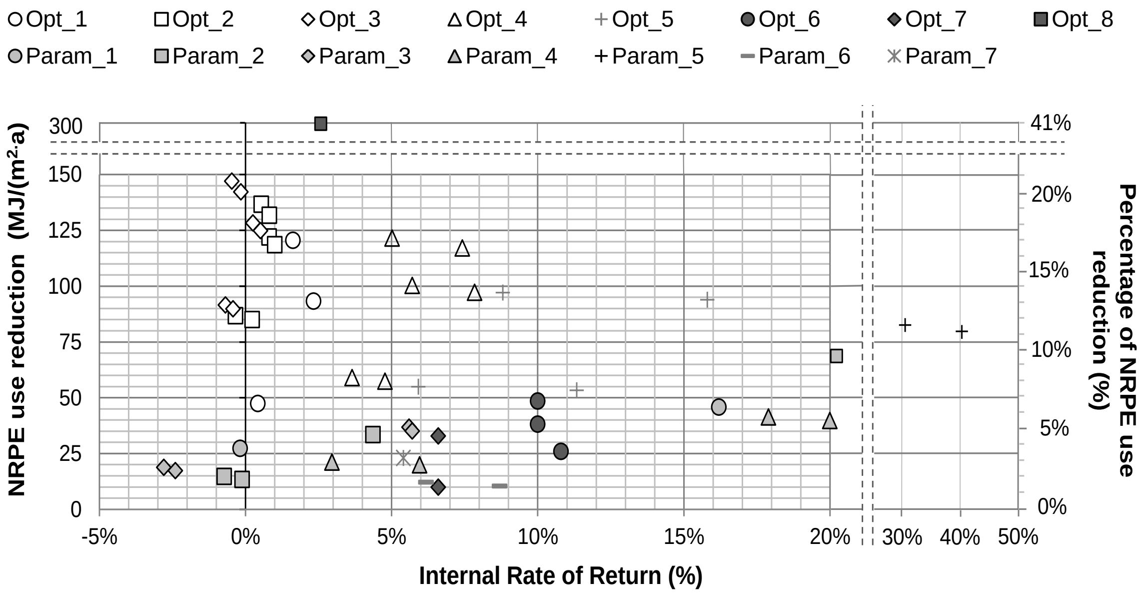


Figure 80 Analysis of the NRPE use reduction and IRR values of each refurbishment strategy.

Even if rehabilitation strategies such as the installation of ventilated facades or the external insulation system ("2 - 3") did reduce the existing building NRPE use overall impact by 20% during its life cycle ("3al"), in most cases, their profitability is negative (-0.69% in "3bl") reaching, at best, the 1% value ("2eh"). Meaning that, in a similar scenario to the one suggested in this case study, economic profitability for this type of rehabilitation strategies is less than 3% of the advised profitability. This low profitability is directly linked to the LC-PB value, as shown by such strategies in groups "2" and "3" in which the value of LC-PB exceeds 42 years, reaching values of up to 54 years ("3bl").

As for strategies "4" and "5", focused on increasing the building's envelope thermal resistance on the inside of the outer wall and installing thermal insulation in the existing enclosure air chamber, due to the system's material reduction and resources applied on the construction process stage, the IRR value during the evaluation period shall be positive, reaching values of up to 15.8%. ("5eh"). The LC-PB value of these strategies shall also be much lower, with values ranging from 10 ("5bh") and 27 ("4bl") years of return on investment. On the contrary, this type of strategy does not allow for insulating the outer facade in a continuous basis, hampering the building's thermal behaviour and reducing the NRPE use impact decrease with regards to strategies "2 - 3".

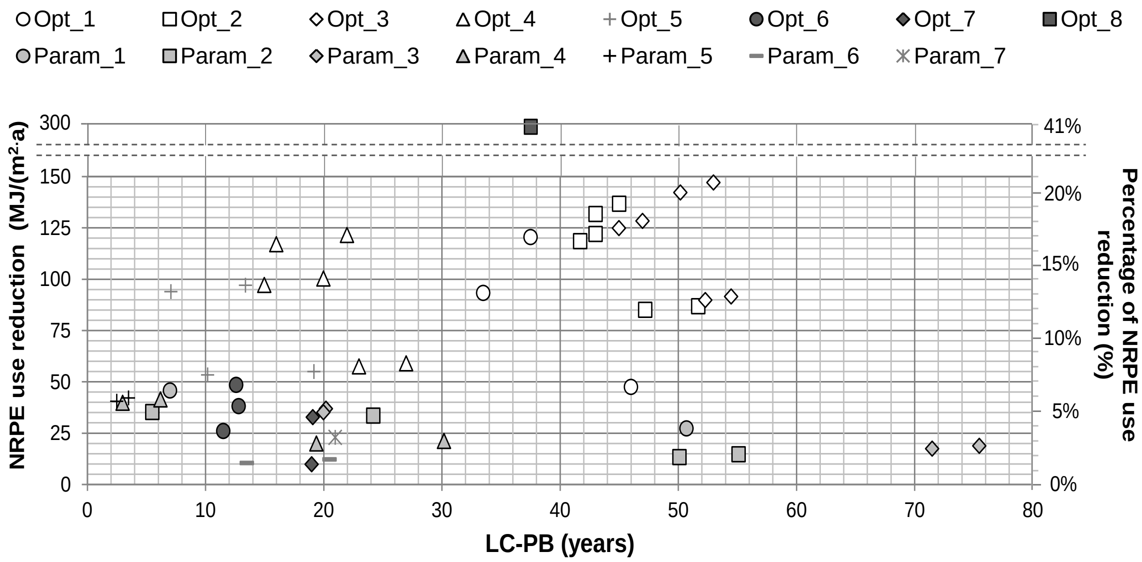


Figure 81 Analysis of the NRPE use reduction and LC-PB values of each refurbishment strategy.

The economic strength of renewable systems (“6-7”) is. In solar thermal systems (“6”), their IRR value can reach 10% and the LC-PB value is less than 12 years. Regarding PV systems (“7”), their IRR value is 6% and their LC-PB value shall be 19 years (directly linked to each country’s electricity prices and electrical policies). However, due to superficial limitations when implementing these kind of technologies (usually limited to their placement on the roofs of buildings), it is difficult to considerably reduce the building’s NRPE use overall impact. For instance, all the energy generated by the two systems (“6a - 7a”) of this case study only reduced the baseline NRPE use impact by 11% (81 MJ/m^2·a).

Finally, the different rehabilitation strategies parametrisation (evaluations based on option “B”) allows for going into detail when prioritising between different options and making decisions based on their level of efficiency. The more the thermal-energy performances of each strategy, the greater the amount of materials used (increase in insulation thickness, in the aluminium frame section of the strategy "2" substructure or in the surface of solar thermal and PV panels), increasing the different life-cycle stage’s environmental and economic impact. These results show a greater reduction in NRPE use and IRR values and a lower LC-PB value when the efficiency level increase is positioned in basic and efficient levels. On the contrary, when positioned between efficient and advance levels, results show a more negative scenario. In comparison with the change between basic and efficient level, NRPE use reduction and IRR values are lower and the LC-PB value increases.

The following is an example of the results obtained during the parameterised evaluation of strategy "3h", which shows a different environmental and economic behaviour with regards to the efficiency level growth.

	NRPE use reduction (MJ/(m²·a))	NRPE use reduction (%)	NER	LC_PB (years)	IRR (%)
3bh-3eh	3.51E+01	5%	18.43	20	5.71%
3eh-3ah	1.73E+01	2%	10.31	71.5	-2.40%

For strategies "4-5", although IRR values are positive and LC-PB values are lower than 50 years (RSL_b value of this case study), it is very difficult to justify the need to increase the level of efficiency from efficient to advance.

	NRPE use reduction (MJ/(m²·a))	NRPE use reduction (%)	NER	LC_PB (years)	IRR (%)
4bl-4el	4.13E+01	6%	174.79	6.2	17.90%
4el-4al	2.11E+01	3%	54.26	30.2	2.96%

With regards to renewable systems (“”6-7”), the efficiency levels growth scarcely reduces their IRR value and their NRPE use reduction percentage and LC-PB value stay in an almost straight line. Therefore, it justifies the implementation of a greater amount of this type of technologies.

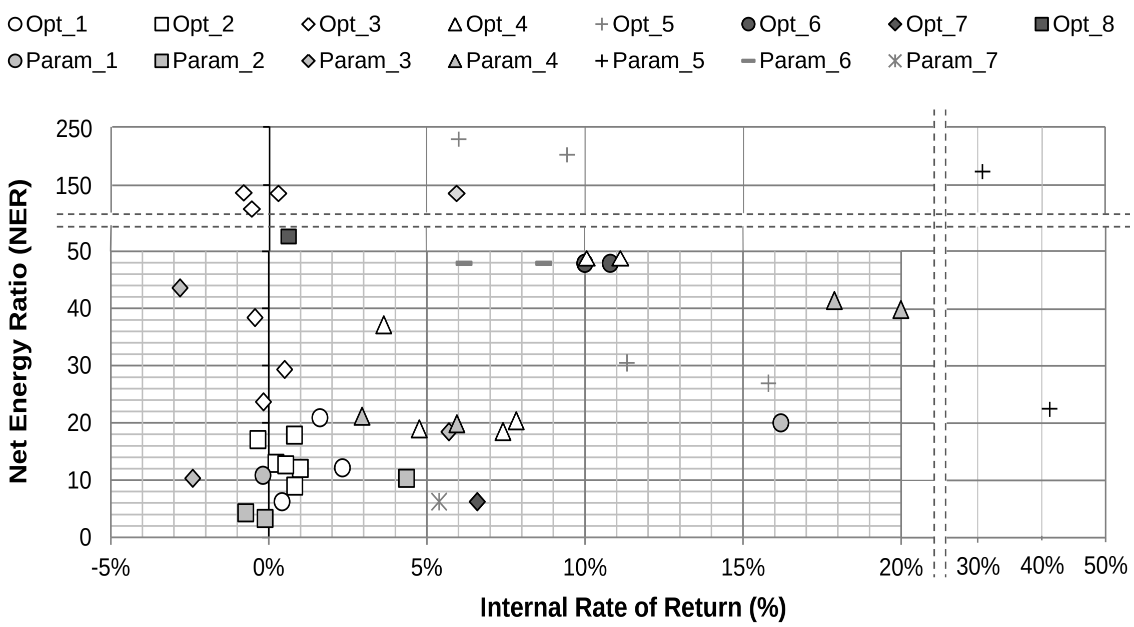


Figure 82 Analysis of the NER and IRR values of each refurbishment strategy.

Furthermore, the results show how the values obtained by integrating a biomass boiler ("8") are suitable for reducing the NRPE use. Due to its energy source origin, this type of power generation systems significantly reduces the amount of primary energy resource use and CO_2 emissions during their generation and transformation. Therefore, when the building has an inefficient thermal generation system, this type of strategies, along with the envelope's isolation (which directly increases the user's comfort degree), greatly improve the overall environmental performance of the building. On the other hand, the initial investment to be made is high (new boiler + storage space for fuel) and the price of commercial biomass is not much lower than that of the natural gas, being necessary to conduct a more comprehensive study (especially with regards to the energy generation system business model).

Although in some studies (*Hernandez & Kelly, 2010*) the NER indicator is applied when prioritising strategies with a life-cycle energy perspective, the values obtained in this study (see figure 83) show how whereas the vast majority of suggested energy rehabilitation strategies have NER values higher than 10 or 20 (high ratio between energy impact reduction during the building's use stage and the growth of the impact generated during the other stages), their IRR value is negative and their LC-PB value exceeds that of the building subject to rehabilitation's service life.

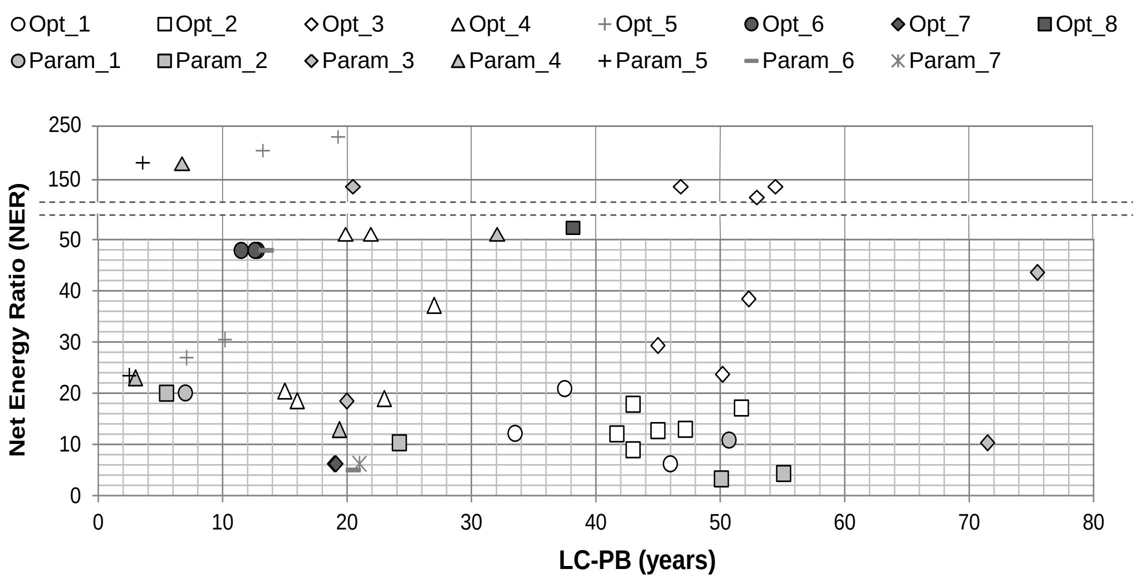


Figure 83 Analysis of the NER and LC-PB values of each refurbishment strategy.

For example, in the case of strategy "3bl", the NER value is 141.3 (that is, for every 1 MJ of the rehabilitation strategy's embodied primary energy, 141.3 MJs are reduced during the rehabilitated building's life-cycle use), being one of the strategies with higher NER value. However, this strategy's IRR value is negative (-0.7%) and its LC-PB value is 54.5 years. These kinds of results show the need to consider the economic dimension when prioritising rehabilitation strategies and not just focusing on one of the environmental indicators.

Results also show that when lower embodied energy materials are used (insulating materials “l”), this strategy’s NER value increases, improving its life-cycle’s energy ratio (NER). On the other hand, due to issues such as manufacturing, construction or maintenance, the economic investment required to integrate such low embodied energy materials might be greater, reducing its IRR value and increasing the LC-PB value. For example, shown below is how the NER values for strategy "4el" (which focuses on rehabilitating the house’s interior by applying a low embodied energy insulating material) is 54, whereas, when the same strategy integrates a “high” embodied energy insulation material, the NER value is reduced to 20. On the contrary, due to the price difference between these two insulating materials, the "4el" return is five years higher and its IRR value is reduced by 2.1% in comparison with the strategy that integrates the high embodied energy insulation material.

	NRPE use reduction (MJ/(m^2·a))	**NRPE use reduction (%)**	**NER**	**LC_PB (years)**	**IRR (%)**
4el	1.00E+02	14%	54.65	20	5.71%
4eh	9.72E+01	13%	20.37	15	7.84%

Regarding the different rehabilitation strategies, "4-5" shall be the highest energy ratio options, reaching NER values of up 231 (“5bl”). Solar thermal systems ratio is very positive (47.8), whereas due to the high environmental impact generated mainly during the production stage, photovoltaic panels NER value is reduced to 6.2.

Finally, with regards to the analysis of the efficiency level change or the parameterised study of each rehabilitation strategy, NER values between the basic and efficient levels are much higher than those obtained from the efficient-advanced level, being thus difficult to justify strategies with advanced levels of efficiency in moderate climates such as San Sebastian (Spain) and in buildings with similar characteristics.

** Annex 7.5.6 shows the study in which the evaluated building has been assessed in two new climatic conditions: Oslo and Palermo. This way, the study allows for comparing the results obtained from the evaluation of the same building in 3 different climates, selecting the parameters that influence each of the scenarios and reflecting the difficulty of generalising findings on the applicability or necessary efficiency level of rehabilitation strategies on buildings.*

5.6.2. Uncertainty of data. Sensitivity evaluation

It seems that with the environmental and economic results obtained, the various stakeholders would have enough information to evaluate each impact indicator, thus prioritising between different rehabilitation strategies. However, this research has highlighted the issue of the data quality or the inputs applied in order to define the various parameters that make up the calculation methodology. An example of this being the comprehensive sensitivity analysis carried out during the system boundary's optimisation section (see 5.5.1). Therefore, based on this line of work, this last section examines the direct influence of the uncertainty of some of the parameters in the prioritisation process between different energy rehabilitation strategies. Based on the work previously conducted, this section still takes into consideration the sensitivity scenarios:

	RSL_b	ESL_m	D_m	EE	OE	CF	EPI	IR
New 1	25	Half	Not	Process	+20%	+20%	0%	0%
New 2	100	Double	relevant	Hybrid	-20%	-20%	Double %	3%

The calculation which would allow for showing the influence of each of these parameters on the results obtained during section 5.6.1 is based on the percentage difference between the results obtained by the original and new inputs (see equation 15).

$$Influence\ of\ the\ new\ input\ (\%) = \frac{Result\ with\ new\ input - Result\ with\ original\ input}{Result\ with\ original\ input} \times 100 \qquad (15)$$

The 0% axis shall draw the line of the results obtained by means of the original inputs defined for the case study and, from that point, the influence of uncertainty on the proposed parameters shall be evaluated (see figure 84). Positive" values shall influence each indicator's value growth (NRPE use reduction, NER, IRR and LC-PB). On the other hand, negative values shall mark these four indicators reduction.

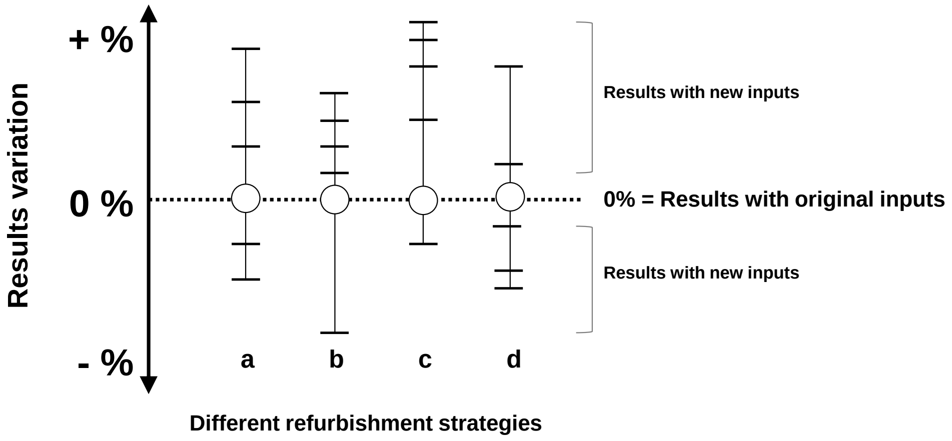


Figure 84 Calculation scheme of the influence of the inputs data quality on the final results of the different environmental and economic impact indicators. Values of this section are available in annex 7.5.6.

According to the input data defining criteria, source or uncertainty, figure 85 shows how the NRPE use reduction value after applying different rehabilitation strategies varies ± 30%, reaching a maximum variation of 91%. In this case study, the factors that shall influence a more accurate definition of the results are three.

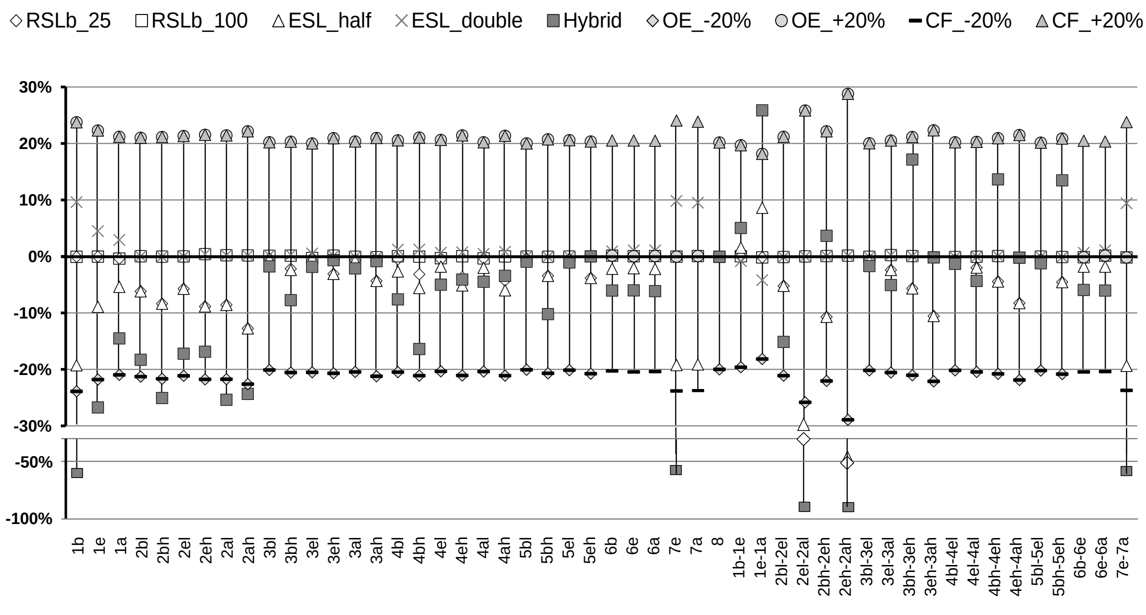


Figure 85 Variation of the NRPE use reduction value due to the application of each refurbishment strategy according to new inputs

The first is related to embodied energy data of products and systems. Most current studies, including the present one, use environmental data from LCI databases and/or environmental product declarations. This process based LCA approach may conduct to a large associated uncertainty (*Treloar, 1997*) due to the truncation error derived from data scarcity at a certain point of the upstream supply chain. Therefore, some studies

(*Crawford, 2011*; *Crawford & Stephan, 2013*; *Stephan & Stephan, 2014*) had proposed to use hybrid LCA analysis, combining process and input-output analysis, to capture all the upstream processes. The impact of the products embodied energy, calculated by means of the hybrid system is much higher, increasing the negative impact generated during the product stage, thus lowering the NRPE use impact reduction during the building's life-cycle.

The second critical parameter is the operational energy demand uncertainty. Throughout this work, it has shown different studies that highlight the importance of the building's end user when considering the energy demand. Therefore, according to the data's degree of uncertainty, the interpretation of the results can vary up to ± 25%.

The third parameter is connected with the conversion factors applicable when calculating the environmental impact on the different impact categories. According to the source of the data or the adaptation of each factor to each member state, results can vary up to ± 25%. In the case of Spain, there are an ever growing number of studies attempting to upgrade and integrate the LCA concept in such calculation (*IDAE, 2014*). However, there are still substantial uncertainties when it comes to making a proper calculation with regards to this factor with such an influence on the final results.

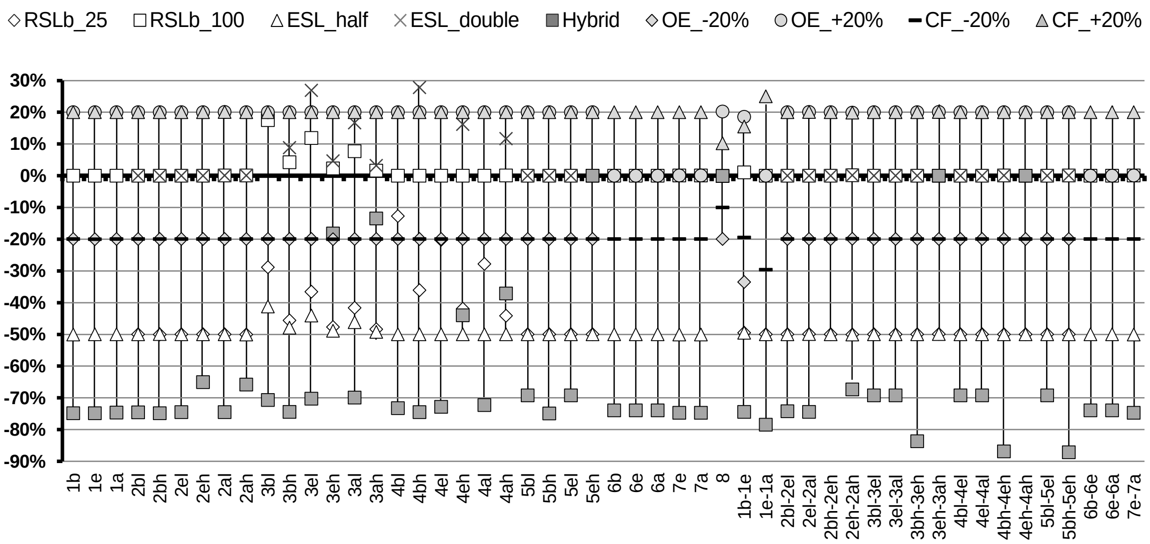


Figure 86 Variation of the Net Energy Ratio (NER) value due to the application of each refurbishment strategy according to new inputs

The second environmental impact indicator assessed is the NER of each and every rehabilitation strategy. Following the reading of previous impact indicator results, according to the input data definition criteria, source or uncertainty, figure 86 shows how the NER value might vary by ± 80%, reaching a maximum variation of - 93%. In this case study, the factors that shall influence a more accurate definition of the results are three.

Data source used to determinate the embodied energy of products and systems will be one of the pillars of this indicator. When applying hybrid LCA data, the different strategies' NER values are reduced by 76% on average, reaching values of up to -87% (optimization of the "5h" strategy: "5bh-5eh"). Meaning that the higher the environmental impact of each product or embodied system, the lower the NER value.

Together with the uncertainty of the embodied energy data, values of the Reference Service Life (RSL_b) of the building and the Estimated Service Life (ESL_m) of each refurbishment strategy will be directly related to the NER results. And the lower the RSL_b value, the lower the potential reduction generated during the building's use stage, leading to a reduction of the different strategies' NER value by 50%. The same applies to the ESL_m value. Although it is almost impossible to accurately define the value of this parameter in most of the studies, the variation between the initial input and the ESL_m value can lead to a variation of the NER value by more than ± 40%, increasing the NER value up to 100%

Finally, although the influence of the parameters related to the operational energy demand and conversion factor uncertainty is lower, it is difficult not to take them into account, since an inadequate definition of these two parameters may vary the NER value by ± 20%.

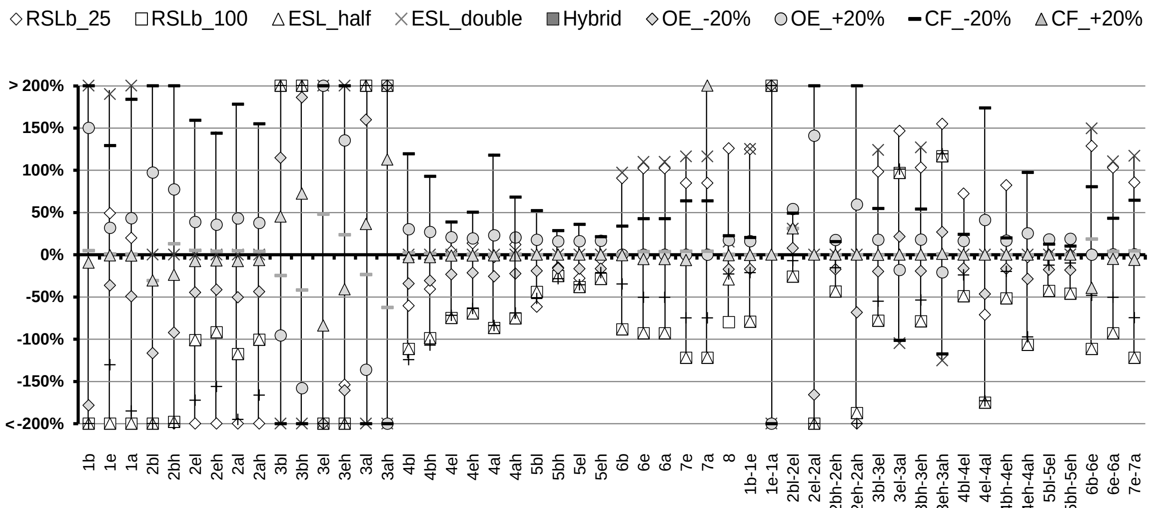


Figure 87 Variation of the Internal Rate of Return (IRR) value due to the application of each refurbishment strategy according to new inputs

Results obtained by the economic impact indicators' (IRR and LC-PB) sensitivity analysis reflect the same concerns: the high uncertainty about some of the parameters and their high influence on the final results. When performing a critical review of economic results, parameters such as the LCA data source or the conversion factor have been left out, since these parameters do not affect the calculation of either of these two economic impact indicators. However, based on the sensitivity study conducted above, two new parameters have been added: uncertainty about the energy's price increment and about the inflation rate during the rehabilitated building's life-cycle.

As shown in the results of figure 87, the IRR economic impact indicator variation results surpasses the ± 200% barrier, reaching values of up to + 450% or -320%. Meaning that, due to uncertainty about aspects like the ESL_m of the products used, the Reference Service Life (RSL_b) of the rehabilitated building, the building's energy demand (ED_b) or the energy's rising price during the rehabilitated building's life-cycle, it is difficult to accurately determine the profitability of each rehabilitation strategy. Regarding the inflation factor in comparison with other parameters, its influence is not as relevant in those strategies with low maintenance costs. However, in the case of renewable systems, we must be careful with this type of variable economic indicator.

Finally, although the variation in results is less than that of the IRR economic indicator, figure 88 shows that depending on the input or uncertainty data quality, the LC-PB value may vary by ± 50%. This value can be significantly increased, reaching values of up to + 300% (triple the return period of the investment) in scenarios where the EPI is zero and the ESL_m value of the refurbishment strategy is reduced. On the other hand, in scenarios suggesting significant increases of the energy price or in which the strategies' ESL_m value is increased (good maintenance, proper material behaviour, etc.), the value of the investment return period may be reduced by 60%.

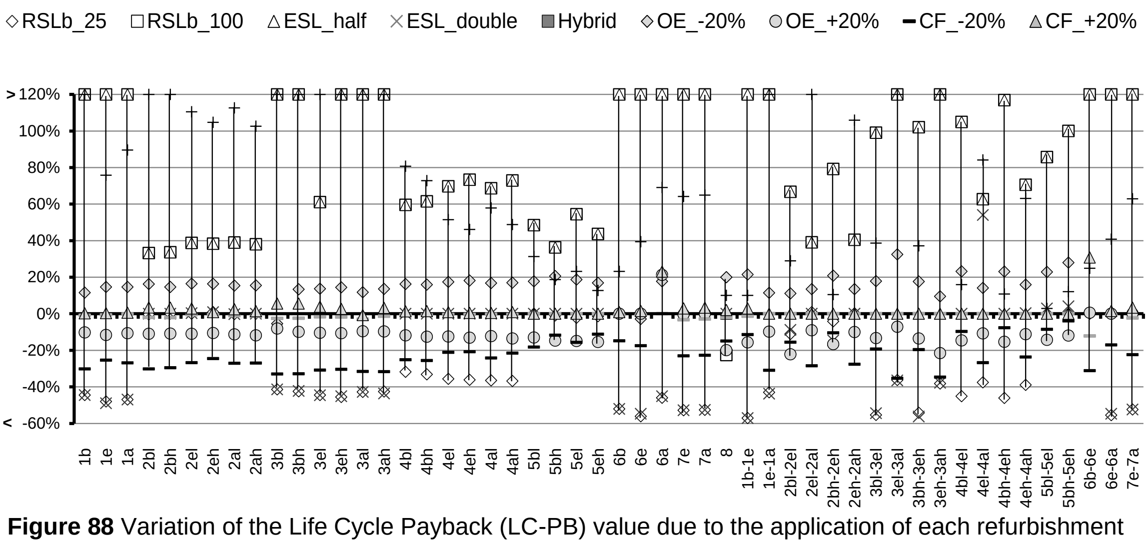


Figure 88 Variation of the Life Cycle Payback (LC-PB) value due to the application of each refurbishment strategy according to new inputs

Example of one of the refurbishment strategies

In order to show the relevance and direct influence of the uncertainty in determining the inputs of some parameters, this last section develops in detail a Life Cycle Cost assessment of the building (case of study of this work) after being refurbished by the strategy "2bl". Together with the results obtained by original inputs (defined inputs during the development of this work), this exercise offers 3 new input data for two parameters which directly influence the calculation methodology:

a) Energy Price Increment double: electricity 8% a year and natural gas 6% a year.
b) Energy Price Increment 0%.
c) Reduction of the Estimated Service Life value (ESL_m) of each product that compose this strategy in half.

The figure 89 shows how the inputs change totally the interpretation of the results of the Life Cycle Cost evaluation of the rehabilitated building.

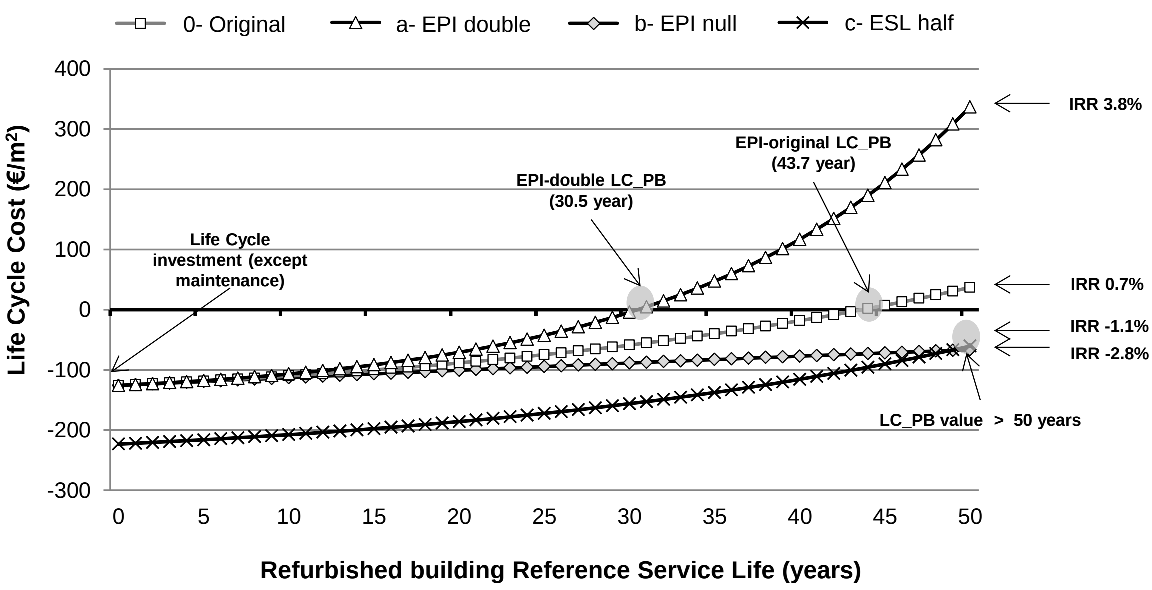


Figure 89 Life Cycle Cost assessment of the building due to the application of the "2bl" refurbishment strategy

At the initial point of rehabilitation (year 0), based on the criteria proposed for this calculation methodology, the Life Cycle investment will be the same in 3 of the scenarios ("0-a-b"). However, if the user proposes to reduce the ESL_m value of the products, due to increased number of replacements during the life of the refurbished building (RSL_b), the initial point (Life Cycle investment) is greater in the option "c". From this initial point, according to the different proposals of the increase in energy price, the reduction of the economic impact during the operational stage varies, generating 3 different trends.

The first trend defined by the option "a" proposes a scenario where the price increase of the energy is very high. In this case, the Internal Rate of Return value of the investment will be 3.8% and the Life Cycle Payback of 30.5 years. However, due to different reasons unrelated to this study, in the case that the price increase of the energy will be null (“b”), the profitability of the rehabilitation strategy will be negative (-2.8%) and the value of LC-PB will exceed the value of the building RSLb rehabilitated. Between these two tendencies is located the original scenario, whose profitability is 0.7% and the LC-PB value is nearly 44 years. Regarding the "c" option, due to its high impact related to the replacement stage (B4), the IRR value decreases (-1.1%) and the return on investment exceeds the barrier of the life of the refurbished building (> 50 years).

	Original	**Scenario “a”**	**Scenario “b”**	**Scenario “c”**
Internal Rate of Return – IRR (%)	0.7	3.8	-2.8	-1.1
Life Cycle Payback (years)	43.7	30.5	> 50	> 50

CHAPTER 6 – Conclusions

Main conclusions, diffusion of the results and further works

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6 ATALA – Ondorioak

Ondorio nagusiak, ekarpenak eta ondorengo lanak

6. Main conclusions, diffusion of the results and further work / *Ondorio nagusiak, ekarpenak eta ondorengo lanak*

The refurbishment of the existing building stock with the aim of reducing its operational energy use environmental and economic impact is being fostered for different reasons and by different actors in the EU.

It is also well recognized that applying a full life cycle perspective for environmental evaluation of construction projects is very valuable in terms of defining policies and strategies for reduction of environmental impact of the construction sector. Some examples of the application of this life cycle perspective include the ecodesign regulation (covering various construction products), the integration of the “Life Cycle Zero Energy Building” concept (directly related to EPBD recast, 9. Article), green public procurement, ecolabelling initiatives for building projects, or the implementation of the BWR 7 of the Construction Product Regulation, which requires environmental information for construction products with the goal of improving the whole building environmental performance. The intense standardization efforts on the assessment of the sustainability of buildings carried out by the European Committee for Standardization Technical Committee 350 (*CEN TC 350*), also suggests that the application of the life cycle approach will be more

EBko zenbait eragile, hainbat arrazoirengatik, eraikinen stocka birgaitzea bultzatzen ari dira haien energia erabilera murrizteko asmoarekin, baita ingurumen eta ekonomiaren inpaktua ebaluatzeko ere.

Gauza jakina da, halaber, eraikuntza proiektuen ingurumen ebaluazioa egiteko bizi ziklo oso baten ikuspegia ezartzea oso baliagarria dela eraikuntza sektoreko ingurumen inpaktua murrizteko politika eta estrategiak definitzeko orduan. Bizi zikloko ikuspegi honen ezarpenaren hainbat adibide hauek dira, besteak beste: ekodiseinu erregulazioa (hainbat eraikuntza produktu biltzen dituena), “Zero Eraikuntza Energiaren Bizi Zikloaren” kontzeptua txertatzea (zuzenean lotua EPBDren testu bateratuarekin, 9. artikulua), kontratazio publiko ekologikoa, eraikuntza proiektuetarako ekoetiketa duten ekimenak, edo Eraikuntza Produktuen Araudiaren BWR 7aren ezarpena, eraikuntza produktuetarako ingurumen informazioa behar izaten duena eraikinen ingurumen arlo osoa hobetzeko asmoz. Eraikinen iraunkortasuna ebaluatzeko Normalkuntzarako Europako Batzordearen 350 Batzorde Teknikoak (CEN TC 350) egin duen normalkuntza ahalegin trinkoak iradokitzen du, common in the near future.

Moreover, the use of new impact indicators like the Net Energy Ratio (NER) or the Life Cycle Payback (LC-PB), that of new calculating tools including a life cycle perspective in the decision-making process, the new needs generated among the different stakeholders in the industry and the large numbers of studies conducted over the last ten years all reflect the concern and the need to apply this methodology including a life cycle perspective in all the processes related to the building industry. This makes it possible to quantify and at the same time maximise a building's environmental and economic performance. However, while this argument shows and highlights the potential of this methodology, more and more studies are questioning the added value that can result from its use in setting priorities between the different strategies for energy-efficient retrofitting of buildings.

That is to say, there is concern about the relationship between the increased "accuracy" of the final results of using this methodology and the time and effort (i.e. the economic investment) represented by its implementation throughout the retrofitting process. Due to this concern, increasing doubt has arisen over the influence of the system boundary simplification over the accuracy of the results and the resulting decisions or about the relationship

halaber, bizi zikloaren ikuspegia ezartzea ohikoagoa izango dela etorkizun hurbilean.

Halaber, Energia Garbi Ratioa edo Bizi zikloko inbertsioaren berreskuratze epea moduko inpaktu adierazle berriak ezartzeak, erabakiak hartzeko prozesuan bizi zikloko ikuspegia duten kalkulu tresna berrien erabilerak, sektorearen eragileen artean sortutako premia berriek edo azken hamarkadan garatu diren lan ugariek, horiek guztiek, eraikuntzaren sektorearekin lotutako prozesu guztian zehar bizi zikloaren ikuspegia duen metodologia hau erabiltzeko beharra eta kezka islatzen dute, hartara, kuantifikatu, eta aldi berean, optimizatu egingo baita eraikin batean ingurumen eta ekonomia arloko jokabidea. Hala ere, nahiz eta tesi honek islatu eta azpimarratu metodologia honek duen ahalmena, gero eta ugariagoak dira hura ezartzeak eskaintzen duen balio erantsiari buruz eztabaidatzen duten lanak, eraikinen birgaitze energetikoaren arloan dauden hainbat estrategiaren artean lehentasunak ezartzeko orduan.

Hau da, metodologia hau ezarri ondorengo azken emaitzen "zehaztasuna" gehitzearen eta birgaitze osoan metodologia hau txertatzeak eskatzen duen ahaleginaren eta denboraren artean (inbertsio ekonomikoa) dagoen erlazioari buruzko kezka dago. Kezka hori dela eta, gero eta ugariagoak dira sistemaren irismenaren sinplifikazioak emaitzen between the impact reduced during the use stage and the impact generated during the other stages of the life cycle.

zehatasunean izango duen eragin edo erabilera etapan murriztutako inpaktu eta bizi zikloko beste etapetan sorturiko inpaktuaren arteko erlazioaren inguruan sortu diren zalantzak.

ACCURACY of the results

Emaitzen ZEHAZTASUNA

EFFORT – INVESTMENT

ESFORTZU - INBESTIMENDU

After validating the methodology for calculation proposed in the thesis using a residential building in Donostia (San Sebastián, Basque Country) and an extensive sensitivity analysis, the results obtained allow the environmental/economic impact of the retrofitted building to be reduced in relation to the baseline at every one of the stages in the building’s life cycle. Thus, an answer is arrived at as to the relationship between the increased accuracy of the results and quantification at every stage in the life cycle.

The first conclusion shows that in 98% of the environmental scenarios currently assessed (in accordance with the scope of this methodology), the impact generated at the stages of transport (A4), construction process (A5) and end of life (C1-4) can be quantified at less than 1% of the final results. The same is the case with an economic assessment with a perspective on life cycle, where the results show that in 99% of

Donostiako bizitegi eraikin urbano baten bitartez tesian proposatu den kalkulu metodologia baliozkotu ondoren, eta sentiberatasun analisi zabala egin ondoren, lortutako emaitzei esker, birgaitu den eraikinaren ingurumen eta ekonomia inpaktuaren murrizketa erlaziona daiteke oinarrizko eraikinari dagokionez, eraikinaren bizi zikloaren etapa bakoitzarekin. Horrela, emaitzen zehaztasuna gehitzearen arteko eta bizi zikloaren etapa guztien kuantifikazioaren arteko erlazioari buruzko emaitza batera irits gaitezke.

Lehen ondorioak erakusten du ingurumenaren ikuspegitik ebaluatu diren agertokien % 98n (metodologiaren irismenaren arabera), garraio (A4), eraikuntza prozesu (A5) eta deuseztatzeak (C1-C4) sortutako inpaktuaren kuantifikazioak % 1eko baino gutxiagoko inpaktua izango duela azken emaitzetan. Gauza bera gertatzen da bizi zikloaren ikuspegia duen ebaluazio ekonomiko batean, non lortutako emaitzek erakusten baitute scenarios the impact generated at the stages of transport (A4) and end of life (C1-4) can be quantified at less than 5% of the final results.

Regarding the relevance of the other stages, this study has identified two totally different retrofitting groups or scenarios. On the one hand there are scenarios where after implementing the different retrofitting strategies the reduction in impact in the operational energy use stage is less. This means those where the relative weight of the operational energy use stage is very small. In these cases, as well as quantifying the reduction in impact during the operational energy use stage (B6), the impact generated in other stages in its life cycle such as production (A1-A3), construction process (A5), maintenance (B2) and replacement (B4) needs to be quantified. The results obtained show that in some cases the impact in the production or replacement stage can reach 50-60% of the total reduced impact, making it a central factor in the process of decision-making and prioritising strategies. The same applies to the other stages, the impact of which account for less than 10% of the total final impact.

However, in the second group or scenario the reduction in impacts is very high because the greater importance of the operational energy use stage changes the results completely. In 74% of environmental studies and 19% of

agertokien % 99ren garraio (A4) eta deuseztatze (C1-C4) etapetan sortutako inpaktuaren kuantifikazioak % 5eko baino gutxiagoko eragina izango duela azken emaitzetan.

Beste etapen garrantziari dagokionez, azterlan honetan bi birgaitze talde edo agertoki erabat desberdin finkatu dira. Batetik, agertoki jakin batzuk daude, non, birgaitze estrategiak ezarri ondoren, eraikinaren erabilera etaparen inpaktuaren murrizketa txikiagoa izango den. Hau da, erabilera etaparen (B6) pisu erlatiboa oso txikia duten agertokiak. Kasu horietan, birgaitutako beste bizi etapa batzuetan sortutako inpaktua kuantifikatzeaz gainera, beharrezkoa da kuantifikatzea bizi zikloaren beste etapa batzuetan sortutako inpaktuak, besteak beste, ekoizpena (A1-A3), eraikuntza prozesua (A5), mantentzea (B2) eta ordezkatzea (B4). Lortutako emaitzek erakusten dute, zenbait kasutan, produkzio edo ordezkatze etapako inpaktuak birgaitzearen inpaktu osoaren % 50-60 gainditu dezakeela, eta horrela, erabakiak hartzeko eta estrategien artean lehenesteko prozesuaren zutabeetako bat bihur daiteke. Gauza bera gertatzen da beste etapekin, haien inpaktuak azken inpaktu osoaren % 10 baino gehiago islatzen baitu.

Hala ere, erabilera etapak duen garrantzia handiagatik, inpaktua murrizten duen bigarren talde edo agertokiak emaitzak guztiz bestelakoak islatzen ditu. Haietan ikus daiteke nola economic studies the impact of the building during its life cycle after retrofitting accounts for more than 90% of the reduction, which means that all the other stages (product, transport, construction proccess, maintenance, replacement and end of life) in its life cycle make up less than 10% of its impact.

ingurumen azterlanean % 74an eta azterlan ekonomikoen % 19n, eraikinaren erabilera etapan zehar izaten den murrizketa bizi ziklo osoan eraikina birgaitu ondoren murriztutako inpaktuaren % 90etik gora dela; horrek frogatzen du bizi zikloko beste etapa guztiek (ekoizpena, garraioa, eraikuntza prozesua, mantentzea, ordezkatzea eta deuseeztatzea) inpaktuaren % 10 baino gutxiago dutela.

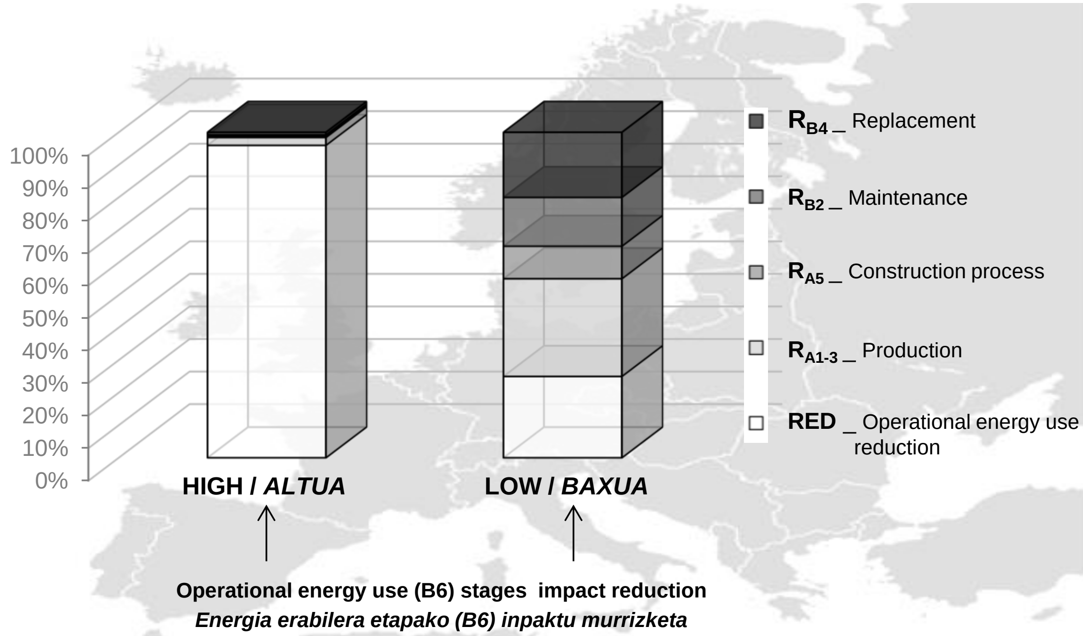

Figure / Irudia 90 Impact percentage of each life cycle stage with respect to the global impact reduction of the refurbished building during its life cycle / *Birgaitutako eraikinaren bizi zikloan zeharreko inpaktu murrizte osoarekiko bizi ziklo etapa bakoitzaren inpaktu portzentaia*

Therefore, the first part of the thesis has shown that due to the variation in results from the sensitivity analysis, it is very hard to get a single result to define the relationship between the accuracy of the results and the increased effort involved in applying the life cycle methodology. There are many results that show the need to include different stages of the life cycle in decision-making. For

Beraz, tesiaren lehen zatiak frogatu du sentiberatasun analisian lortzen diren emaitzen bariazioaren ondorioz, oso zaila dela bizi zikloko metodologia ezartzea eskatzen duen emaitzen zehaztasunaren eta ahaleginaren gehitzearen arteko harremana definituko duen emaitza bakar bat lortzea. Ugariak dira erabakiak hartzeko prozesuan bizi zikloaren etapen zati handi bat example, they highlight the need to apply this methodology to buildings for retrofitting located in climate zones whose Heating Degree Days value is less than 2000. On the other hand, the results for retrofitted buildings located in cold climate zones or buildings with a large reduction in impact during the operational energy use stage show that applying this complex methodology does not add rigour to the end results.

For all these reasons, as with the content outlined in this thesis, a need is shown to fix the scope of the system for assessing and prioritising retrofitting strategies on the basis of recommendations related to the climate or the thermal or energy features of the current building stock. In this way, on the basis of a single methodology based on life cycle, new retrofitting policies, regulations, economic assistance or new Energy Performance Certification systems in each member state can be adapted to the general features of each scenario, so ensuring maximum return on each decision-making process.

Finally, together with discussion of the importance of simplifying the scope of the life cycle methodology in the end results, a lot of work went into showing the influence of uncertainty or lack of information in the inputs used to calculate the impact of the different stages of the life cycle on the end results. The results obtained show that the values for the different impact indicators used to prioritise different

txertatzeko beharra islatzen duten emaitzak. Esate baterako, berokuntza egun gradu balioa 2000tik beherako duten eskualde klimatikoetan kokatuta dauden eraikinetan metodologia hau ezartzeko beharra azpimarratu da. Aitzitik, eskualde klimatiko hotzetan edo erabilera etapan zehar inpaktuaren murrizketa handia duten eskualdeetan kokatutako eraikinetako emaitzek frogatzen dute metodologia konplexu hau aplikatzeak ez diola zehaztasunik ematen azken emaitzei.

Horregatik, tesi honetan zehar garatu denaren antzera, beharrezkoa da birgaitze estrategien ebaluazio eta leheneste sistemen irismena ezartzea, klimaren araberako edo gaur egungo eraikuntza parkearen prestazio termiko edo energetikoen araberako gomendioetan oinarrituz. Horrela, bizi zikloan oinarritutako metodologia bakar batean, birgaitze politika berrietan, laguntza ekonomikoetan edo estatu kide bakoitzeko Energia Portaera Ziurtagiri berrietan oinarrituz agertoki bakoitzeko ezaugarri nagusiak egokitu ahal izango dira, eta, horrela, ahalik eta gehien optimizatu erabakiak hartzeko prozesu bakoitzaren errendimendua.

Azkenik, azken emaitzetan bizi zikloaren metodologiaren irismenaren sinplifikazioak duen garrantziari buruzko eztabaidarekin batera, lanean bereziki ahalegindu gara azken emaitzetan bizi zikloaren etapetako inpaktua kalkulatzeko orduan ezartzen diren inputen ziurgabetasunaren edo retrofitting strategies can vary considerably, even showing deviations of ±200% or more. However, these deviations are not evidence of a lack of quality in the life cycle analysis or insufficient rigour in the results. They simply reflect uncertainty over some aspects including the LCA data source, variations in energy prices, the length of the building's useful life or how a building's energy demands will develop over the course of its life cycle.

This is why, as mentioned in the "future works" section, this thesis stresses the need to improve data quality, expand the content with environmental and economic information on the different stages in the life cycle in each member state's databases on construction materials and energy systems and roll out new policies to help quantify the impact generated in all the processes that form part of the life cycle of a building to be retrofitted. These new policies on quantifying impacts in a rule-based, standardised way will make it possible to reduce the current high degree of uncertainty and help to integrate life cycle methodology into new processes to prioritise strategies for the energy-efficient retrofitting of buildings.

informaziorik ezaren eragina erakusten. Lortutako emaitzek erakusten dute birgaitze estrategien artean lehentasunak ezartzeko orduan erabilitako adierazleen balioak nabarmen alda daitezkeela, zenbaitetan % ±200eko desbideratzeetara iritsi baitaitezke. Hala ere, desbideratze horiek ez dute bizi zikloaren analisiaren kalitate apala edo emaitzen zehaztasunik eza erakusten. Besterik gabe, hainbat alderdiri buruzko ziurgabetasuna erakusten dute, besteak beste, BZA datuen iturria, energiaren prezioaren bariazioa, eraikinaren bizi baliagarriaren balioa edo bizi zikloan zehar eraikin baten eskari energetikoak jasango duen bilakaera. Horregatik, "ondorengo lanak" atalean erakusten den bezala, tesi honen bitartez honako alderdi hauek azpimarratu nahi dira: datuen kalitatea hobetu egin behar da, zabaldu egin behar da edukia, estatu kide bakoitzeko eraikuntza eta energia osagaien datu baseen barruan bizi zikloko etapen ingurumen eta ekonomia informazioarekin, eta politika berriak txertatu behar dira birgaitu beharreko eraikin baten bizi zikloa osatzen duten prozesu guztietan sortutako inpaktuaren kuantifikazioa errazteko asmoz. Modu estandarizatuan eta normalizatuan inpaktuen kuantifikazioa egiteko politika berri horiek egungo ziurgabetasun handia murrizten utziko dute, eta bizi zikloko metodologia hau txertatzen lagunduko dute, eraikinen birgaitze energetikorako estrategiak lehenesteko prozesu berrietan zehar.

6.1. Diffusion of results / *Emaitzen ekarpenak*

Even though some results have been already published, the diffusion of the results is, at the time of writing these lines, under process. The main relevant contributions to the dissemination of the results at international and national level so far are subsequently listed.

Lan hau garatu bitartean jada zenbait emaitza argitaratu diren arren, ekarpen lanen garapena prozesuan dago tesia idazten hari den tarte honetan. Ondoren, nazioarte eta nazio barruan egindako ekarpenik garrantzitsuenak aipatzen dira.

International Journals / *Nazioarteko aldizkariak*

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Article

Integrating Simplified and Full Life Cycle Approaches in Decision Making for Building Energy Refurbishment: Benefits and Barriers

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Abstract: The life cycle assessment (LCA) method is a powerful tool that can serve to aid decision making regarding the environmental benefits of refurbishment projects. However, due to the relative complexity of LCA studies, simplified LCA methodologies are frequently used, focusing on just some of the building life cycle phases or a reduced number of indicators. The most common and widespread simplification is to only evaluate the differences a refurbishment project makes on the operational energy use of the building. This paper compares the results of applying full LCA, simplified LCA and operational energy use assessment in a refurbishment case study. Results show that simplified LCA methodologies including building use phase and product manufacturing phase can generally be sufficiently accurate to aid decision making for building energy refurbishment, as other building life cycle phases related to transport of products, on site construction, deconstruction or end of life represent a generally negligible part of the total life cycle impacts, both in terms of resource use or environmental impacts. Barriers and benefits of applying simplified LCA approaches to building energy refurbishment projects are subsequently discussed.

Keywords: refurbishment; life cycle assessment (LCA); simplified life cycle assessment; building refurbishment; embodied energy; life cycle energy performance; sensitivity analysis

1. Introduction

Buildings are one of the world's largest energy-consuming sectors, accounting for nearly 30% of final global energy consumption, reaching 40% in the European Union (EU) [1]. With new constructions adding at most 1% a year to the EU existing stock [2], there is large potential for improving the energy performance of the other 99% of the building stock, making "energy refurbishment" a top priority in current EU and national policies. In the last decade, a remarkable number of studies have focused on quantifying the environmental improvement potential of buildings. Some of these studies [3] focus on the quantification of energy consumption during the use phase of the building, without taking into account the environmental impacts, resources needed and the waste and emissions generated from the building processes. In the cases in which a life cycle approach has been applied on an assessment, there is a general consensus that the use phase contributes more than 80%–85% share in the total life cycle energy use of buildings [4–7]. The study carried out by Karimpour *et al.* [8] shows that when considering the time value of carbon, in relation to emission targets, the embodied energy (total energy required for the extraction, processing and manufacture of building materials) can represent up to 35% of the future emissions target of a building in a mild climate. In buildings with a very low energy use in the operational phase, logically other phases of the life cycle like raw materials supply, product manufacturing, transport and installation, and end of life would have a much larger relative impact, becoming the only energy related impact in the so called "zero energy buildings". In that sense, Cellura *et al.* [9] have emphasized the embodied energy of the building as a key issue to not be neglected in the exhaustive evaluation of the primary energy demand of low energy buildings, whereas according to Lützkendorf *et al.* [10] the embodied energy of a passive house with PV installation could be 44% higher than its operation energy for a 60 years lifespan.

From these observations it is clear and generally accepted that when undertaking an environmental assessment of a new building, it is necessary to evaluate all its phases with a life cycle approach, and recent standardization efforts from ISO TC 59/SC17 [11] or CEN TC 350 [12] have developed a methodology and standards to apply this approach in a structured way. However, the effort needed for such analysis is relatively large, and the discussion about whether the evaluation of all building phases is also necessary in building energy refurbishment projects arises. As buildings are extremely complex systems entailing an enormous amount of products, systems, stages and processes, a fully-fledged application of the life cycle assessment (LCA) methodology is still not widely applied, and analysts usually apply some simplifications to reduce the amount of time and facilitate the interpretation of the results. Cabeza *et al.* [13] and *Chau et al.* [14], provided a review on comparing life-cycle-based methodologies in the building sector.

In this context and based on a building case study, the main objective of this paper is to verify whether different simplified methodologies currently applied for analyzing building refurbishment strategies are sufficiently reflective of a comprehensive application of the LCA, in terms of reducing resource use and environmental impacts of existing residential buildings. Several sensitivity analyses trying to capture a wide range of potential scenarios have been developed in order to assess the influence of key parameters in the comparison between the different methodologies.

2. Methodology and Case Study

With the aim of identifying to what extent simplifications may influence the results of a decision-making process, three different methodologies, namely LCA, simplified life cycle assessment (LCA-Si) and operational stage assessment (OSA), are applied to the same case study, an existing block of apartments in San Sebastian (Spain). Section 2.1 explains LCA, LCA-Si and OSA methodologies and how are they used by the authors to assess each refurbishment strategy. The case study context, including climate conditions and existing building construction characteristics, are evaluated in Section 2.2, also presenting a diagnosis of the baseline energy performance. Section 2.3 analyzes the selected refurbishment strategies, which have been designed with the objective of decreasing the final heating consumption of the building. Finally, Section 2.4 presents the calculation details for each life cycle phase of the refurbishment strategy.

2.1. Difference between LCA, LCA-Si and OSA Methodologies

According to the European Commission Communication on Resource Efficiency Opportunities in the Building Sector [15], the LCA methodology is currently the best framework available to assess the potential environmental impacts of any activity, product or service without geographical, functional or time limits, since it quantifies the environmental impact of the inputs and outputs along its whole life cycle, including the extraction of raw materials, production process, use and end of life stages.

LCA is standardized by ISO 14040 [16] and 14044 [17] standards, and consists of four phases. The first phase is to define the goal and scope of the assessment, which serves as a description of the type of study. The scope of the study determines which processes should be included in the inventory phase of the assessment. In the second phase, the life cycle inventory (LCI) includes information on all of the environmental inputs and outputs associated with a product or service, *i.e.*, material and energy requirements, as well as emissions and waste. The third phase is the impact assessment, where the potential contribution of each substance to predefined environmental impact categories is calculated. Once the impact has been calculated, the fourth and final step of the assessment is the interpretation, where the results of the calculations are summarized and discussed. LCA can choose from several methods to quantify the environmental performance of a product, system or process. For example, the CML method (Centrum voor Milieukunde Leiden) [18] uses indicators at midpoint level showing direct potential impact on the environment situated halfway along the chain of causes and effects. On the other hand, the Eco-indicator method [19] includes endpoint indicators, which represent the ultimate consequences of the environmental impact for humans and ecosystems.

Specifically for the construction sector, new standards, such as EN 15978:2011 [20], already define the different phases of a building life cycle and a number of indicators and methods used to declare the results of the analysis, which are midpoint level (e.g., Global Warming Potential in kg CO_2 equivalent, or Non Renewable Primary Energy Use, in MJ). A description of the building stages defined by EN 15978 is shown in Figure 1.

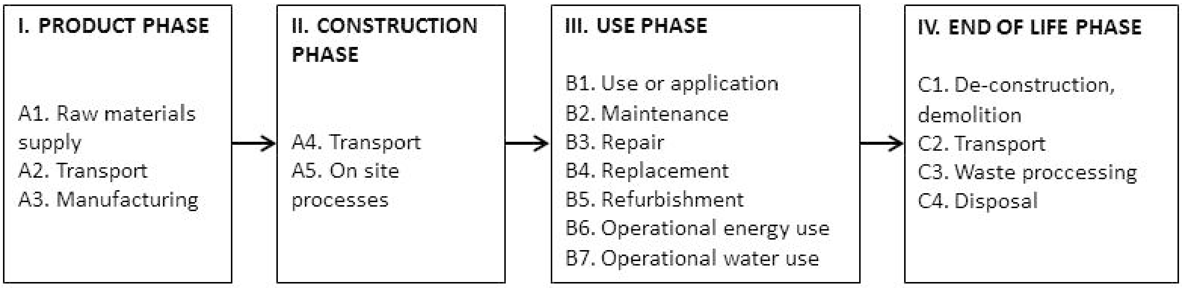

Figure 1. Building stages defined by EN 15978 [20].

Despite the standardization efforts, it is difficult to find published work including all the described life cycle stages, and instead most studies have focused on just some of the stages, *i.e.*, product phase (A1-3) and operational energy use stage (B6). Table 1 shows that very few authors considered all the LCA phases in their studies, being a general trend the omission of some life cycle modules such as on site processes (A5) or maintenance (B2). These omissions are due mainly to the lack of information, the difficulty of predicting future scenarios and the relatively low impact in comparison to the whole life cycle, which according to previous studies [21,22] is less than 1% for the life cycle energy use. Only some studies assess the replacement phase (B4), which is directly related to the estimated service life (ESL) of each product used which may have a remarkable influence in achieving Life Cycle Zero Energy Buildings (LC-ZEB) [23]. Regarding the calculation method used, it is worth mentioning that a process LCI approach is generally used, except for few studies such us Stephan *et al.* [24,25] or Kofoworola *et al.* [26], which use the hybrid LCI analysis.

In order to evaluate the relation between different simplifications and to analyze the influence of these simplifications in the evaluation of a building energy refurbishment, the authors will compare three calculation methodologies: the first methodology is the full LCA methodology (see Table 2), which obviously considers all life cycle stages. The second methodology is a simplified LCA (LCA-Si), focusing only on the evaluation on the product, replacement and operational energy use phases, as applied by Hernandez *et al.* [23] prior to the definition of the concept of Zero Energy Building with a life cycle approach. Finally, the third methodology is an operational stage assessment (OSA), where the evaluation focuses only on the reduction of the impact during the operational stage of the building. This third methodology is much simpler and generally more accessible to a wider range of technicians, as can be linked with building energy performance evaluation and with building energy rating schemes.

Table 1. Building Life Cycle Stages in relation to existing studies.

Building Life Cycle Stages	**Erlandsoona *et al.*, 2004 [27]**	**Junnilla, 2004 [28]**	**Citherlet *et al.*, 2007 [29]**	**Zabalza *et al.*, 2009 [30]**	**Utama *et al.*, 2009 [31]**	**Kofoworola *et al.*, 2009 [26]**	**Blom *et al.*, 2010 [32]**	**Blengini *et al.*, 2010 [33]**	**Gustavsoon *et al.*, 2010 [34]**	**Hernandez *et al.*, 2010 [23]**
Product phase (A1-3)	X	X	X	X	X	X	X	X	X	X
Transport (A4)	-	X	X	-	X	X	X	X	X	-
On site processes (A5)	-	X	-	-	X	X	-	X	-	-
Maintenance (B2)	-	X	X	-	-	X	X	X	-	-
Replacement (B4)	-	-	X	-	X	-	X	X	-	X
Operational energy use (B6)	X	X	X	X	X	X	X	X	X	X
End of life phase (C1-4)	-	X	X	-	-	X	X	X	-	-

Building Life Cycle Stages	**Oritz *et al.*, 2010 [35]**	**Dodoo *et al.*, 2010 [36]**	**Malmqvist *et al.*, 2011 [37]**	**Rossi *et al.*, 2012 [38]**	**Stephan *et al.*, 2012 [24]**	**Ramesh *et al.*, 2012 [39]**	**Stephan *et al.*, 2013 [25]**	**Mosteiro *et al.*, 2014 [40]**	**Dodoo *et al.*, 2014 [41]**	-
Product phase (A1-3)	X	X	X	X	X	X	X	X	X	-
Transport (A4)	X	X	-	X	X	X	X	X		-
On site processes (A5)	X	X	-	-	X	X	X	X	X	-
Maintenance (B2)	X	-	-	-	-	-	-	-	-	-
Replacement (B4)	-	-	-	-	X	X	X	X	-	-
Operational energy use (B6)	X	X	X	X	X	X	X	X	X	-
End of life phase (C1-4)	X	X	-	X	-	-	-	X	X	-

Table 2. Building Life Cycle Stages in relation to the three methods considered: Life Cycle Assessment (LCA), simplified LCA (LCA-Si) and Operational Stage Assessment (OSA).

Building Life Cycle Stages	Building Stages	LCA	LCA-Si	OSA
A1–3	Product phase	X	X	-
A4	Transport	X	-	-
A5	On site processes	X	-	-
B2	Maintenance	X	-	-
B4	Replacement	X	X	-
B6	Operational energy use	X	X	X
C1–4	End of life phase	X	-	-

2.2. Case Study

In order to assess to what extent simplifications in the life cycle calculations may help or mislead decision-making processes, the three methodologies are applied for selecting the best energy refurbishment option for the same building: A residential building built in 1962 in San Sebastian (Spain).

The analysis takes into account the different life cycle phases of the building, starting from the existing scenario and considering a range of refurbishment strategies. A Reference Service Life (RSL_b) of 50 years from the date of refurbishment is considered, a value often used by default, since it is generally difficult to foresee the real life span of a building [37].

The functional equivalent used to compare the different options is the building itself and the results are expressed per year and per unit of useful heated floor area, meeting the conditions of design requirements (thermal comfort, *etc.*).

From the range of environmental and resource indicators that are used on common LCA, this study will focus for simplicity on one indicator, which is "Use of non-renewable primary energy resources" (in MJ-Eq/functional unit) according to the CML method [18]. A sensitivity analysis for using a range of other environmental indicators on the evaluation is presented in Section 4 of this paper.

2.2.1. Building Context

With a total net floor area of 9484 m^2 and a heated surface of 8574 m^2, the building consists of a commercial ground floor and 9 residential floors (with 12 apartments on each floor), which are heated by a centralized natural gas heating system (see Figure 2). All apartments are naturally ventilated and no cooling or renewable energy systems are installed. U-values (W/(m^2·K)) of the building envelope before its refurbishment include cavity wall façade 1.12 W/(m^2·K), reinforced concrete deck with ceramic finish 2.34 W/(m^2·K), reinforced concrete first floor slab 1.79 W/(m^2·K), monolithic glazing 5.77 W/(m^2·K) and aluminum frame 4.2 W/(m^2·K). These values do not meet the minimum requirements [42] specified by the current national building regulations.

The building is located in San Sebastian, where the annual average temperature is 14 °C. In summer, the daily average temperature is below 20 °C, so cooling systems are generally unnecessary, particularly if measures such as solar shading or night cooling are implemented. In winter, the daily average temperature is about 10 °C, justifying the need for heating systems.

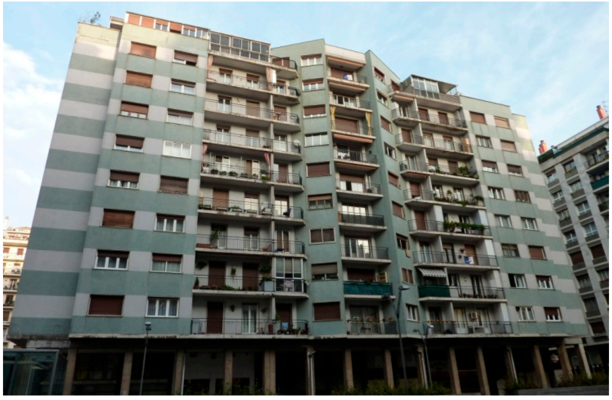

Figure 2. Picture of the case study building.

2.2.2. Baseline Operational Energy Use

During their use phase, buildings require operational energy for meeting the demand for heating, cooling, hot water, ventilation, lighting and the use of appliances. However, refurbishment projects such as the one discussed in this paper are focused on the building envelope and aimed at reducing the operational energy use of buildings for heating and cooling, and do not directly affect other building end-uses.

Using the Design Builder [43] software and the International Weather Files for Energy Calculation [44] for the city of San Sebastian, the final energy demand for heating the building before refurbishment was estimated. Being an interface for Energy Plus, Design Builder is a dynamic energy simulation tool that generates detailed data about the energy performance of a building during 1 year by using real weather data as well as temporal aspects such as solar radiation, thermal mass or user occupancy. The building model developed replicates the real geometry, including overhangs, setbacks and the surrounding buildings. Parameters like occupancy rate, schedules, and internal gains have been estimated following current Spanish regulations [42]. For example, a general occupancy value of 0.03 people/m^2 was considered and the common areas (stairs and portals) and ground floor were treated as unheated without occupation or internal gains.

The heating system is composed of a centralized natural gas installation with a nominal performance of 0.92. Thermostats are set at 21 °C from 4 p.m. until 11 p.m. for the heating period (from 30 September to 31 May). The baseline operational heating demand calculated according to these parameters is 264 MJ/(m^2·a). This demand is multiplied by the system performance and by 1.13, which is the conversion factor from natural gas to Non-Renewable Primary Energy use (NRPE) in Spain, taken from the Ecoinvent 3.0 database [45]. The resulting baseline operational Non Renewable Primary Energy (NRPE) use for the building is 324 MJ/(m^2·a). For the variables in Equation (1), refer to Table 3.

$$B_{B6} = \sum_{m=1}^{m} \frac{ED_b}{\rho_m} \times CF_m / HS \tag{1}$$

Table 3. Variables applied during the calculation of the Non Renewable Primary Energy (NRPE) of each building life cycle phase.

Acronym	Description	Unit
B_{B6}	Operational energy use of the baseline building	NRPE (MJ)
CE_{A5}	Energy use associated to construction waste treatment of each refurbishment strategy	NRPE (MJ)
CF_m	Conversion factor of the energy source m (MJ non renewable primary energy/MJ final energy)	NRPE (MJ)
D_m	Transport distance of product m	km
DW_m	Transport distance of waste m from site to waste management facility	km
ED_b	Baseline operational annual energy demand	MJ
ED_m	Operational annual energy demand for the refurbished building	MJ
EE_m	Embodied energy of material or system m applied during the refurbishment, expressed per unit of material or system (in kg, m^2 or m^3)	NRPE (MJ)
ESL_m	Estimated service life of the material m	years
HS	Heated surface	m^2
IA_t	Energy used in the transportation per t and km	NRPE (MJ)
$IEE_{A1\text{–}3}$	Initial embodied energy of each refurbishment strategy	NRPE (MJ)
IE_{A4}	Initial energy used in the transportation of each refurbishment strategy	NRPE (MJ)
$IE_{C1\text{–}4}$	Energy use associated to the end of life stage of each refurbishment strategy	NRPE (MJ)
RB_{B6}	Operational energy use of the refurbished building	NRPE (MJ)
$REE_{B4(A1\text{–}3)}$	Recurrent embodied energy of each refurbishment strategy	NRPE (MJ)
$RE_{B4(A4)}$	Recurrent energy use associated to the transport of each refurbishment strategy	NRPE (MJ)
RSL_b	Reference service life of the building	years
Q_m	Quantity of materials and systems in each refurbishment strategy	kg-m^2-m^3
Q_{mt}	Quantity of material and system in each refurbishment strategy	t
WP_m	percentage of waste generated in each refurbishment strategy	%
WT_m	Energy use of the waste treatment process per kg	NRPE (MJ)
ρ_m	Performance of the energy generation system m	%

2.3. Energy Refurbishment Strategies

In order to reduce the environmental impact related to the building's heating, different energy refurbishment strategies have been evaluated during this study, taking into account that the area where the case study is located shows no historic, urban or architectonic restrictions, allowing direct refurbishment actions on all the envelope elements.

Refurbishment strategies will be applied to the case study in two efficiency levels. The basic efficiency level is based on restoration strategies that enforce the minimum thermal requirements determined by the existing regulations and standards. The advanced efficiency level strategies improve the thermal properties adding insulation to very high values such as those used in standards like the Passive House [46].

Another variable considered for defining refurbishment strategies has been the type of material used, which is important for the life cycle performance particularly in relation to their embodied energy. The strategies have been subsequently divided also by the employment of low and high embodied energy materials. Table 4 details the strategies chosen.

Table 4. Set of energy refurbishment strategies applied in the case study.

Strategy	Efficiency Level	Embodied Energy of Construction Products	Strategy ID
Window replacement (1)	Basic (b)		1b
	Advanced (a)		1a
Ventilated façade (2)	Basic	Low (l)	2bl
		High (h)	2bh
	Advanced	Low	2al
		High	2ah
External Insulation System (3)	Basic	Low	3bl
		High	3bh
	Advanced	Low	3al
		High	3ah
Internal (4)	Basic	Low	4bl
		High	4bh
	Advanced	Low	4al
		High	4ah

The first strategy focuses on the replacement of all existing windows with a new frame and glazing. The windows for the basic energy efficiency level (1b) consist of a double glazing (2.7 W/(m^2·K)) and aluminum frame (2.9 W/(m^2·K)), meeting the minimum thermal requirements for refurbishments in Spain. The windows for advanced level (1a) consist of a low-emissivity coated glazing (1.4 W/(m^2·K)) and wooden frames (1.2 W/(m^2·K)). The second solution is a ventilated facade system, which is composed of an aluminum substructure, a layer of insulation and a ceramic outlayer. The third strategy is an external insulation system composed of an insulation layer and mortar outlayer. Finally, the fourth strategy is an indoor thermal improvement solution consisting of a layer of insulation and plasterboard.

According to the efficiency level parameter, different insulation thicknesses are proposed for basic and advanced levels. The projected insulation thicknesses for the basic efficiency energy level are 5 cm for the façade, 8 cm for the deck and 6 cm for the first floor slab. The thicknesses proposed for the advanced energy efficiency level are 25, 30 and 15 cm, respectively. Regarding the aluminum profile of the ventilated façade, 10.2 cm^2 of aluminum per m^2 is projected for the basic level and 49.6 cm^2 for the advanced level. Strategies with low embodied energy insulation apply wooden fiber and high embodied energy strategies apply Extruded Polystyrene (XPS) insulation. Regarding the other products that make up the three systems (outlayer, mortar and plasterboard), their properties and quantities are maintained in all cases. It should also be highlighted that secondary products that form part of these strategies, such as screws, sealants, glues are not considered within the scope of the study.

2.4. Calculation of Non Renewable Primary Energy (NRPE) Use for Each Life Cycle Phase

2.4.1. Input Data

Product Phase (A1–3), Initial Embodied Energy. The embodied energy or initial energy input associated with the production phase of each product and system has been calculated applying Equation (2) (for variables, refer to Table 3) using process data from Ecoinvent [45] and GaBi [47] databases as well as Environmental Product Declarations (EPDs) issued by manufacturers (see Table 5).

$$IEE_{A1-3} = \sum_{m=1}^{m} EE_m \times Q_m \Big/ (RSL_b \times HS) \tag{2}$$

Transportation from Production Unit to Point of Use (A4). The transportation of building materials to construction sites involves a variety of transportation modes. Equation (3) describes the calculation of the NRPE use for this stage (for variables, refer to Table 3). Due to the lack of detailed transportation data for each of the materials used to the building site, three different distances are considered (see Table 5): 50 km (distribution within the province), 120 km (distribution within the region) and 300 km (distribution within the same country). The 300 km value is based on a standard parameter defined in EeB Guide [48], which sets up an average transportation distance in Europe.

$$IE_{A4} = \sum_{m=1}^{m} D_m \times Q_{mt} \times IA_t \Big/ (RSL_b \times HS) \tag{3}$$

Construction Process (A5). Energy use associated with the construction stage of a new envelope is not considered since it typically represents less than 1% of the life cycle energy demand of the building [21]. However the transportation and end of life treatment processes of the inert and non-hazardous wastes that will be managed in a landfill are considered. For this case study, it is considered that 3% of the total final product will be wasted during their placement and transported 50 km to the landfill.

$$CE_{A5} = \sum_{m=1}^{m} [(Q_{mt} \times WP_m) \times DW_m \times IA_t] + [(Q_{mt} \times WP_m) \times WT_m] \Big/ (RSL_b \times HS) \tag{4}$$

Replacement (B4). Recurrent Embodied Energy (A1–3). As described in Equation, the recurrent embodied energy represents the sum of energy inputs associated with the energy required to manufacture and replace refurbishment materials across the building's service life. Service life and durability of materials are among the most important factors affecting the recurrent embodied energy. In accordance with ISO 15686-8:2008 [49], construction materials and systems usually do not possess the same Estimated Service Life (ESL_m) as the building Reference Service Life (RSL_b) and may require one or multiple replacements over the building's service life. The lower the service life of a material, the greater the quantity of material required for ongoing maintenance and repair and therefore the greater the embodied energy associated with manufacturing and installing replacement materials throughout a building's life. Table 5 shows the values of ESL_m applied in this case study, selected according to the information obtained by different EPDs or databases such as National Association of Home Builders (NABH) [50].

$$REE_{\mathrm{B4\,(A1-3)}} = \sum_{m=1}^{m} EE_m \times Q_m \times \big((RSL_b/ESL_m) - 1\big) \Big/ (RSL_b \times HS) \tag{5}$$

$RSL_b/ESL_m = 1$, No replacement (same or longer material SL than the RSL_b).

$RSL_b/ESL_m > 1$, Replacement is necessary.

Replacement (B4). Recurrent Transportation from Production Site to Point of Use (A4). Due to the replacement of some products during the RSL_b of the case study, the environmental impact related with the transportation process of the additional products is estimated using Equation (6). The same transport distances of the initial transport phase have been used.

$$RE_{\mathrm{B4\,(A4)}} = \sum_{m=1}^{m} D_m \times Q_{mt} \times IA_t \times \left((RSL_b/ESL_m) - 1\right) \Big/ (RSL_b \times HS) \quad (6)$$

Operational Energy Use (B6). As explained before, in this case study focused on refurbishment of the building envelope, the operational energy use only includes the heating of the building during its useful life (see Equation (7)). Other end-uses (hot water production, use of appliances, illumination, *etc.*), despite being very relevant in an overall building energy use evaluation will not be affected by the proposed refurbishment. The new heating demands of the refurbished building scenarios have been calculated with the same methodology as the baseline operational energy use, *i.e.*, through building energy simulations with Design Builder software.

$$RB_{\mathrm{B6}} = \sum_{m=1}^{m} \frac{ED_m}{\rho_m} \times CF_m / HS \quad (7)$$

End of Life (C1–4). Energy consumption of the end-of-life stage is usually not considered since it typically represents less than 1% of the life cycle energy of buildings [51]. However, in order to assess all building phases, during this study the transportation of the products (initial and recurrent) to the waste treatment facility and their management is evaluated (see Equation (8)). For this case study, road transportation during 50 km to the landfill for inert and non-hazardous waste is considered. Being beyond the scope of the study, potential recycling or reuse of the aluminum used in the frame of the windows (strategy 1) and in the ventilated facade sub-structure (strategy 2) is not included.

$$IE_{C1-4} = \sum_{m=1}^{m} (Q_{mt} \times DW_m \times IA_t) + (Q_{mt} \times WT_m) \Big/ (RSL_b \times HS) \quad (8)$$

Table 5 shows information about the parameter applied to evaluate the NRPE use for each product and process that participates in different refurbishment strategies, allowing the calculation of the impact of each Life Cycle Phase.

Table 5. Non Renewable Primary Energy (NRPE), Transport characteristics, and Estimated Service Life of the materials (ESL_m) for products and processes included in the analysis.

Product/Process	Non Renewable Primary Energy Use		Transport	ESL_m	
	Value	Data Source	(km)	Years	Data Source
Double glazed	463 (MJ/m²)	INIES—FDES SGG Climaplus [52]	Truck-120	30	Environmental Product Declaration (EPD)
Triple glazed	707 (MJ/m²)	INIES—FDES. SGG Climatop [53]	Truck-300	30	EPD
Aluminum frame	1852 (MJ/m²)	GaBi. Aluminum wing profile, powder coated PE (2010)	Truck-50	20	National Association of Home Builders (NAHB)

Table 5. *Cont.*

Product/Process	Non Renewable Primary Energy Use		Transport	ESL$_m$	
	Value	Data Source	(km)	Years	Value
Wood frame	206 (MJ/m^2)	ENVIRONDEC-Cormo [54]	Truck-300	30	EPD
Aluminum sub-structure	118 (MJ/kg)	GaBi. Aluminum extrusion profile PE (2010)	Truck-120	50	NAHB
Insulation (high)	92.4 (MJ/kg)	Ecoinvent. Polystyrene, extruded (XPS), at plant	Truck-50	50	NAHB
Insulation (low)	5 (MJ/m^3)	GaBi. Lightweight wood fibers panel PE (2010)	Truck-300	50	NAHB
Outlayer	256 (MJ/m^2)	GaBi. Ceramic façade panels—NBK Ceramic PE (2008)	Truck-120	50	NAHB
Mortar	1.3 (MJ/kg)	Ecoinvent. Cement mortar, at plant	Truck-50	35	NAHB
Plasterboard	54 (MJ/m^2)	Ecoinvent. Gypsum plaster board, at plant	Truck-120	30	NAHB
Transport-truck	0.8 (MJ/(t·km))	GaBi. Articulated lorry (40t) incl. fuel ELCD (2005)	-	-	-
Landfill	0.2 (MJ/kg)	GaBi. Landfill for inert matter (construction waste) (2010)	-	-	-

2.4.2. Sample Calculation of Non Renewable Primary Energy (NRPE) Use for one of the Energy Refurbishment Strategies

As an example, in this section, the environmental calculation of a proposed rehabilitation strategy (1a + 2ah) is explained. This strategy focuses on replacing existing windows with 204 m^2 of new wooden frames (11,526 kg) and 1018 m^2 of triple glazing (34,917 kg). The façade will be refurbished with a ventilated façade system, which consists of 5581 m^2 of 25 cm XPS insulation (60,275 kg), 12,830 kg of Aluminum sub-structure with a section of 49.6 cm^2 and 4409 m^2 of ceramic façade panels (60,274 kg). Through this information, and the values previously defined in Table 5 (B_{B6}, RSL_b, ESL_m, EE_m, D_m, Q_m, Q_{mt}, IA_t, DW_m, CF_m and ρ_m), the authors have performed the calculation of the NRPE use of each of the life cycle phases of this strategy.

Figure 3 shows that the NRPE use of the building after applying the refurbishment strategy 1a + 2ah is reduced from 324 MJ/(m^2·a) to 92 MJ/(m^2·a), reaching a reduction of 72%, which is mostly due to the operational energy use phase (69.6 MJ/(m^2·a)) and the Initial Embodied Energy phase (20.93 MJ/(m^2·a)).

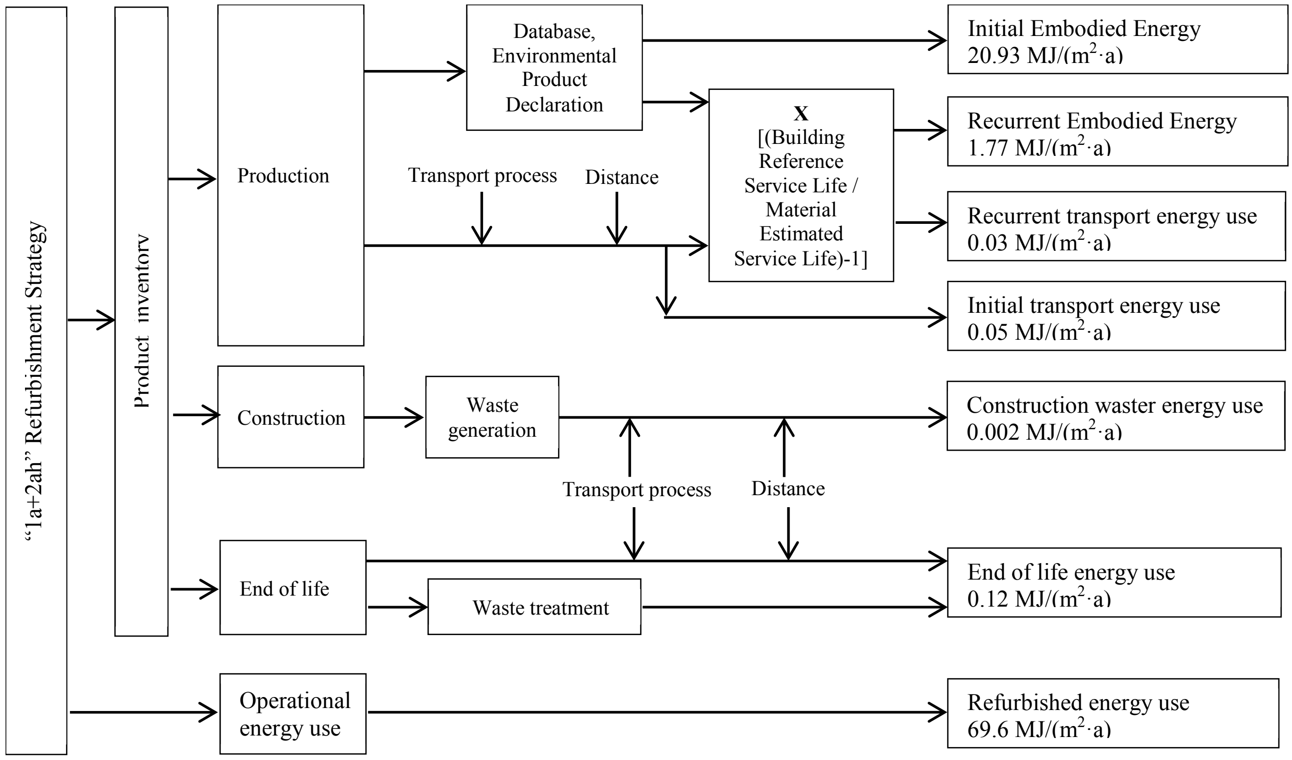

Figure 3. Scheme of inputs and Non Renewable Primary Energy (NRPE) use of each life cycle phase of the 1a + 2ah energy refurbishment strategy.

3. Results

3.1. Life Cycle Energy Performance Evaluation—NRPE Results

Applying the same calculation procedure for all energy rehabilitation strategies, the NRPE use of each phase was obtained. Figure 4 shows, in comparison with the baseline scenario, the decrease on the NRPE during the operational stage and the increase of NRPE derived from the production, transportation, construction, replacement and end of life phases of the products and systems applied in each refurbishment strategy.

For the particular building studied, Table 6 shows that the refurbishment option with the highest NRPE use reduction (*i.e.*, 77%) calculated with the LCA methodology is strategy "1a + 3al", which increases the building envelope insulation level and replaces the current glazing with double-glazed low-emissivity coated window. Results show that the influence of the constructive characteristics and embodied energy parameters is very low, being the advanced level refurbishment strategies the most effective and efficient to reduce the baseline NRPE use. As for the refurbishment option with the highest reduction on energy use according the OSA methodology (only considering operational stage of the building), "1a + 2al", "1a + 2ah", "1a + 3al", and "1a + 3ah" strategies present the same result, as differences amongst them occur in other life cycle stages.

As expected the reduction of life cycle NRPE is much larger than the energy consumed by the different refurbishment strategies. The ratio between the increase and decrease on NRPE reach up to 15%, for strategies using products with higher embodied energy (*i.e.*, 2ah strategy). Consequently, the ratio has lower values (up to 0.12%) when the products applied have lower embodied energy (*i.e.*, 3bl strategy).

NRPE attributed to the replacement phase represents less than 5% of the decrease on operational NRPE, whereas NRPE attributed to the transportation (initial and recurrent), construction and end of life phases (neither of which is covered by the LCA-Si method), do not reach 0.19% of the NRPE reduction. Detailed values for the NRPE indicator for each of the refurbishment strategies and each of the calculation methodologies are presented in Table 6.

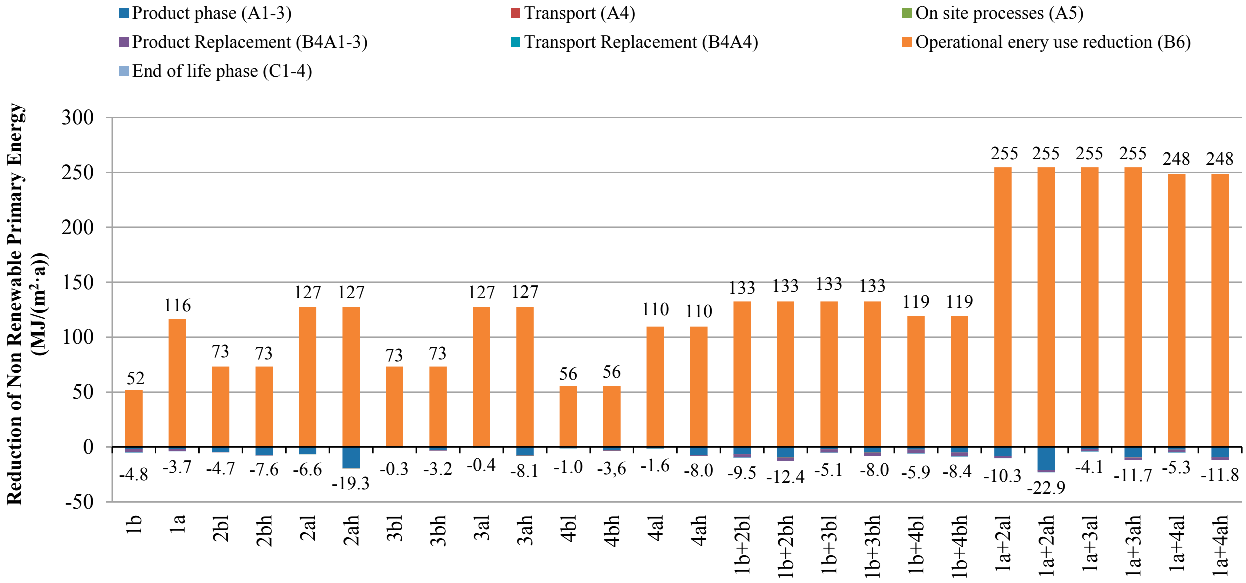

Figure 4. Reduction of Non Renewable Primary Energy use (MJ/(m^2·a)) from each refurbishment strategy in relation to the baseline. Positive values indicate a reduction of energy use on the operational phase. Negative values represent the energy use on the rest of the life cycle phases.

Table 6. Reduction of Non Renewable Primary Energy use of each refurbishment strategy according to Life Cycle Assessment (LCA), simplified LCA (LCA-Si) and Operational Stage Assessment (OSA) (MJ/(m^2·a)).

Strategy	LCA	LCA-Si	OSA	Strategy	LCA	LCA-Si	OSA
1b	47.1	47.1	51.9	**1b + 2bl**	123.1	123.1	132.6
1a	112.6	112.7	116.2	**1b + 2bh**	120.2	120.2	132.6
2bl	68.6	68.6	73.3	**1b + 3bl**	127.4	127.4	132.6
2bh	65.7	65.7	73.3	**1b + 3bh**	124.6	124.6	132.6
2al	120.8	121.3	127.4	**1b + 4bl**	113.3	113.3	119.2
2ah	108.2	108.3	127.4	**1b + 4bh**	110.7	110.7	119.2
3bl	73.0	73.0	73.3	**1a + 2al**	244.4	245.0	254.7
3bh	70.1	70.1	73.3	**1a + 2ah**	231.8	232.0	254.7
3al	127.0	127.1	127.4	**1a + 3al**	250.6	250.8	254.7
3ah	119.4	119.4	127.4	**1a + 3ah**	243.0	243.2	254.7
4bl	54.7	54.7	55.7	**1a + 4al**	243.3	243.9	248.4
4bh	52.1	52.1	55.7	**1a + 4ah**	236.7	237.0	248.4
4al	108.3	108.7	109.7	-	-	-	-
4ah	101.7	101.8	109.7	**-**	-	-	-

3.2. Comparison of LCA, LCA-Si and OSA Methodologies

In order to evaluate the influence of the methodological simplifications in a building energy refurbishment decision making process, the difference between the OSA and LCA-Si from a full LCA is expressed as a relative difference (see Equations (9) and (10)) in Figure 5.

$$LCA - Si_{relative\ difference\ (\%)} = ([LCA - LCAsi]/LCA) \times 100 \quad (9)$$

$$OSA_{relative\ difference\ (\%)} = ([LCA - OSA]/LCA) \times 100 \quad (10)$$

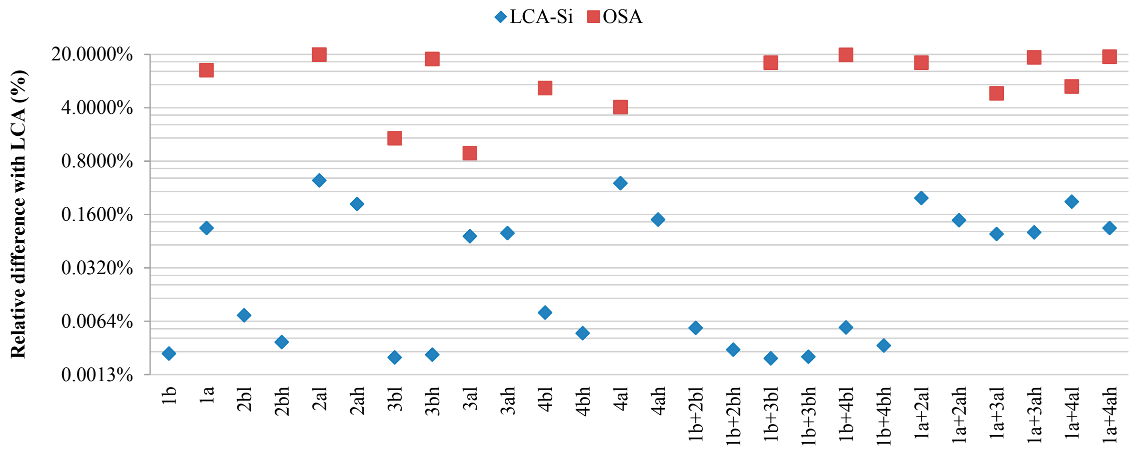

Figure 5. Relative difference of LCA-Si and OSA with LCA.

The values of Figure 5 shows that for this case study and for the selected NRPE indicator, the difference between the results obtained with LCA and LCA-Si methodologies is below 0.39%. However, the results obtained with the OSA methodology in comparison with LCA present differences varying from 0.34% (for 3al strategy) to 15% (for 2ah strategy). Higher differences occur in the case of strategies using products with higher embodied energy associated.

4. Sensitivity and Uncertainty Evaluation

With the aim of drawing a general conclusion that offers an overview of residential building refurbishment actions, a sensitivity analysis tackling different relevant aspects is conducted in this section. In order to simplify and facilitate the reading of the results, the study only reflects the results for the strategies 2ah and 3al, which presented the largest and lowest percentage differences on the results when analyzed respect the LCA methodology.

4.1. Reference Service Life of the Building (RSL_b)

The annualized NRPE use has been assessed for different RSL_b values: 25, 50 (current scenario), 75 and 100 years. Table 7 shows that the difference between the results obtained by LCA and OSA methodologies increases when RSL_b is lower, up to a difference of 30.24% in strategy 2ah. This difference falls to 0.36% for strategies applying products with lower embodied energy and when the same RSL_b (25 years) is applied. Regarding the difference between the LCA and LCA-Si methodologies, the lower RSL_b value, and the greater the difference. However differences between these two methodologies are in all cases below 1%.

Table 7. Sensitivity analysis results for refurbishment strategies 2ah (advanced efficiency level ventilated façade system with high embodied energy products and 3al (advanced efficiency level external insulation system with low embodied energy products).

Non Renewable Primary Energy use Reduction (MJ/(m²·a))							
Variable	**2ah Strategy**			**Variable**	**3al Strategy**		
	LCA	**LCA-Si**	**OSA**		**LCA**	**LCA-Si**	**OSA**
Reference Service Life Building (RSL_b)							
RSL_{25}	89.1	89.1	127.4	RSL_{25}	127.1	127.1	127.4
RSL_{50}	108.2	108.3	127.4	RSL_{50}	127.0	127.1	127.4
RSL_{75}	114.5	114.7	127.4	RSL_{75}	127.0	127.1	127.4
RSL_{100}	117.8	117.9	127.4	RSL_{100}	127.1	127.2	127.4
Estimated Service Life Materials (ESL_m)							
ESL_{half}	88.9	89.1	127.4	ESL_{half}	126.8	126.9	127.4
$ESL_{current}$	108.2	108.3	127.4	$ESL_{current}$	127.0	127.1	127.4
$ESL_{50\ years}$	108.2	108.3	127.4	$ESL_{50\ years}$	127.2	127.3	127.4
Product Transport Distance (D_m)							
Dm_{50}	108.2	108.3	127.4	Dm_{50}	127.1	127.1	127.4
Dm_{120}	108.2	108.3	127.4	Dm_{120}	127.0	127.1	127.4
Dm_{300}	108.1	108.3	127.4	Dm_{300}	127.0	127.1	127.4
Dm_{500}	108.1	108.3	127.4	Dm_{500}	126.9	127.1	127.4
Dm_{1000}	107.9	108.3	127.4	Dm_{1000}	126.8	127.1	127.4
Dm_{2000}	107.7	108.3	127.4	Dm_{2000}	126.6	127.1	127.4
Dm_{5000}	106.8	108.3	127.4	Dm_{5000}	125.8	127.1	127.4
Climate Zone							
Current	108.2	108.3	127.4	**Current**	127.0	127.1	127.4
Cold	233.8	233.9	253.1	**Cold**	252.7	252.8	253.1
Warm	59.3	59.4	78.6	**Warm**	78.1	78.2	78.6
Life Cycle Inventory							
LCI-Process	108.2	108.3	127.4	**LCI-Process**	127.0	127.1	127.4
LCI-Hybrid	49.7	50.2	127.4	**LCI-Hybrid**	125.6	126.2	127.4
Operational Energy Use							
+20%	131.7	131.8	151.0	**+20%**	150.6	150.7	151.0
−20%	72.8	72.9	92.1	**−20%**	91.7	91.8	92,1

4.2. Estimated Service Life of the Products (ESL_m)

ESL_m values for each product and system where defined for the baseline scenario (see Table 5). However, depending on the real use and maintenance practices, these values may be reduced or increased and, therefore, two additional ESL_m are assessed: Reducing the lifetime of all products by half and increasing their life by up to 50 years. Table 7 shows that the reduction of the ESL_m increases the difference between the LCA and OSA methodologies, obtaining a difference of up to 30.2% in 2ah strategy. On the other hand, for the same strategy, ESL_m 50 year values reduce the difference to 15.11%. For those refurbishment strategies using products with a lower embodied energy the difference decreases but continues below 0.5%.

4.3. Transportation Distance

Transportation distance values from the production gate to the building site have been changed to 50, 120, 300, 500, 1000, 2000 and 5000 km. Table 7 clearly shows that except in very long distances (5000 km or more), the transportation distance of the products does not alter the initial results obtained from the different methodologies. Furthermore, although all products and systems are transported from 5000 km, the overall NRPE use of the building will only be 0.01% higher than in a scenario where all products and systems are transported within a distance of 50 km. Although these results reflect that transport distance is practically irrelevant for reducing the NRPE use, it is worth noting that transport may have remarkable contributions to other environmental impact categories related to air quality or noise, as well as in economic terms where transport costs are also relevant.

4.4. Climate Zone

In order to check the influence of applying the same refurbishment strategies in other climate zones, two additional climate zones are evaluated: Warm climate (south of Italy, Palermo) and cold climate (Norway, Oslo). Due to the relevance of cooling consumption in warm climates, in this case the operational energy includes energy consumption for both heating and cooling indoor spaces (see Equation (7)). The cooling system consists of individual air-air electric installations with a nominal performance of 3 (ρ_m value). Thermostats are set at 26 °C from 12 a.m. until 8 p.m. for the cooling period (from 1 June to 31 August). To calculate the cooling related Non-Renewable Primary Energy use (NRPE), the demand is multiplied by the system performance and by a conversion factor value of 2.34 corresponding to an average value for the electricity mix in Europe [55].

Table 7 shows that in countries with a cold climate, refurbishment strategies lead to high reductions of NRPE during the use phase, and therefore the influence of other life cycle stages is reduced. The maximum difference between LCA and OSA results to 8.5% (strategy 2ah) for cold climates. In warm climates with a lower heating demand, the difference between LCA and OSA results to 32% (strategy 2ah), because the NPRE increase due to the use of products is relatively higher.

4.5. Uncertainty on Data on Embodied Energy of Products

Most current studies, including the present one, use environmental data from LCI databases and/or environmental product declarations, which are based on the LCA methodology for calculating the environmental inputs and outputs of each process involved in the corresponding supply chain (bottom-up technique). This process based LCA approach may conduct to a large associated uncertainty [56] due to the truncation error derived from data scarcity at a certain point of the upstream supply chain. Crawford [57] has shown that this error can be up to 87% of the embodied energy of building products, and has proposed the use of input-output LCA analysis, a top-down technique that establishes a link between economic transactions and the energy intensity of economic sectors, or hybrid LCA analysis, combining process and input-output analysis, to capture all the upstream processes. Crawford [58], Crawford and Stephan [59] and Stephan and Stephan [60] have shown that input-output-based hybrid analysis can produce embodied energy figures around four times higher than process analysis, for the same building. In order to assess the effect of a potential underestimation of the embodied energy values, a new scenario has been calculated multiplying the energy values by an average coefficient of 4.03 [60].

When data derived from hybrid LCA studies is used instead of process-based data, the difference between LCA and OSA increases, reaching a maximum difference of 60.5% for strategies with highest embodied energy values. This large difference on the results respond to the much high values of NRPE for building products that are obtained through LCI-hybrid methods. With these values, the overall reduction of NRPE for the LCI-Hybrid method is less than half the reduction obtained with the LCI-Process method for the LCA and LCA-Si.

4.6. Uncertainty in Relation to Occupancy Schedules and User Behavior

Occupancy schedules may significantly vary the results of operational energy use. This parameter adds a remarkable uncertainty to the results, as it has a critical role when estimating energy loads in residential buildings, as shown for example by Topouzi [61]. Indeed, Pettersen [22] and Juodis *et al.* [62] have shown that user behavior could vary the primary operational energy associated with space heating by ±15%–20%. Therefore, two new scenarios have been added to take these issues into account, assuming that the heating demand of the baseline scenario can be 20% higher and 20% lower than initially calculated due to occupancy and behavioral issues. Table 7 shows that when the operational energy consumption increases, the difference between LCA and OSA decreases, and *vice versa*.

4.7. Sensitivity Analysis for a Combination of Different Factors

In order to explore additional potential situations, 32 new refurbishment scenarios were assessed by combining extreme values for the different parameters evaluated separately in the previous sections (see Table 8). Taking into account the low influence of the material transportation distance (less than 0.01%), this parameter was not included in the combination of different factors.

For simplicity, Figure 6 shows the relative difference with LCA of the results obtained with LCA-Si and OSA for those refurbishment strategies with the highest and the lowest difference in their parameter values: 2ah and 3al, respectively.

As presented in Figure 6, for almost all the additional scenarios differences obtained using LCA and LCA-Si methodologies are lower than 3%. However, new scenarios highlight the differences between LCA/LCA-Si with OSA, which can reach up to 319% in buildings located in warm climates and by the application of hybrid embodied energy data. The second lecture of the Figure 6 is related to the embodied energy of applied products. The results show that the relative difference between LCA and OSA in refurbishment strategies with low embodied energy products is lower that 4%, except in scenarios such as C1 and C9 (with a relative difference of 4.1%, 5.4% respectively). However, in refurbishment strategies with high embodied energy, the difference between LCA and OSA in considerable, increasing the importance of obtaining objective and actual information about each product, and therefore showing the relevance of the application of hybrid data, which can have much higher embodied energy values.

Regarding service life, in energy refurbishment projects with high RSL_b and low ESL_m values, the difference between these LCA and OSA methodologies is greater than 35% (C1, C3, C5, C17 and

C51). However, in climate zones with high operational heating energy demand, this difference is decreased to 5.6% (C23).

Table 8. Definition of new energy refurbishment scenarios by the combination of different Reference Service Life of buildings (*RSL_b*), Estimated Service Life of material (*ESL_m*), Climate zone (*Cl*), type of Embodied Energy data (*EE*) and Operational Energy use uncertainties (*OE*).

Scenario ID	***RSL_b* (years)**		***ESL_m* (years)**		***Cl***		***EE***		***OE***	
	100	**25**	**Half**	**50**	**Warm**	**Cold**	**Hybrid**	**Process**	**−20%**	**+20%**
C1	X	-	X	-	X	-	X	-	X	-
C2	X	-	-	X	X	-	X	-	X	-
C3	X	-	X	-	-	X	X	-	X	-
C4	X	-	-	X	-	X	X	-	X	-
C5	X	-	X	-	X	-	-	X	X	-
C6	X	-	-	X	X	-	-	X	X	-
C7	X	-	X	-	-	X	-	X	X	-
C8	X	-	-	X	-	X	-	X	X	-
C9	-	X	X	-	X	-	X	-	X	-
C10	-	X	-	X	X	-	X	-	X	-
C11	-	X	X	-	-	X	X	-	X	-
C12	-	X	-	X	-	X	X	-	X	-
C13	-	X	X	-	X	-	-	X	X	-
C14	-	X	-	X	X	-	-	X	X	-
C15	-	X	X	-	-	X	-	X	X	-
C16	-	X	-	X	-	X	-	X	X	-
C17	X	-	X	-	X	-	X	-	-	X
C18	X	-	-	X	X	-	X	-	-	X
C19	X	-	X	-	-	X	X	-	-	X
C20	X	-	-	X	-	X	X	-	-	X
C21	X	-	X	-	X	-	-	X	-	X
C22	X	-	-	X	X	-	-	X	-	X
C23	X	-	X	-	-	X	-	X	-	X
C24	X	-	-	X	-	X	-	X	-	X
C25	-	X	X	-	X	-	X	-	-	X
C26	-	X	-	X	X	-	X	-	-	X
C27	-	X	X	-	-	X	X	-	-	X
C28	-	X	-	X	-	X	X	-	-	X
C29	-	X	X	-	X	-	-	X	-	X
C30	-	X	-	X	X	-	-	X	-	X
C31	-	X	X	-	-	X	-	X	-	X
C32	-	X	-	X	-	X	-	X	-	X

Finally, climate zone and operational energy use demand is analyzed together because are directly linked. Generally, when the baseline operational energy demand is lower (warmer climates), the possibility to improve the energy performance by the refurbishment strategies is lower, increasing the importance of other building life cycle phases, and therefore increasing the relative difference between LCA and OSA methodologies.

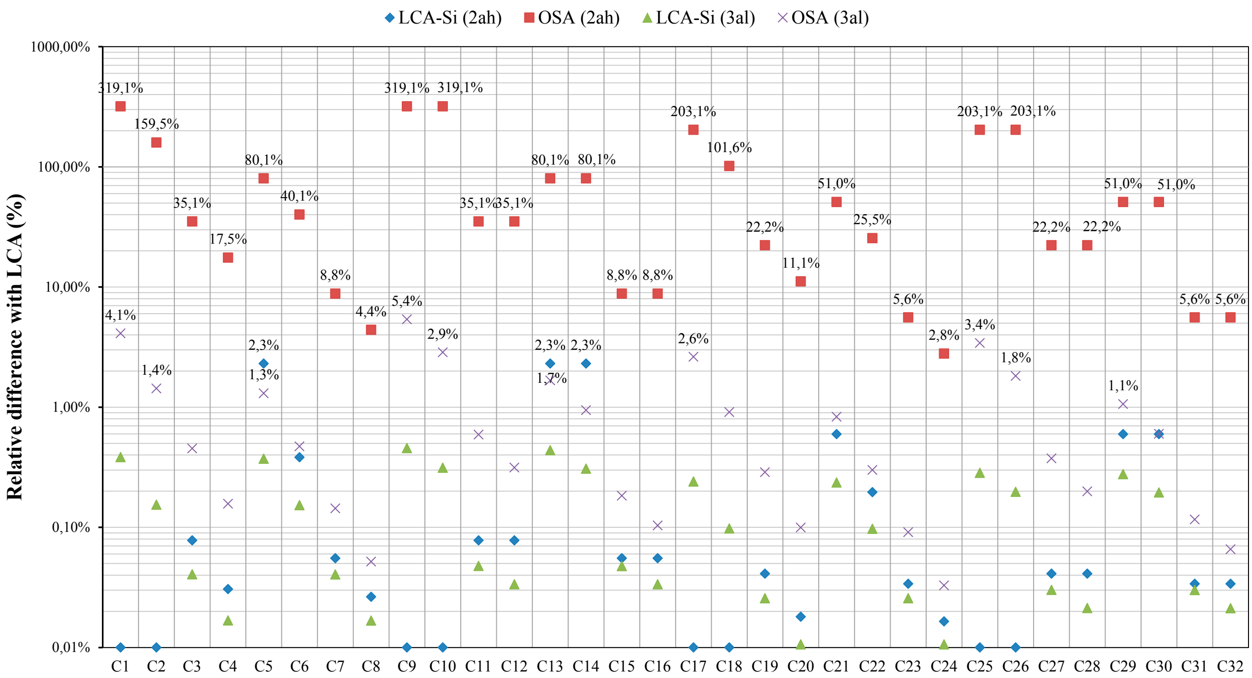

Figure 6. Relative difference with LCA for 2ah (advanced efficiency level ventilated façade system with high embodied energy products) and 3al (advanced efficiency level external insulation system with low embodied energy products) refurbishment strategies.

4.8. Other Indicators and Environmental Impact Categories

For simplicity, previous sections have presented only the NRPE results for the different refurbishment scenarios and using different calculation methodologies. However, as previously mentioned, a number of indicators need to be used in LCA to avoid potential shifting of impacts between different categories. Various previous studies as shown in Table 9 have studied different environmental impact categories.

Table 10 presents the results for additional environmental impact categories calculated for the case study. Differences between LCA and simplified methodologies are similar to the previously calculated for NRPE for indicators ADP and GWP, as it could be expected taking into account the strong correlations between these categories. For other frequently used environmental indicators such as ODP, POCP or AP, which are part of the indicators set in the CEN TC 350 standards [12], there is also a large similarity on the differences between methodologies, as the life cycle impacts on these categories are still strongly linked to the use of fossil fuels. For other impact categories not considered in this study or in the recent standardization efforts, for example those related to toxicity, further research is needed on the impact of all the different life cycle phases as there is currently not enough data available and results could differ in this case.

Table 9. Environmental impact categories used in previous studies.

Environmental impact categories	**Erlandsoona *et al.*, 2004 [27]**	**Junnilla, 2004 [28]**	**Citherlet *et al.*, 2007 [29]**	**Zabalza *et al.*, 2009 [30]**	**Utama *et al.*, 2009 [31]**	**Kofoworola *et al.*, 2009 [26]**	**Blom *et al.*, 2010 [32]**	**Blengini *et al.*, 2010 [33]**	**Gustavsoon *et al.*, 2010 [34]**	**Hernandez *et al.*, 2010 [23]**
Resource use, primary energy, PE	-	-	-	X	X	X	-	X	X	X
Depletion of Abiotic resources, elements, ADP-elements.	-	-	-	-	-	-	X	-	-	-
Global warming, GWP	X	X	X	X	-	-	X	X	X	-
Ozone Depletion, ODP	-	-	-	-	-	-	X	X	-	-
Photochemical Ozone Creation, POCP	X	-	X	-	-	-	X	X	-	-
Acidification for soil and water, AP	X	X	X	-	-	-	X	X	-	-
Eutrophication, EP	X	X	-	-	-	-	X	X	-	-

Environmental impact categories	**Oritz *et al.*, 2010 [35]**	**Dodoo *et al.*, 2010 [36]**	**Malmqvist *et al.*, 2011 [37]**	**Rossi *et al.*, 2012 [38]**	**Stephan *et al.*, 2012 [24]**	**Ramesh *et al.*, 2012 [39]**	**Stephan *et al.*, 2013 [25]**	**Mosteiro *et al.*, 2014 [40]**	**Dodoo *et al.*, 2014 [41]**	-
Resource use, primary energy, PE	-	X	-	-	X	X	X	X	X	-
Depletion of Abiotic resources, elements, ADP-elements.	X	-	-	-	-	-	-	-	-	-
Global warming, GWP	X	-	X	X	-	-	-	X	-	-
Ozone Depletion, ODP	X	-	-	-	-	-	-	X	-	-
Photochemical Ozone Creation, POCP	-	-	-	-	-	-	-	-	-	-
Acidification for soil and water, AP	X	-	-	-	-	-	-	X	-	-
Eutrophication, EP	-	-	-	-	-	-	-	X	-	-

Table 10. Results of the analysis for other impact indicators expressed for m^2 and year. For abbreviations, refer to Table 9.

Environmental impact reduction							
Environmental Impact Indicators (EII)	**2ah Strategy**			**EII**	**3al Strategy**		
	LCA	**LCA-Si**	**OSA**		**LCA**	**LCA-Si**	**OSA**
ADP fossil fuels (MJ/(m^2·a))	95	96	110	**ADP**	110	110	110
GWP (kg CO_2/(m^2·a))	5.5	5.6	8.2	**GWP**	8.1	8.1	8.2
ODP (kg CFC 11/(m^2·a))	2.5×10^{-7}	2.5×10^{-7}	2.1×10^{-6}	**OPD**	2.1×10^{-6}	2.1×10^{-6}	2.1×10^{-6}
POCP (kg ethene/(m^2·a))	1.3×10^{-3}	1.3×10^{-3}	1.8×10^{-3}	**POCP**	1.8×10^{-3}	1.8×10^{-3}	1.8×10^{-3}
AP (kg SO_2-eq/(m^2·a))	2.4×10^{-2}	2.4×10^{-2}	2.9×10^{-2}	**AP**	2.9×10^{-2}	2.9×10^{-2}	2.9×10^{-2}

5. Discussion

Simplifications of the LCA methodology can have important implications in decision-making process for selecting the most appropriate energy refurbishment solutions of existing buildings. The exercise previously developed, and especially the results obtained from the sensitivity analysis, provide useful information about how simplifications can bring insignificant or very remarkable uncertainties in comparison to a fully-fledged LCA methodology.

Differences between LCA and Simplified LCA are negligible in the case of assessing the use of Non-Renewable Primary Energy (NRPE) when comparing different refurbishment solutions oriented to reduce the energy consumption of existing buildings. The use of OSA does, however, have important limitations. For warm climates and ambitious goals for reducing the energy consumption of buildings by using materials and systems with a high energy embodied values, OSA is an oversimplified methodology and can mislead the decision making for choosing solutions with the best life cycle environmental performance. If products with low embodied energy are used, OSA, which studies only the reduction on energy use during the operational stage of the building, might be of sufficient accuracy. Of course, it should then be decided and benchmarked which materials are considered low embodied energy. In the case of colder climates or situations with drastic reductions on operational energy use due to a refurbishment strategy, values obtained with the OSA methodology will be very similar to those yielded by an LCA, as relative importance of products and other building life cycle phases is lower. In addition, OSA is not recommended if construction products and systems with short Estimated Service Life are used.

Regarding the quantity and type of environmental indicators used on the analysis, it has to be considered that when applying LCA to compare different options, commonly there is not a specific alternative that scores the best in all the impact categories. Therefore, the decision maker needs to select the best option according to his/her environmental values and objectives and apply some kind of weighting among the different impact categories. This study is focused on the NRPE Indicator as it generally offers a good correlation with other related impact categories (such as Global Warming and Abiotic Depletion of fossil fuels) and, on the other hand, captures the consequences of applying energy efficiency strategies. Other environmental impact categories not so correlated to the use of fossil use (such as toxicity) are not well represented by this indicator.

The source of data used in the LCA has a remarkable influence increasing the uncertainty of the results, as significant differences exist in the calculations using data derived from process inventories (e.g., from Ecoinvent and GaBi databases, for instance, or from EPDs) or from hybrid Input-Output analysis This observation is in line with previous studies from Crawford [57] and Stephan *et al.* [25] which have demonstrated that the truncation error associated to process-based life cycle inventories may significantly affect the final results.

Regarding data associated to the construction stage, the main barrier is again related to the lack and uncertainty of environmental information, which largely depends on project specific parameters and are difficult to assess for a set of different strategies. As for data associated for transportation, technicians usually have information on the exact location of the distributor of the product or system applied in the refurbishment project, but in many cases the manufacturing location is unknown, being the impacts associated to transport from manufacturer to distributor difficult to calculate. Due to the lack of information about future waste management processes, the uncertainty of the end of life stage is also very large.

Finally, it is important to mention that despite heating being one of the major contributors to the operational energy consumption of buildings, cooling of indoor spaces (especially in warm climate zones) should not be left out of the scope of the assessment of energy refurbishment in any case (LCA, LCA-Si or OSA) as, for some scenarios, it can have a significant influence on the decision-making process.

6. Conclusions

The refurbishment of the existing building stock with the aim of reducing its operational energy consumption is being fostered for different reasons and by different actors in the EU. The intense standardization efforts on the assessment of the sustainability of buildings carried out by the European Committee for Standardization Technical Committee 350 [12] suggests that the application of the life cycle approach will be more common in the near future. In this context, simplified LCA (LCA-Si) could be seen as a first step towards a comprehensive and extensive application of LCA within the construction sector. On the other hand, depending on the objectives pursued and the resources available, the practical application of the LCA methodology could be neither necessary nor possible, and in some circumstances an analysis of the energy reduction derived from the refurbishment during the operational stage (OSA) could be sufficient. As proved through a complete case study, in the case of assessing different refurbishment strategies oriented to reduce the energy consumption of buildings, a simplified LCA study may underestimate the absolute energy values, but it generally allows identifying the most (life-cycle) efficient solution. However, considering only the operational energy use (OSA) may lead to the selection of less efficient solutions.

The application of the fully-fledged LCA methodology still faces important challenges, and the construction industry needs to play a key role in the calculation and publication of data to facilitate accurate assessments of building energy refurbishment projects.

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Author Contributions

The paper is based on Xabat Oregi's PhD research work. Oregi was responsible for the research design, data collection and analyses. Patxi Hernandez and Cristina Gazulla provided guidance and supervision respectively. Marina Isasa provided additional insights.

Conflicts of Interest

The authors declare no conflict of interest.

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6.2. Future work / *Ondorengo lanak*

Although this PhD thesis finishes here, the research work is still in progress. Different directions have been identified to carry on with it in the future. Thus, this thesis sets up the bases for future works.

Nahiz eta tesi hau hemen amaitu, ikerketa lanak oraindik martxan jarraitzen du. Etorkizunean jarraitzeko norabide ezberdinak identifikatu dira, zenbait puntu desberdin zehaztuz.

6.2.1. Related to data / *Datuekin lotua*

As shown during the thesis, it is necessary to reduce uncertainty and lack of information about many of the environmental and economic aspects that form a project for energy rehabilitation.

On the one hand, for the economic aspect, it is very difficult to determine and to estimate values as the increased price of energy or inflation variation, since they are values which depend on energy and economic policies of the different countries.

Regarding the environmental section, it is necessary to increase the volume of information which can facilitate the evaluation and quantification of the impact generated in all stages of the life cycle.

It is expected that by the introduction of the Regulation (EU) No 305/2011, growing number of construction products will contain the environmental impact information generated during their production stage.

Tesian zehar erakutsi den bezala, beharrezkoa da birgaitze energetikoko proiektu baten parte diren ingurumen eta ekonomia aspektu askori buruzko ziurgabetasuna eta informazio gabezia murriztea.

Alde batetik, atal ekonomikorako, energiaren prezioaren igoera eta inflazioaren aldaketa bezalako balioak aurreikusi eta zehaztea oso zaila izango dela garbi ikusten da, lurralde ezberdinetako politika energetiko eta ekonomiko ezberdinen menpe dauden balioak baitira.

Ingurumenarekiko atalari buruz, beharrezkoa da informazio bolumena handitzea, bizi zikloaren etapa guztietan sortutako inpaktua ebaluatu eta zenbatzea erraztuz.

EB-ak abian duen No 305/2011 arautegia martxan jartzean, gero eta eraikuntzako produktu gehiagok izango dute beren ekoizpen prozesuan zehar sortutako ingurumen inpaktuei buruzko informazioa. Modu honetara, produktu edo sistema bakoitzaren dentsitatea, In this way, together with characteristics such as density, fire resistance or conductivity of each product or system, the technician shall have a value of the environmental impact, allowing homogenize and standardize the evaluation of a stage which is currently limited to research studies. In conjunction with this legislation, should be highlighted other initiatives such as the research project "SOFIAS". Through the work done in this project, they have begun to generate a generic environmental impact database of the production stage for all the construction products that are part of the Spanish construction elements database *(Gazulla et al., 2014).*

In turn, another concern marked by the thesis is focused on the direct relationship between the inhabitant of each building and final energy demand. It is becoming increasingly necessary to consider and integrate in energy demand calculations social and economic characteristics of each user of the building. Along with the technical performance of the building, the inhabitant behaviour will mark which is the performance of one of the stages of the life cycle that most influences an energy rehabilitation, the stage of operational energy use.

suaren aurkako erresistentzia edo eroankortasuna bezalako ezaugarriekin batera, ingurumen balio berri hau eskuragai izango da, gaur egun ikerketa lanetara mugatzen den etapa baten ebaluazioaren homogeneizatzea eta estandarizatzea lortuz. Europar araudi honekin batera, nabarmentzekoak dira “SOFIAS” ikerketa proiektua bezalako nazio mailako ekimenak. Proiektu honetan egindako lanaren ondorioz Espainiako eraikuntza elementuen datu baseetako produktu guztientzako ekoizpen etapako ingurumen inpaktuaren datu base orokor eta generikoa sortzen hasiak bait dira (Gazulla et al., 2014).

Honekin batera, tesiak azpimarratutako beste kezka bat eraikin bakoitzeko biztanleak eta eskari energetikoaren artean dagoen erlazio zuzena da. Gero eta beharrezkoagoa da kalkulu energetikoetan eraikinaren erabiltzaile bakoitzaren ezaugarri sozial eta ekonomikoak kontuan hartu eta sartzea. Eraikinaren ezaugarri teknikoekin batera, erabiltzailearen portaerak birgaitze energetikoan eragin handienetakoa duen bizi zikloko etaparen portaera zein izango den adieraziko du, erabilera etapa.

6.2.2. Related to evaluation scale / *Ebaluazio eskalarekin lotua*

Up to recent years, the concept of the energy rehabilitation of the building sector has been linked to the concept of a single action, where each community or user rehabilitates some element of their dwelling or building. However, due to issues such as innovation in technologies (district heating - cooling, seasonal thermal energy storage, ...), potential for centralized power generation using renewable systems, the increase in population of the cities (according to United Nations (*WUP, 2014*) by the year 2050 close to 70% of the world population will be living in cities) or the new requirements of the different stakeholders, is becoming more necessary to define calculation methodologies that enable making decisions about the different rehabilitation strategies to a larger scale (see figure 91).

Thus, along with the strategies defined for energy rehabilitation of an element isolated as a single building, based on a new methodology with a larger scope, would enable to integrate and assess new strategies and energy rehabilitation systems (see annex *7.7*).

Azkenengo urteak arte, eraikuntza sektoreko birgaitze energetikoaren kontzeptua banakako eskuhartze batekin lotu da, bakoitzak bere eraikinaren edo etxebizitzaren elementuren bat energetikoki birgaitzean oinarrituz. Hala ere, teknologia berrien hobekuntza (auzo berokuntza/hozkuntza, energia termikoaren sasoian sasoiko metaketa sistema, etab.), sistema berriztagarrien sorkuntza zentralizatuen ahalmena, gizartearen aldaketa (2050.urterako munduko biztanleriaren %70a hirietan biziko da (WUP, 2014)) edo aktore desberdinen behar berrien ondorioz, gero eta beharrezkoagotzat ikusten da birgaitze estrategia ezberdinei buruzko erabakiak eskala handiago batean hartzea ahalbidetzen duten kalkulu metodologiak zehaztea (ikus 91. irudia).

Modu honetara, eraikin bakar bat bezalako elementu isolatu baten birgaitze energetikorako definitutako estrategiekin batera, metodologiaren irismen berri eta zabalagoaren bidez, energia birgaitze estrategia eta sistema berriak proposatu eta ebaluatzeko aukera egongo da (ikus 7.7 eranskina).

Figure / Irudia 91 Change of the evaluation scale, from the building to the neighborhood: energy refurbishment assessment of the Amara neighborhood (San Sebastian, Spain) realized by the software NEST / *Ebaluazio eskalaren aldaketa, eraikinetik auzora: NEST software-aren bidez Amara auzoaren (Donostia, Espainia) birgaitze energetikoaren analisia.* Source / *Iturria:* Own elaboration / *Norbere garapena*

The study conducted by the author of this thesis (*Oregi et al., 2015b*) proposes a review about the different software for integration of energy in urban planning projects. This work defines the overall performance of software and evaluation systems that analyze and quantify the environmental and economic impact of a district or city (see annex 0). The review shows how the number of applications available are quite numerous, although very few enable to evaluate activities related to energy rehabilitations at district or city level.

Therefore, seeing the need to change the scope of assessment, the new line which is working the author of this thesis focuses on defining a new calculation methodology for evaluating the reduction of the environmental, economic and social impacts after application of different energy rehabilitation strategies at the district level. Emphasize the different contributions to the dissemination of this

Tesi honen autoreak egindako azterlanak (Oregi et al., 2015b) hirigintza proiektuetan energiarekin loturiko parametroak aztertzea ahalbidetzen duten software ezberdinei buruzko berrazterketa bat proposatzen du. Bertan auzo edo hiri baten ingurumen eta ekonomia inpaktua analizatu eta zenbatzea ahalbidetzen duten software eta ebaluazio sistemen ezaugarri orokorrak definitzen dira (ikus 0 eranskina). Berrazterketak eskuragarri dauden aplikazioak asko direla erakusten du, nahiz eta oso gutxik ahalbidetzen duten auzo edo hiri mailako birgaitze energetikoak ebaluatzea.

Horregatik, ebaluazio irismenaren aldaketaren beharra ikusirik, tesi honen autorea lanean ari den ildo berria auzo mailako birgaitze energetikoko estrategia ezberdinen aplikazioaren ondoren ingurumen, ekonomia eta gizarte inpaktuaren murrizpena ebaluatzeko kalkulu metodologia berri methodology at international and national level conferences realized by the author:

bat definitzean datza. Azken bi urteetan, metodologia berri honen inguruan nazio mailan eta nazioarteko hitzaldeetan egindako ekarpenen artean aipatzekoak dira ondorengo lanak:

- Zambrana, D., Zabalza, I., Isasa, M., Yepez-Salmon, G., Partidário, P., **Oregi, X**., (2014). Impact Assessment and Life Cycle improving energy efficiency in urban áreas. SB14. World Sustainable Building 2014, Barcelona, Spain
- Isasa, M., Gazulla, C., Zabalza, I., Zambrana, D., **Oregi, X**., Partidário, P., Pousse, M., (2014). Evaluación del impacto del Ciclo de Vida y mejora de la eficiencia energética en áreas urbanas. Conama 2014. Congreso Nacional del medio ambiente. Madrid, Spain.
- **Oregi, X**., Mabe, L., Pousse, M., Lotteau, M., Gastañares, J., (2015). Evaluación ambiental y social del nuevo barrio de Txomin Enea (Donostia) y propuesta de nuevos escenarios de optimización. Congreso ciudades inteligentes. Madrid, Spain.
- **Oregi, X**., Mabe, L., Pousse, M., Lotteau, M., Gastañares, Jon., (2015). Environmental and social evaluation of the new district of Txomin Enea (San Sebastian) and investigation of optimisation scenarios. LCM 2015. Mainstreaming Life Cycle Management for sustainable value creation, Bordeaux, France.
- **Oregi, X**., Mabe, L., (2015). Evaluación de los impactos ambientales-sociales de tres distritos de la ciudad de Donostia y la proposición de escenarios optimizados de rehabilitación energética. Jornada: “Hablamos de Europa”: Eficiencia Energética en el Entorno Urbano – Desarrollo Sostenible. Bilbao, Spain.

ANNEXES

ERANSKINAK

7. Annexes / *Eranskinak*

7.1. Chapter 2. Section 2.4.1. Multi Criteria Voluntary Sustainability Evaluation Systems (MCVSE)

During this section of the annex some of the current MCVSE systems are described.

LEED (http://www.usgbc.org/leed)

The US Green Building Council developed LEED (Leadership in Energy and Environmental Design) to encourage and accelerate global adoption of sustainable green building. In order to adapt to the architectural Project, currently, there are available different versions of LEED: new constructions, existing buildings, schools, homes, hospitals or neighbourhoods. LEED considers different aspects of the building, such as sustainable site development, water savings, energy efficiency, materials selection and indoor environmental quality. These aspects or list of measures are rewarded with points (without weighing) and finally the technician obtains the total score or final rating score by the sum of all awarded points. Regarding to the evaluated aspects, according to the type of the building, the indicators are adapted to each scenarios. "LEED O+M Existing Building" offers the possibility of assessing the sustainability of existing building, which helps building owners and operators measure operations, improvements and maintenance on a consistent scale, with the goal of maximizing operational efficiency while minimizing environmental impacts.

Sustainable Sites	
LEED Certified Design and Construction (4p)	Site Development—Protect or Restore Open Habitat (1p)
Building Exterior and Hardscape Management Plan (1p)	Stormwater Quantity Control (1p)
Integrated Pest Management. Erosion Control and Landscape Management Plan (1p)	Heat Island Reduction—Non-Roof (2p)
Alternative Commuting Transportation (3-15p)	Light Pollution Reduction (1p)
Water Efficiency	
Minimum Indoor Plumbing Fixture and Fitting Efficiency	Water Efficient Landscaping (1-5p)
Water Performance Measurement (1-2p)	Cooling Tower Water Management (1-2p)
Additional Indoor Plumbing Fixture Efficiency (1-5p)	
Energy and Atmosphere	
Energy Efficiency Best Management Practices	Performance Measurement (2-3p)
Minimum Energy Efficiency Performance	On-site and Off-site Renewable Energy (1-6p)
Fundamental Refrigerant Management	Enhanced Refrigerant Management (1p)
Optimize Energy Efficiency Performance (1-18p)	Emissions Reduction Reporting (1p)
Existing Building Commissioning (1-6p)	
Materials and Resources	

Sustainable Purchasing Policy	Sustainable Purchasing (1-5p)
Solid Waste Management Policy	Solid Waste Management—Waste Stream Audit (1-4p)
Indoor Environmental Quality	
Minimum IAQ Performance	Controllability of Systems—Lighting
Environmental Tobacco Smoke (ETS) Control	Occupant Comfort—Thermal Comfort Monitoring (1)
Green Cleaning Policy	Daylight and Views (1p)
Indoor Air Quality Best Management Practices (1-5p)	High Performance Cleaning Program (1-6p)
Occupant Comfort—Occupant Survey	
Innovation in Operations	
Innovation in Operations: Specific Title (1-4p)	Documenting Sustainable Building Cost Impacts (1p)
LEED Accredited Professional (1p)	
Regional Priority Credits (1-4p)	

BREEAM (http://www.breeam.org)

BREEAM is an environmental assessment method and rating system for buildings and neighbourhoods, which sets the standard for best practice in sustainable building design and construction. It encourages designers, clients and others to think about low carbon and low impact design, minimising the energy demands created by a building. For rehabilitation activities Breeam has created "BREEAM Refurbishment - Domestic buildings". This system scheme describes an environmental performance standard against which, domestic refurbishment projects can be assessed, rated and certified. It is designed to help building owners and occupiers to save operating costs, reduce the environmental impacts of refurbishments and to increase the sustainability of the existing building stock. The scheme provides a methodology and certification for delivering sustainable refurbishment projects, covering aspects such as the reduction of the energy use, water and carbon or the improvement of the health of inhabitants.

Management	
Home Users guide (3p)	Security (2p)
Responsible construction practices (2p)	Protection and enhancement of ecological features (1)
Construction site impacts (1p)	Project Management (2-4p)
Health and Wellbeing	
Daylight (2p)	Inclusive Design (2p)
Sound insulation (4p)	Ventilation (2p)
Volatile Organic Compounds (1p)	Safety (1p)
Energy	
Improvement in Energy Efficiency Rating (6p)	Drying Space (1p)
Energy Efficiency Rating Post Refurbishment (4p)	Lighting (2p)
Primary Energy Demand (7p)	Display Energy Devices (2p)
Renewable Technologies (2p)	Cycle Storage (2p)
Energy Labelled White Goods (2p)	Home Office (1p)
Water	
Internal water use (3p)	Water meter (1p)
External Water Use (1p)	

Materials	
Environmental Impact of Materials (25p) Responsible Sourcing of Materials (12p)	Insulation (8p)
Waste	
Household waste (2p)	Refurbishment Site Waste Management (3p)
Pollution	
Nitrogen Oxide Emissions (3p) Surface water runoff (3p)	Flooding (2p)
Innovation (10p)	

HQE (http://www.behqe.com/)

The Haute Qualité Environnementale or HQE (High Quality Environmental standard) is a standard for green building in France, based on the principles of sustainable development first set out at the 1992 Earth Summit and which is controlled by the Paris based Association pour la Haute Qualité Environnementale (ASSOHQE). Within this standard there are different methodologies for assessing new buildings, districts and also for assessing rehabilitation activities of non-residential buildings: HQE – Certivéa: Renovation of non-residential buildings. The certified characteristics represent the achievement of a level of performance, defined in the Technical Schemes, for each of the following 4 categories: environment, energy, comfort and health.

Environment	
Harmonious relation between buildings and their immediate environment	Management of water
Integrated choice of products and construction materials	Management of waste caused by activities
Low site nuisance	Management of servicing and maintenance
Energy	
Management of energy	
Comfort	
Hygrometric Acoustic	Visual No unpleasant smells
Health	
Health quality of spaces Health quality of air	Health quality of water

DGNB (http://www.dgnb.de).

The German Sustainable Building Certificate was developed by the German Sustainable Building Council (DGNB) together with the Federal Ministry of Transport, Building and Urban Affairs (BMVBS) to be used as a tool for the planning and evaluation of buildings in this comprehensive perspective on quality. As a clearly arranged and easy to understand rating system, the German Sustainable Building Certificate covers all relevant topics of sustainable construction, and awards outstanding buildings in the categories bronze, silver and gold. Six subjects affect the evaluation: ecology, economy, social-cultural and functional topics, techniques, processes and location. DGNB defined a new rating system: *DGNB New Office and Administrative Buildings with modernization measures*. This scheme was designed for existing buildings used mainly as offices or administrative buildings with modernized facades, building services, etc. The assessment is based on the DGNB scheme "New office and administrative buildings" and focuses on operational costs and payback periods; in other words, the Certification System is especially suitable as an optimization tool for architects and building owners in the planning phase.

Ecological quality	
Life Cycle Assessment	Primary Energy Demand
Local Environmental Impact	Drinking Water Demand and Wastewater Volume
Environmentally Friendly Material Production	Land Use
Economical quality	
Building-Related Lifecycle Costs	Value Retention. Suitability for Third Party Use
Socio-cultural and functional quality	
Thermal Comfort	Efficient Use of Floor Area
Indoor Air Quality	Suitability for Conversion
Acoustic Comfort	Public Access
Visual Comfort	Cycling Convenience
User Influence on Building Operation	Design and Urban Planning Quality through Competition
Quality of Outdoor Spaces	Integration of Public Art
Safety and Security	Site Features
Barrier free Accessibility	
Technical quality	
Fire Prevention	Resistance to Hail. Storms. and Flooding
Indoor Acoustics and Sound Insulation	Ease of Dismantling and Recycling
Building Envelope Quality	Pollution Control
Backup Capacity of Technical Building Systems	Noise Emission Control
Ease of Cleaning and Maintenance	
Process quality	
Comprehensive Project Definition	Documentation for Facility Management
Integrated Planning	Environmental Impact of Construction Site / Process
Comprehensive Building Design	Construction Quality Assurance /Quality Control Measures
Sustainability Aspects in Tender Phase	Systematic Commissioning
Location quality	
Site Location Risks	Access to Transportation
Site Location Conditions	Access to Specific-Use Facilities
Public Image and Social Conditions	Connections to Utilities

OPEN HOUSE (*Essig et al., 2011*)

The OPEN HOUSE project aims to merge existing methodologies for sustainability assessment of buildings towards a common view. With the aim of being widely adopted in Europe, the OPEN HOUSE methodology is developed in a fully transparent, collective and open process, with extensive communication and interaction between all stakeholders.

Environmental quality (category weighting 33%)	
Global Warming Potential (GWP)	Non-Renewable Primary Energy Demand
Ozone Depletion Potential (ODP)	Primary Energy Demand (ADP_Enr)
Acidification Potential (AP)	Total Primary Energy Demands
Eutrophication Potential (EP)	Water and Waste Water
Photochemical Ozone Creation Potential (POCP)	Land use
Risk from materials	Waste
Biodiversity and Depletion of Habitats	Energy efficiency of building equipment
Light Pollution	
Social / Functional Quality (category weighting 33%)	
Barrier-free Accessibility	Electro Magnetic Pollution
Personal Safety and Security of Users	Public Accessibility
Thermal Comfort	Noise from Building and Site
Indoor Air Quality	Quality of the Design
Water Quality	Area Efficiency
Acoustic Comfort	Conversion Feasibility
Visual Comfort	Bicycle comfort
Operation Comfort	Responsible Material Sourcing
Service Quality	Local Material
Economic Quality (category weighting 33%)	
Building-related Life Cycle Costs (LCC)	Value Stability

Extra note (are not part of the main assessment)	
Technical Characteristics	
Fire protection	Noise Protection
Durability of the structure	Quality of the building shell
Cleaning and maintenance	Ease of Deconstruction. Recycling. and Dismantling
Resistance against hail	
Process Quality	
Project Briefing Strategy	Quality of the Executing Contractors
Integrated Planning	Quality Assurance of Construction Execution
Building Performance Targets	Commissioning
Evidence of Sustainability during Bid Invitation	Handover and Performance Evaluation
Construction Site impact/ Construction Process	
Location	
Risks at the Site	Image and conditions of the location
Circumstances at the Site	Access to amenities
Options for Transportation	Adjacent media. infrastructure

VERDE (http://www.gbce.es/pagina/certificacion-verde)

VERDE – GBCe's Environmental Certificate - acknowledges the reduction in environmental impact of the building, compared to a standard reference building. This building is a model conceived according to the minimum parameters established by law and common practice. VERDE entails the recognition by an independent organization - unrelated to the developer or designer - of the ecological values of a building by applying an internationally approved evaluating method. Among the different categories that VERDE offers, there is "Verde RH Residencial", which is a method of evaluating rehabilitation interventions in simple dwellings. The different categories are: location; energy and atmosphere; resource use; indoor air quality; quality of services; social and economic aspects; and innovation

SUPERBUILDINGS (http://cic.vtt.fi/superbuildings/)

SuPerBuildings project developed and selected sustainability indicators for buildings; improved the understanding about performance levels considering new and existing buildings. different building types and different national and local requirements; developed methods for the assessment and benchmarking of sustainable buildings; and made recommendations for the effective use of benchmarking systems as instruments of steering and in different stages of building projects.

Environmental	
Consumption of non-renewable primary energy	Protection of atmosphere (other pollutants)
Non-renewable and scarce material resources	Construction and demolition waste generation
Sustainable management of renewable resources	Solid waste separation
Rational use of water	Respect of the local original species (planting)
Land use	Climatic systems (risk of extreme climatic events)
Preservation / improvement / restoration of local biodiversity	Potential impact on climate change / Global warming potential / Carbon footprint
Loss of biodiversity	
Society	
Indoor air quality	Safety / security
Indoor Thermal Environment / Thermal comfort	Human interactions / relationships
Visual comfort	Architectural quality - Aesthetic quality
Acoustic comfort	Cultural heritage - Historical value
Economy	
Life cycle costs	Costs in the operational phase
Capital Cost	Long term stability of value

7.2. Chapter 2. Section 2.4.2. Building Life Cycle Stages in relation to existing studies analysed

Junnilla (*Junilla, 2004*) developed his doctoral thesis quantifying and comparing the potential environmental impact caused by an office building during its life cycle. This study did not consider the Estimated Service Life of the materials applied during the construction process, omitting the impact of the replacement stage.

Citherlet and Defaux (*Citherlet & Defaux, 2007*) published a study whose aim was to analyse and compare three variants of a family house in order to evaluate the total environmental impacts. In this case, they considered all the life cycles stages in their study.

In 2008 the European research Project "Environmental Improvement Potentials of Residential Buildings" (*Nemry et al., 2008*) was published, which seeks to minimise the environmental degradation caused the life cycle of products. This report presented a systematic overview of the environmental life cycle impacts of residential buildings in EU-25 and it was one of the first European researches that took into account the life cycle perspective when analysing rehabilitation projects. However, it did not considered all the stages, because of the stages such as process of construction (they justified that the operation of construction generally did not exceed 2% of the life cycle impacts), maintenance or replacement were omitted.

Along with the presentation of the state-of-the-art regarding the application of life cycle assessment (LCA) in the building sector, the study of Zabalza (*Zabalza et al., 2009*) proposed a simplified LCA methodology and applied this to a case study focused on Spain. The simplified approach proposed allowed global comparisons between the embodied energy and emissions of the building materials and the energy consumption and associated emissions at the use stage. Therefore, they considered only the product and operational energy use stages in their study.

Utama (*Utama & Gheewala, 2009*) evaluated the effect of building envelopes on the life cycle energy consumption of high rise residential buildings in Jakarta. Indonesia. They did not consider the maintenance stage during their study. In addition, they justified that the life cycle did not include the end use of the material due to the very limited possibilities to consume energy since there are no experiences before for dismantling the high rise building in Indonesia over its life time and the building materials are mainly land filled at the end of life of the building (concrete based materials); some parts will probably be reused (aluminium and wooden materials).

Kofoworola (*Kofoworola & Gheewala, 2009*) analysed a typical office building in Thailand using the life cycle energy analysis (LCEA) method. In their study considers all life cycle stages except the stage of replacement, since only major construction components such as concrete, structural steel, reinforcing Steel and bricks were considered. The results of the case study show that the influence of the primary energy consumption of the construction, maintenance and demolition stages is less than 1% (0.6%. 0.8% and 0.4% respectively).

Blom (*Blom et al., 2010*) intended to assess the environmental aspects of the operational phase of dwellings, including the maintenance of façade components, building services, operational energy use and major interior replacements. Because of the lack of information, they did not consider the on-site construction stage.

Blengini (*Blengini & Di Carlo, 2010*) developed a detailed Life Cycle Assessment (LCA) based on a low energy family house in Northern Italy. They considered all the life cycle stages in their environmental assessment.

Gustavsoon (*Gustavsoon & Joelsson, 2010*) realized a life cycle primary energy analysis of five different residential buildings. They concentrated on detailed studies of the production and operation phases from a primary energy perspective. They were based on publications other studies (*Cole, 1999; Scheurer et al., 2003*) to exclude the on-site construction stage, due to these publications justified that the energy used during this stage accounted for a minor proportion of the life cycle energy. According the publication of Dodoo (*Dodoo et al., 2009*), the energy used for the demolition and renovation of buildings was also expected to be small and was therefore excluded. In addition, the energy use for maintenance and replacement during the building's lifetime was not included.

Hernandez (*Hernandez & Kenny, 2010*) published an article proposing the definition of life cycle zero energy buildings (LC-ZEB), as well as the use of the net energy ratio (NER) as a factor to aid in building design with a life cycle perspective. However this study ignored some important aspects such as transport to building site, end of life disposal and maintenance, which could had a potentially high impact as discussed by various authors (*Thomark, 2002; Itard & Klunder, 2007*)

The main objective of the paper realized by Ortiz (*Ortiz et al., 2010*) was to study and quantify the differences in energy consumption and environmental impacts of two dwellings during the full building life cycle. The study considers all stages except the stage of replacement, discarded because they did not need to replace any product. Among the results it is shown that the overall environmental Impacts of the end-of-life phase represented less than 1% of the total life cycle.

Dodoo *(Dodoo et al., 2010*) analysed the life cycle primary energy implication of retrofitting a four-storey wood-frame apartment building to the energy use of a passive house. They followed the building life cycle to analyse the primary energy reduction achieved by the retrofitting, considering different energy supply systems. The energy for building maintenance and for refurbishment elements replacements were not included provides a summary of the life cycle.

In 2011, Malmqvist (Malmqvist et al., 2011) presented a simplified methodology to adopt a systematic approach guiding the user through the Life Cycle process. Among the different options for simplifying the process, along with the operation energy use, the product stage is considered. Due to the simplified methodology, all the other life cycle stages were omitted.

Due to the ease of remodelling apartment buildings, as well as the increased lifespans and performances required of apartment buildings, the demand for new plaster board drywall materials with outstanding flexibility is growing and the importance of assessing the associated environmental load is increasing. This study (*Tae et al., 2011*) evaluates the CO2 generated during the life cycle of a building (LCCO2) and its economic efficiency to assess the environmental loads and costs of buildings that use plaster board drywall.

This study (*Wallhagen et al., 2011*) examined whether simplified life cycle-based calculations of climate change contributions can provide better decision support for building design. They are based on earlier publications to reject the quantification of the impact of the other stages.

Rossi (*Rossi et al., 2012*) assessed the environmental impact of a residential building in three different European locations, calculating impacts of product, transport and operational energy-water use stages. Transport to and from site (A4) was included in the study, but was only slightly affecting the final results. According to steel producers' recommendations (*Arcelormittal*), this study omitted the assessment of the on-site processes (A5) stage. In addition, the end-of-life stages were not included in the analysis for non-metallic material (concrete. insulation. plaster. finishes).

This paper (*Sharma et al., 2012*) quantifies the significant environmental effects of a three storey building in Northern India.

During the project Energy Efficient Buildings Initiative - EeB Guide (*Wittstock et al., 2011*), Gazulla (*Gazulla & Oregi, 2012*) published a study whose aim was the calculation and interpretation of the LCA results of the building (before and after being rehabilitated). Due to the lack of data, it had not been possible to include the energy consumption associated with the onsite construction stage. In addition, this study decided to omit other stages such as maintenance (B2), replacement (B4), de-construction (C1) and waste processing for reuse, recovery and/or recycling (C3).

This paper (*Iyer & Wong, 2012*) presents an integrated life cycle framework developed by combining life cycle modelling with building energy efficiency simulation software. The study also investigated different intervention strategies and recommends strategies that facilitate the highest reduction in life cycle primary energy consumption.

The article of Stephan (*Stephan et al., 2012*) presented a framework which takes into account energy requirements at the building scale, i.e. the embodied and operational energy of the building and its refurbishment and at the city scale, i.e. the embodied energy of nearby infrastructures and the transport energy (direct and indirect) of its users. They evaluated all the stages except the energy associated with the end-of life stage of the building, since based on other publications (*Winistorfer et al., 2007*), they determined that it typically represented less than 1% of the total energy demand of a building.

This paper (*Cuellar & Azapagic, 2012*) presented for the first time the results of a full life cycle assessment (LCA) study for the three most common types of house in the UK: detached, semi-detached and terraced. All life cycle stages are considered, including house construction, use and demolition after 50 years.

During the study realized by Ramesh (*Ramesh et al., 2012a*) the life cycle energy (LCE) demand of a residential building located at India under different envelopes and climates in Indian context was evaluated. They proposed that energy used for on-site construction and end of life stages could be ignored as they contribute little (1%) to LCE. In addition, they did not consider any impact related to the maintenance stage.

Stephan (*Stephan et al., 2013*) analysed the total life cycle energy demand of a typical Belgian passive house. Based on other publications (*Crowther, 1999; Winistorfer et al., 2007*), who had demonstrated that it often represents less than 1% of the life cycle energy demand, they justified that while the end of life stage could be responsible for large amounts of waste; its contribution to the total energy demand was insignificant.

Asdrubali (*Asdrubali et al., 2013*) carried further analyses to evaluate the influence of various optimizations of the buildings, e.g. more efficient envelopes and facilities on the entire life cycle of the three buildings. In addition, they proposed a methodological approach, which can contribute to the acceptance of LCA as a tool in the eco-friendly design of buildings, especially those buildings whose impact during the construction phase needs to be carefully checked, such as Nearly Zero Energy Buildings.

Allacker (*Allacker & De Troyer, 2013*) proposed an integrated assessment of the life cycle environmental impact and cost methodology for sixteen representative existing and new built dwellings in Belgium. The environmental impact was estimated based on a life cycle assessment (LCA), while a life cycle costing (LCC) analysis was used for the cost aspect. In their study, they considered all the buildings life cycle stages.

The goal of this paper (*Paulsen & Sposto, 2013*) was to visualise the energy use (embodied and operational) during the life cycle of case study for a house in the Brazilian social housing program.

Vrijders (*Vrijders & Wastiels, 2013*) evaluated the cost efficiency and environmental impact in a renovation of a building in Belgium, considering different renovation scenarios (standard and nearly Zero Energy) through the LCC and LCA methodologies. They evaluated all the stages except the end of life stage. However, they did not justified why they had omitted this stage of the assessment.

De Angelis (*De Angelis et al., 2013*) analysed a multi-story residential building located in Northern Italy in order to evaluate different renovation alternatives, considering LCA and LCC approaches. Due to the impact values of maintenance (B2) and replacement (B4) stages were the same in the different renovations options; these stages did not affect the study objectives. Therefore, they omitted these two stages. In addition, while demolitions impacts are almost negligible (about 1%), they omitted also this stage.

Ostermeyer (*Ostermeyer et al., 2013*) realized a study addressing the application and potential of Life Cycle Sustainability Assessment in the built environment with a focus on refurbishments of 3 different residential buildings. They proposed a multidimensional Pareto optimization methodology, considering all stages except the end of life stage.

The objectives of the study of Mosteiro (*Mosteiro et al., 2014*) were to perform energy related life cycle assessments of a typical LEED family home and to assess the effect of rating systems and construction practices on the buildings environmental impacts. They considered all the life cycle stages except the maintenance.

This study (*Bull et al., 2014*) presented a method for assessing energy efficient refurbishment options for schools in the UK. The method accounted for life cycle effects on cost and carbon emissions since refurbished buildings will last for many years.

Dodoo (*Dodoo et al., 2014*) used the lifecycle approach to explore the primary energy implications of three timber building systems for a multi-storey building designed to a high energy-efficiency level. The analysis considered the energy and material flows in the production, use and post-use lifecycle stages of the building. However, at no point of the work they suggested to evaluate aspects such as the energy impact associated with transportation, maintenance or replacement stages.

This study (*Stephan & Stephan, 2014*) released on a multi-scale life cycle energy analysis framework to determine the energy use profile of residential buildings in Lebanon by taking into account embodied, operational and user transport energy requirements. It studied a representative case study building in Sehaileh, a suburb of the capital Beirut, over 50 years and identifies the most effective ways to reduce energy use across the different life cycle stages and scales of the built environment

This research study (*Russell-Smith et al., 2014)* combined life cycle assessment (LCA) and target value design (TVD) to rapidly produce more sustainable building designs. By establishing site-specific sustainability targets and using dynamically-updating life cycle assessments, this research demonstrated that buildings could be designed to perform at higher environmental standards than those designed without a target in place.

The main goal of this article (*Rodriguez & Freire, 2014*) is to perform a comprehensive energy and environmental life-cycle assessment (LCA) of the roof retrofit of a Portuguese single-family house integrating thermal dynamic simulation. This article shows the importance of addressing the entire lifecycle of building retrofit to reduce environmental impacts and provides recommendations for optimal insulation levels for Mediterranean climates. The end-of-life phase of the new roof was not included because these are not accurately predictable and are considered of minor importance for single-family homes (it represents less than 4% of the total environmental impacts of dwellings in southern European countries).

This article (*Bastos et al., 2014*) presents a life-cycle energy and GHG analysis of three representative residential building types in a well-known area in Lisbon. The life-cycle model focused on building construction, retrofit and use phases, applied an econometric model to estimate energy use in Portuguese households. Based in other studies, building end-of-life phase was considered negligible in the overall energy requirement and GHG emissions and thus was not considered in this analysis.

This paper (*Devi & Palaniappan, 2014*) presents a case study on life cycle energy analysis ofa residential development consisting of 96 identical apartment-type homes located in Southern India.

The authors of this study (*Cellura et al., 2014*) extended the Net Zero Energy Buildings (Net ZEB) methodological framework, introducing the life-cycle perspective in the energy balance and thus including the embodied energy of building and its components. The case study was an Italian building, tailored to be a Net ZEB, in which the magnitude of the deficit from the net zero energy target was assessed according to a life-cycle approach.

This paper (*Assiego de Larriva et al., 2014*) was focused on providing information to help in decision-making between five different scenarios for energy refurbishment, evaluating the lifecycle of each and also taking into consideration the level of comfort in dwellings.

Cetiner (*Cetiner & Edis, 2014*) defined an environmental and economic sustainability assessment method to evaluate the effectiveness of existing residential building retrofits for reducing their space heating energy consumptions and the resulting emissions. During this study, they had evaluated all the life cycle stages.

This paper (*Oregi et al., 2015a*) compares the results of applying full LCA, simplified LCA and operational energy use assessment in a refurbishment case study located in Donostia, Spain. They have considered all the stages except the maintenance stage.

7.3. Chapter 2. Section 2.4.2. Social Life Cycle Assessment

Goal and scope definition

The same scheme of the system applied in environmental and economic assessments

Life Cycle Inventory - LCI

The objective of the inventory analysis is to collect and analyse relevant information (inventory quantifiable indicators), identified during the scope definition. This inventory is elaborated for indicators (e.g. number of jobs created) linked to impact categories (e.g. local employment) which are related to five main stakeholder groups: worker, consumer, local community, society and value chain actors.

Worker	
Freedom of Association and Collective Bargaining	Forced Labour
Child Labour	Discrimination
Fair Salary	Health and Safety
Working Hours	Social Benefits/Social Security
Consumer	
Health & Safety	Transparency
Feedback Mechanism	End of life responsibility
Consumer Privacy	
Local community	
Access to material resources	Respect of indigenous rights
Access to immaterial resources	Community engagement
Delocalization and Migration	Local employment
Cultural Heritage	Secure living conditions
Safe & healthy living conditions	
Society	
Public commitments to Sustainability issues	Technology development
Contribution to economic development	Corruption
Prevention & mitigation of armed conflicts	
Value chain actors	
Fair competition	Supplier relationships
Promoting social responsibility	Respect of intellectual property rights

United Nations Environment Programme (UNEP), together with Life Cycle Initiative have developed the document “the Methodological sheets for sub-categories in Social Life Cycle Assessment” (*UNEP et al., 2013*), which provides practical guidance for conducting S-LCA case studies by offering consistent, yet flexible assistance. Aim and scope of this document was developed for each of the 31 subcategories of assessment outlined in the Guidelines. Each sheet includes a subcategory definition tailored to S-LCA, an explanation of how the subcategory relates to sustainable development, information on data assessment, including examples of inventory indicators, units of measurement and data sources, along with a reference section that points the user to further information. The data assessment section is intended to provide adaptable guidance to LCA practitioners by offering examples and does not prescribe comprehensive procedures. However, the Methodological Sheets do not provide guidance on aggregating subcategory indicators or characterization models, nor do they discuss interpretation of results.

Life Cycle Impact Assessment - LCIA

In recent years numerous studies have attempted to assess the impact of some of the social categories. For example, in order to evaluate health impacts in terms of life years lost, the Eco Indicator 99 methodology was used by Norris (*Norris, 2006*). In this case, the health impacts, measured in disability adjusted life-years (DALYs) were found to be dominated by the impacts of primary and secondary particulate emissions ('respiratory inorganic') and the potential health consequences of global warming. Otherwise, the study realized by Neugebauer (*Neugebauer et al., 2014*) proposes an evaluation methodology that transforms the data collected in social impacts (see figure 91).

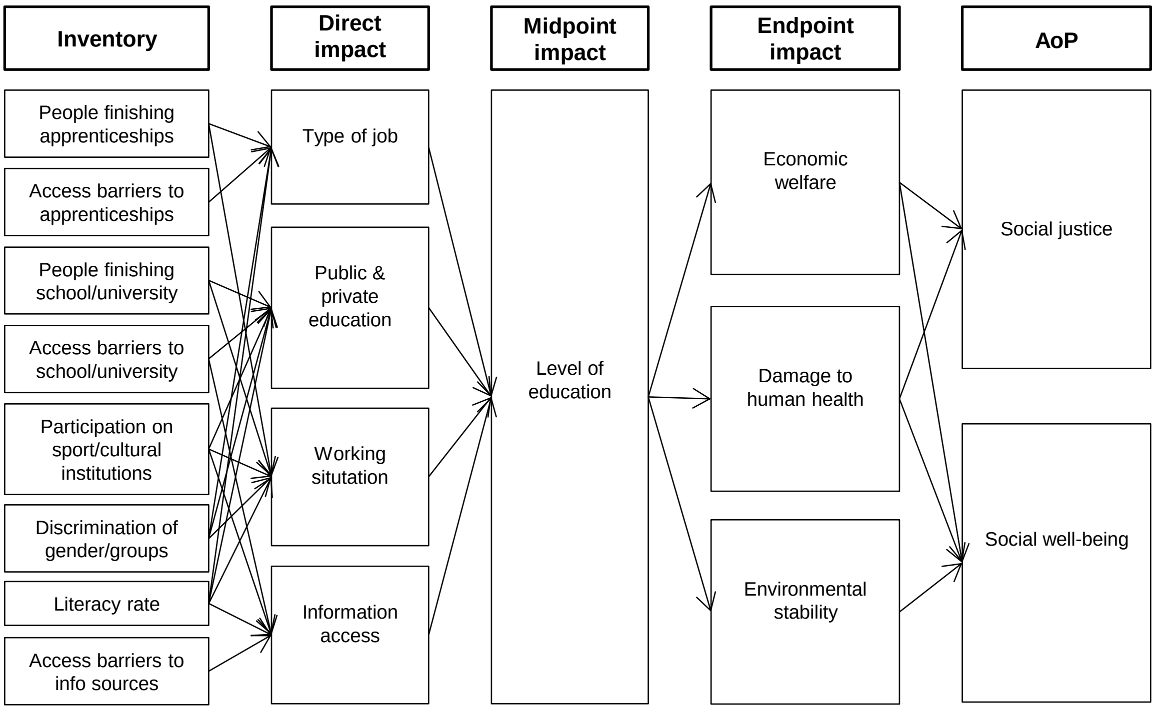


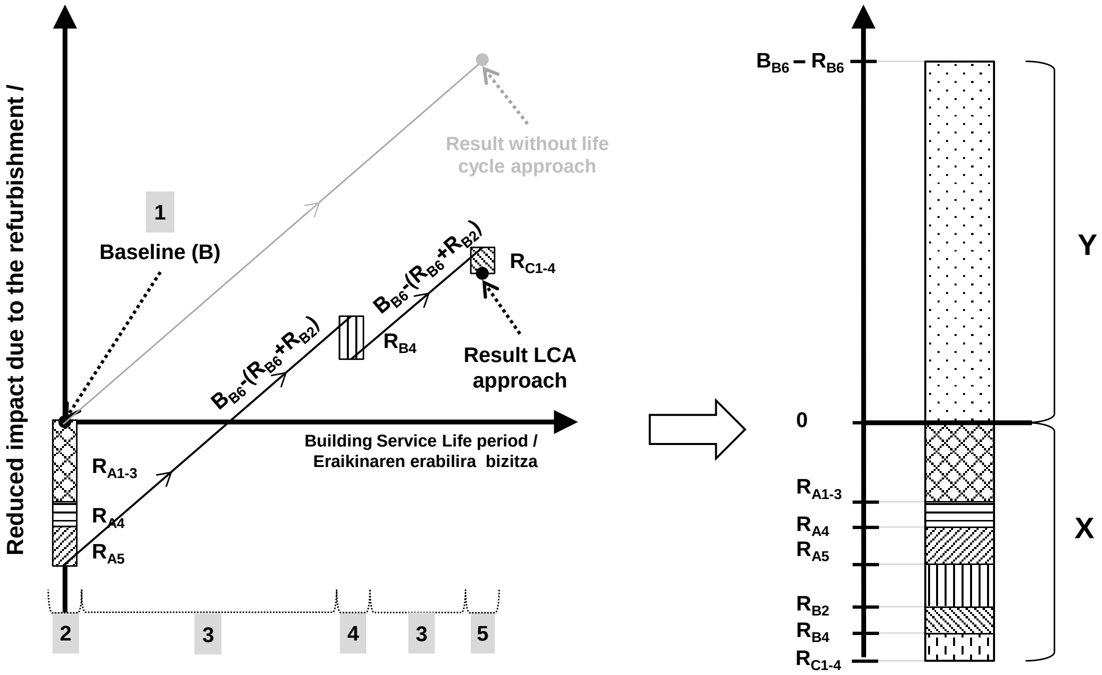
Figure 92 Social LCIA methodology, educational level. Source: own elaboration with data from (*Neugebauer et al., 2014*).

Finally, as shown below, the draft of the standard prEN16309 is also developing its own list of social impact indicators.

Accessibility	
Accessibility for people with additional needs	Access to building services
Adaptability. Ease of potential for adapting to other use	
Health and comfort	
Thermal characteristics Characteristics of indoor air quality Acoustic characteristics Characteristics of visual comfort	Spatial characteristics Thermal comfort Indoor air quality Visual comfort
Impacts on neighbourhood	
Noise Emissions Maintenance and Maintainability	Glare/ overshadowing Shocks/vibrations
Safety – Security	
Resistance to climate change Accidental actions	Personal safety and security against intruders and vandalism Security against interruptions of utility supply

7.4. Chapter 4. Information in English

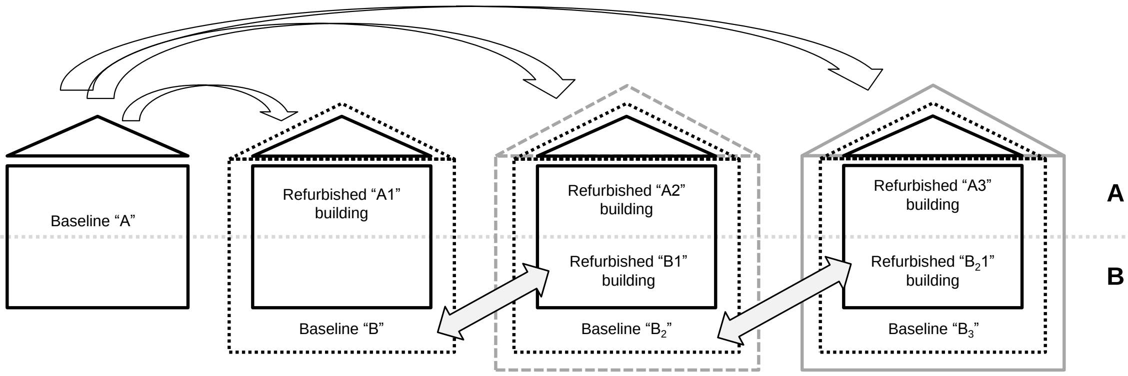
Irudia 25 / Figure 25. Scheme of the environmental and economic impact calculation of a refurbished building during its life cycle



Taula 9 / Table 9. Functional units applied in different building life cycle assessments

Functional Unit	Unit description	Studies
m^2	Net floor area	*Asdrubali et al., 2013.*
	Heated area	*Gustavsson & Joelsson, 2010; Allacker & De Troyer, 2013; Mosteiro et al., 2014.*
	Gross internal area	*Bull et al., 2014*
	Usable floor area	*Cuellar & Azapagic, 2012; Ramesh et al., 2012a; Sharma et al., 2012, Stephan et al., 2013, Paulsen & Sposto, 2013; Stephan & Stephan, 2014.*
	Gross floor area	*Junilla, 2004; Russell-Smith et al., 2014.*
	Living area	*De Angelis et al., 2013; Rodriguez & Freire, 2014; Dodoo et al., 2014.*
	Floor area without detailed specifications	*Dodoo et al., 2010; Tae et al., 2011; Wallhagen et al., 2011; Iyer & Wong, 2012.*
m^2year	Heated area	*Citherlet & Defaux, 2007; Oregi et al., 2015a.*
	Liveable area	*Nemry, 2008; Zabalza et al., 2009; Bastos et al., 2014*
	Net floor area	*Gazulla & Oregi, 2012*
	Usable area	*Devi & Palaniappan, 2014*
	Total area	*Blengini & Di Carlo, 2010*
	Floor area without detailed specifications	*Malmqvist et al., 2011; Ramesh et al., 2012b; Rossi et al., 2012*
Year		*Cellura et al., 2014; Assiego de Larriva et al., 2014*
Inhabitant		*Allacker & De Troyer, 2013*
Person year		*Bastos et al., 2014*
Total energy consumption		*Utama & Gheewala, 2009; Hernandez & Kenny, 2010; Stephan et al., 2012.*
Total environmental impact		*Oritz et al., 2010; Blom et al., 2010; Vrijders & Wastiels, 2013*

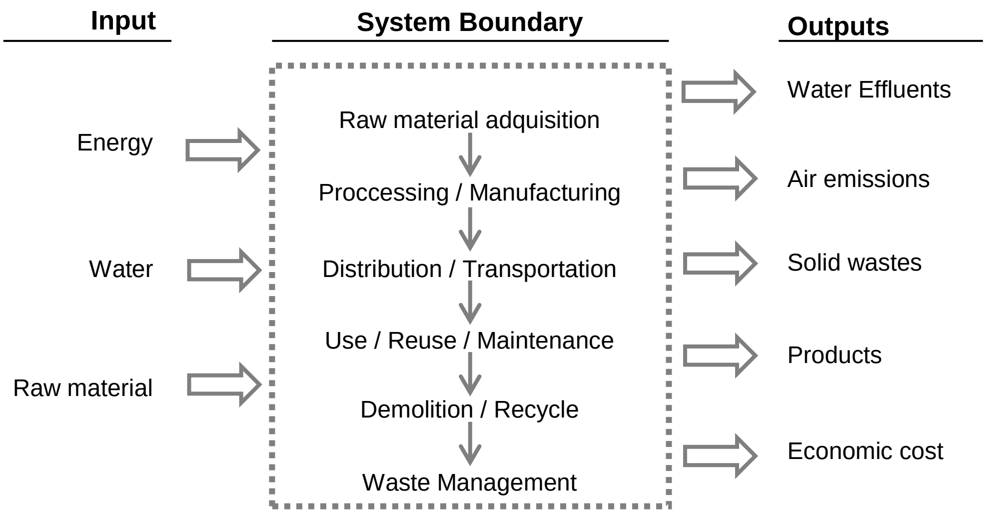
Irudia 27 / Figure 27. Relation between the baseline and the prioritization of the refurbishment strategies.



Taula 10 / Table 10. Evaluation system scope of the refurbished building with life cycle approach

Stage	Evaluated items	Baseline		Refurbished building	
		A	B	A	B
A1-3	Production of the refurbishment materials		X	X	X
A4	Transport of the refurbishment materials		X	X	X
A5	Construction process of the refurbishment materials		X	X	X
B2	Maintenance of the refurbishment materials		X	X	X
B4	Replacement of the refurbishment materials		X	X	X
B6	Operational energy use of the baseline	X			
RB6	Operational energy use of the refurbished building		X	X	X
C1-4	End of life Operational energy use of the baseline		X	X	X

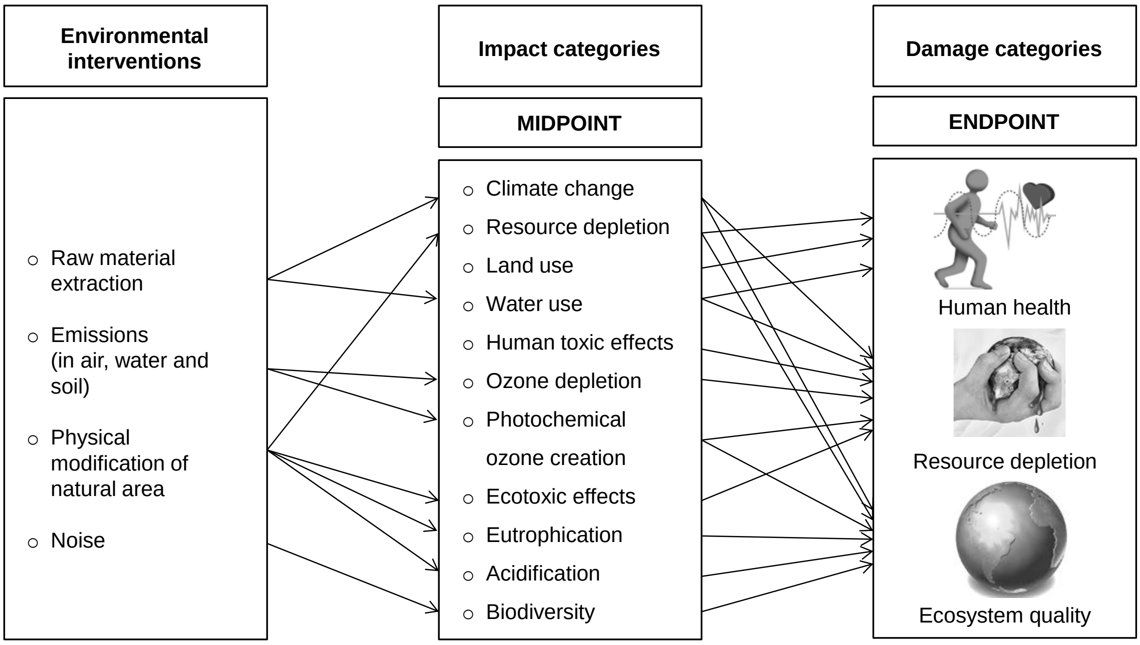
Irudia 28 / Figure 28. Life cycle inventory process applied to a system unit



Taula 11 / Table 11. Current Life Cycle Inventory (LCI) data bases

Multi-sectorial Environmental databases	
European reference Life Cycle Database 3.1 (*ELCD, 2009*)	Life Cycle Inventory (LCI) data from front-running EU-level business associations and other sources for key materials, energy carriers, transport, and waste management
U.S. Life-Cycle Inventory database (*NRPE, 2012*)	Provides individual gate-to-gate, cradle-to-gate and cradle-to-grave accounting of the energy and material flows into and out of the environment that are associated with producing a material, component, or assembly in the U.S
IO-database for Denmark (*2.0 LCA consultants, 1999*)	Input Output Database based on the Danish National Economic and Environmental Accounting Statistics for 1999
Ecoinvent v3.1 (*Ecoinvent, 2014*)	International LCI database that contains most of the industrial, construction and transport processes and systems
GaBi LCA database (*GaBi, 2014*)	International LCI database that contains most of the industrial, construction and transport processes and systems
IVAM LCA Data v.4.06 (*IVAM, 2004*)	Dutch data on materials, transport, energy and waste treatment
GEMIS 4.5 (*Gemis, 2009*)	Free database that includes energy and transport processes, materials, processes, recycling and waste treatment
Construction environmental sector databases	
Athena database v.4, Canada (*ATHENA*)	Comprehensive, comparable life cycle inventory (LCI) databases for building materials and products.
Diogen, France (*Diogen*)	Environmental impacts of the NF P 01-010 standard for materials used in the construction of civil engineering works.
IBO LCA database, Austria (*IBO*)	Information on the impact of buildings on human health and well-being (Baubiologie) and on the environment (Bauökologie).
Ökobau, Germany (*Emara & Ciroth, 2014*)	German database for construction materials and building services provided by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB)
ITec, Spain (*ITEC, 2015*)	Along with economic information of the components, incorporating more environmental data of each constructive element
Leitfaden, Luxembourg (*CRTE, 2008*)	Public database of materials, components and construction products
Minnesota Building Database, USA (*CSBR*)	Database of construction materials with rating about issues such as environmental, cost, health, sourcing, end of use or life cycle thinking (based on Athena and BEES databases)
Construction economic sector databases	
European Construction Cost (*ECC*)	Provides individual gate-to-gate, cradle-to-gate and cradle-to-grave accounting of the energy and material flows into and out of the environment that are associated with producing a material, component, or assembly in the U.S
Generador de Precios, (*CYPE*)	Economic data base of most of the elements, processes, products and systems that are part of the construction, maintenance and end of life of a building
Precio Centro Guadalajara (*PCG, 2015*)	Construction database published by the Technical Architects and Building Engineers of Guadalajara
BATIPRIX	Database of prices of French materials and construction systems

Irudia 29 / Figure 29. Overall UNEP/SETAC scheme of the environmental LCIA framework, linking LCI results via the midpoint categories to damage categories

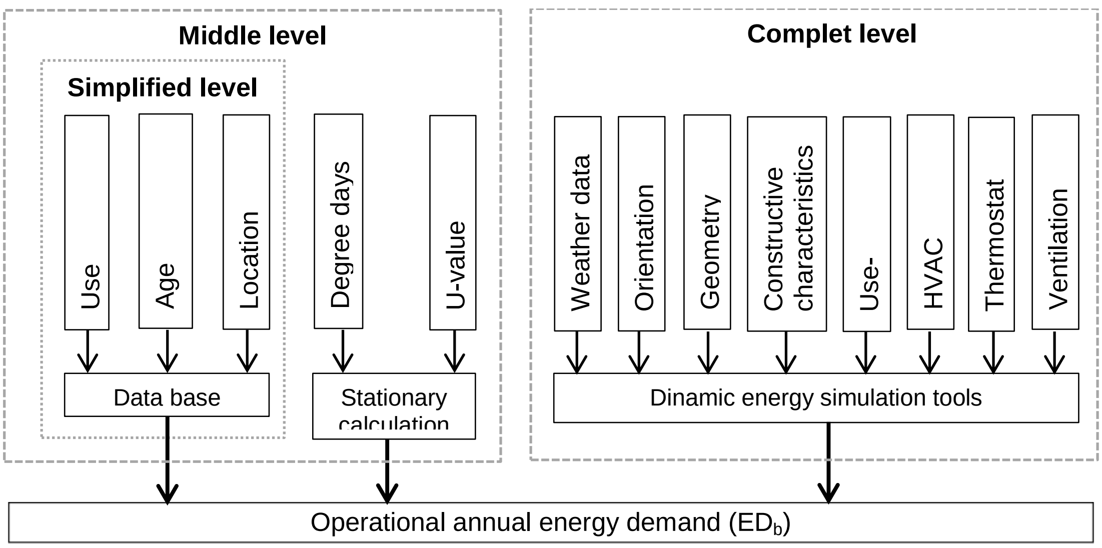


Taula 12 / Table 12. Environmental impact category indicators of LCIA using characterisation factors according to EN 15804.

Environmental impacts	
Global warming potential, GWP	kg CO2 equiv
Global warming - or "greenhouse effect"/"climate change" - addresses the effect of increasing temperature in the lower atmosphere. The possible consequences of the greenhouse effect include an increase of the temperature level leading to melting of the polar ice caps and glaciers in mountain area, resulting in elevated sea levels. The increasing temperature level may also result in regional climate changes.	
Depletion potential of the stratospheric ozone layer, ODP	kg CFC 11 equiv
Stratospheric ozone depletion is the thinning of the stratospheric ozone layer as a result of anthropogenic emissions, such as chlorofluorocarbons (CFCs) and halons. This causes a greater fraction of solar UV-B radiation to reach the Earth's surface, with a potential damage to human health, ecosystems, biochemical cycles and materials.	
Acidification potential of soil and water, AP	kg SO2 equiv
The acidity of water and soil systems can be increased due to acid deposition from the atmosphere, mainly in the form of rain. Sulphur dioxide (SO2) and nitrogen oxides (NOx) emitted by combustion processes are responsible for most acid deposition, commonly called "acid rain". Potential consequences are forest decline, soil acidification and damage to building materials.	
Eutrophication potential, EP	kg (PO4)3- equiv
Eutrophication occurs when there is an increase in the concentration of nutrients, in a body of water or soil, occurring both naturally and as a result of human activity. It may be caused by the run-off of synthetic fertilisers from agricultural land, or by the input of sewage or animal waste. It leads to a reduction in species diversity as well as changes in species composition, often accompanied by massive growth of dominant species such as "algae bloom".	
Formation potential of tropospheric ozone, POCP	kg Ethene equiv
This indicator describes the formation of reactive chemical compounds from certain air pollutants by the action of sunlight. Ozone formation, sometimes referred to as "summer smog" is mainly an issue on sunny days in larger cities with a lot of traffic.	
Abiotic depletion potential (ADP-elements) for non-fossil resources	kg Sb equiv
Abiotic depletion potential (ADP-fossil fuels) form fossil resources	MJ, net calorific value
Abiotic resources are natural resources (including energy resources), such as iron ore and crude oil, which are regarded as non-living. Depending on the definition, different methodologies have been developed,	

including different definitions of impact categories. In some cases, abiotic resource depletion encompasses both the use of non-renewable and renewable abiotic resources (wind, flowing water etc.).	
Resource Use	
Use of renewable primary energy excluding energy resources used as raw material	MJ, net calorific value
Use of Renewable Primary energy resources used as raw material (RPE)	MJ, net calorific value
Use of non-renewable primary energy excluding primary energy resources used as raw material	MJ, net calorific value
Use of Non-Renewable primary energy resources used as raw material (NRPE)	MJ, net calorific value
The Cumulative Energy Demand (CED) has already been used since the seventies as an indicator for energy systems. The assessment of the environmental impacts related to a product or process is based on one parameter: the total energy demand for production, use and disposal expressed in primary energy. Energy resources that can be found in nature, such as coal, crude oil and natural gas are called primary energy resources. Their transformation into "secondary" energy resources, such as gasoline, diesel or electricity involves losses, which depend on the efficiency and level of the transformation.	
Use of secondary material	kg
Use of renewable secondary fuels	MJ
Use of non-renewable secondary fuels	MJ
Use of net fresh water	m^3
This is an indicator of freshwater use that looks not only at the direct water use of a consumer or producer, but also the indirect water use. This indicator reflects the volume of freshwater used to produce the product, measured over the full supply chain.	
Other environmental information describing different waste categories and output flows	
Hazardous waste disposed	kg
Non-hazardous waste disposed	kg
Radioactive waste disposed	kg
Components for re-use	kg
Materials for recycling	kg
Materials for energy recovery	kg
Exported energy	MJ per energy carrier

Irudia 30 / Figure 30. Scheme of the different methodologies for calculating the energy demand.



Taula 16 / Table 16 Summary of the general characteristics of the energy demand calculation methodologies

Strengths	Weaknesses
1-Simplified	
Facility of the calculations Ideal for initial phases of the project Global vision Free databases	Dependency of generic values Low definition grade Low data quality Lack of information about all energetic aspects
2-Middle	
Certainty level of the calculation More detailed information about the building Ease to get necessary generic values	Difficulty to obtain detailed values of each case study Partial energy demand calculation Lack of consideration of parameters such as the building use, occupancy and user behaviour
3-Complet	
Accurate definition of the building Definition of most of the parameters related to the building energy performance Possibility of getting close to reality values by simulation software	Complicate and long calculation Lack of information to define exactly some inputs Economic cost of some software's High workload to define all inputs

Taula 17 / Table 17. Objectives of the different stakeholders in the rehabilitation projects: 1-Local / Regional / National policies; 2-Inhabitant; 3-Building owner; 4-Constractors / builders; 5-Investors; and 6-Design – calculation technicians.

1-Local / Regional / National policies; 2-Inhabitant; 3-Building owner; 4-Constractors / builders; 5-Investors; and 6-Design – calculation technicians.	Stakeholders					
	1	**2**	**3**	**4**	**5**	**6**
Energetic						
Reduce the final energy consumption.		X	X			X
Convert the buildings in nZEB	X	X	X		X	X
Generate x% of the consumption energy by renewable sources	X	X	X		X	X
Comply the minimum energy efficiency values defined by the directives	X					X
Environmental						
Prioritize product and system with low embodied environmental	X			X	X	X
Reduce the environmental impact of the energy generation systems	X					X
Promote new energy sources	X				X	
Economic						
Reduce the operational energy use stages economic impact		X	X		X	X
Find the optimal investment strategy		X		X	X	
Define a maximum profitability of the strategies		X			X	X
Optimize the economic impact during the life cycle		X				
Social (out of this methodology)						
Improve the thermal comfort and life quality of the inhabitants		X				
Reduce the energy poverty	X	X				
Consider the sociodemographic characteristics of the inhabitants	X	X				
Involve different stakeholders in each stage of the process	X	X	X	X	X	X
Maintain the historical heritage of the building to rehabilitate	X		X			X

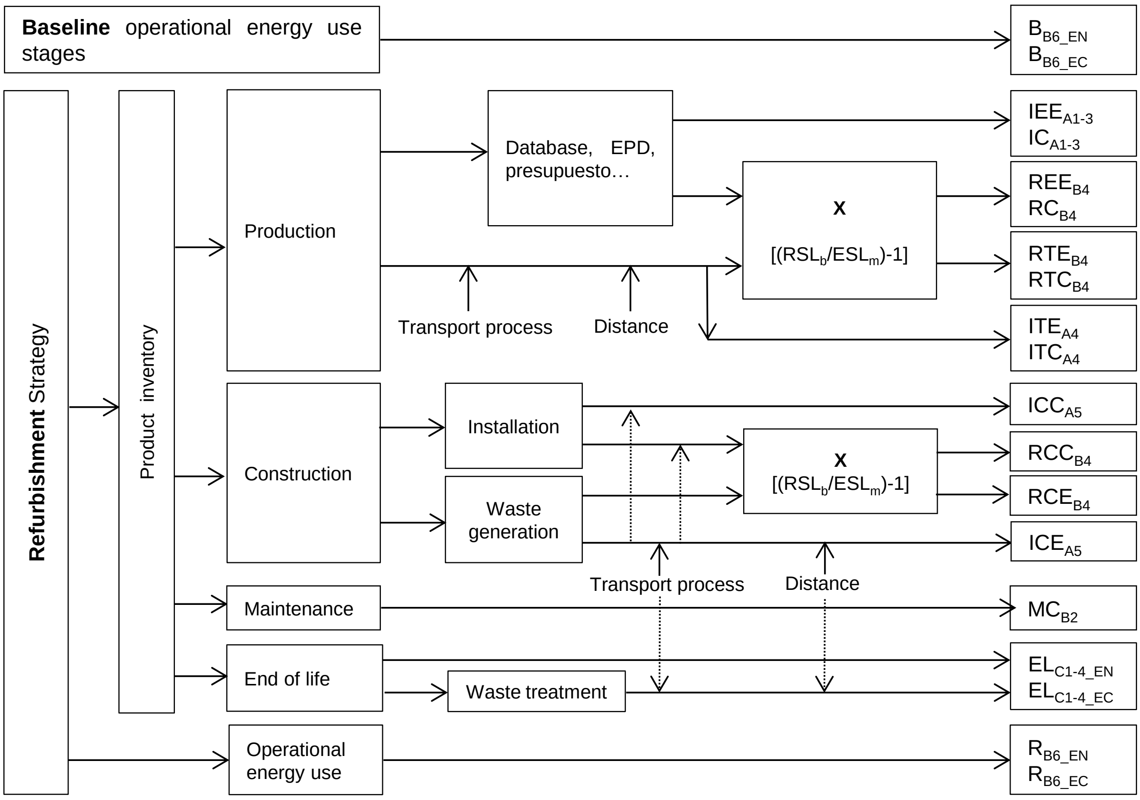
Taula 19 / Table 19. Summary of characteristics and limitations of each energy refurbishment strategies group.

		Envelope insulation	Window replacement	Air leakage reduction	Pipe insulation	Solar thermal	Photovoltaic	Heat pump	Biomass	Cogeneration	Control system
Energy demand / consumption reduction	Heating	X	X	X	X			X		X	X
	Cooling	X	X	X				X		X	X
	DHW				x			X		X	
	Lighting										X
	Appliances										X
	Ventilation										X
Inhabitant thermal comfort improvement		X	X	X							X
Environmental impact reduction		X	X	X	X	X	X	X	X	X	X
Economic impact reduction		X	X	X	X	X	X	X		X	X
Protected building grade I					X			X	X	X	X
Protected building grade II				X	X	X*	X*	X	X	X	X
Protected building grade III		X**		X	X	X*	X*	X	X	X	X
Protected building grade IV		X		X	X	X*	X*	X	X	X	X

Building Life Cycle stages

A1	Extraction and processing of raw materials
A1	Reuse of products or materials from a previous product system
A1	Processing of secondary materials used as input for manufacturing the product
A1	Generation of electricity, steam and heat from primary energy resources, also including their extraction, refining and transport
A2	Transportation up to the factory gate and internal transport
A3	Production of ancillary materials or pre-products
A3	Manufacturing of products and co-products
A3	Manufacturing of Packaging
A4	Transport of materials and products from the factory gate to the building site
A4	Transport of construction equipment (cranes, scaffolding, etc.) to and from the site
A4	All impacts and aspects related to the losses due to the transportation
A5	Storage of products, including the provision of heating, cooling, humidity etc.,
A5	Transport of materials, products, waste and equipment within the site
A5	Temporary works
A5	On site transformation of the product
A5	Installation of the products into the building
A5	All impacts and aspects related to the losses due to the construction
A5	Waste management processes of other wastes generated on the construction site
B2	The production and transportation of the of component and ancillary products used for maintenance
B2	All cleaning processes of the interior and exterior of the building
B2	All processes for maintaining the functional and technical performance, as well as aesthetical qualities
B4	Replacement products production
B4	Replacement products transportation
B4	Waste management for the replaced products
B4	End of life stage of the replaced building component
B6	Heating, cooling, Domestic Hot Water (DWH) supply, ventilation, lighting
C1	Deconstruction process includes on site operations after decommissioning up to and including on site deconstruction and/or demolition
C2	Impacts due to transportation to disposal and/or until the end-of-waste stage
C3	Waste processing and the elementary flows
C4	Waste disposal including physical pre-treatment and management of the disposal site

Irudia 40 / Figure 40. Scheme of the environmental and economic impact assessment of each life cycle stage of the refurbishment strategy



Equation 11

$$Influence\ of\ the\ stage\ (\%) = \frac{Impact\ of\ the\ evaluated\ life\ cycle\ stage}{Positive\ reduction_{X1}\ +\ Negative\ reduction^{*}_{(X2+X3+X4+X5+X6+X7)}} \quad (11)$$

**Define all values by absolute values*

7.5. Chapter 5. Results of the case study.

7.5.1. Section 5.3.3. Renewable systems calculation

<u>Thermal energy generated by solar thermal systems</u>

Based on the British Standard EN 15316-4-3: 2007 (*BS EN 15316-4-3, 2007*), which reflects different calculation methodologies for such systems, it has been calculated the thermal energy generated from radiation heat captured by solar panels (see equation 16).

$$E_{st.out\,[kWh/year]} = E_{sol.hor} \times f_{tit} \times f_{ef} \times A \times f_{losses} \tag{16}$$

where:

Esol.hor	annual solar irradiation on a horizontal surface in a geographic region	[(kWh/(m^2·year)].
f_{tlt}	tilt and orientation conversion factor	[-]
A	total surface of all solar thermal panels	[m^2]
f_{ef}	collector efficiency factor	[-]
$f_{lossess}$	system losses factor	[-]

In systems without thermal storage equipment, with the objective of optimizing the performance of the solar system and avoid periods of excessive heat generation, it is recommended to perform calculations for monthly periods.

$$E_{st.out\,[kWh/month]} = E_{sol.hor} \times f_{sol.m} \times f_{tit} \times f_{perf} \times A \times f_{losses} \tag{17}$$

f_{perf}	porcentaje de radiación solar que incide mensualmente	[-]

The annual or monthly value of the solar irradiation on a horizontal surface ($E_{sol.hor}$) could be obtained applying different data bases or calculation methodologies:

- Solar radiation and PV maps – Europe (*EC, 2007*).
- Simulation software, considering factors such as climate data each city, tilt / orientation of the panels and the projected shadow by the surrounding buildings ($E_{sol.hor} \times f_{tit}$).

Tilt and orientation conversion factor

	Sur	Sureste/Suroeste	Este/Oeste	Noreste/Noroeste	Norte
Inclination (0)	0.85	0.85	0.85	0.85	0.85
Inclination (15)	0.95	0.92	0.85	0.75	0.75
Inclination (30)	1	0.92	0.8	0.65	0.55
Inclination (45)	0.97	0.9	0.7	0.45	0.4

Inclination (60)	0.9	0.8	0.6	0.35	0.2
Inclination (75)	0.75	0.7	0.45	0.2	0.2
Inclination (90)	0.65	0.55	0.4	0.2	0.2

Respect to the $f_{sol.m}$ factor, based on the information defined in the normative EN 15316-4, this work determines the following values of monthly percentage of incident solar radiation.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
3.56	5.05	7.85	9.88	11.84	12.80	14.03	12.28	9.00	6.48	4.04	3.19

Regarding to the collector efficiency factor (f_{ef}), the document developed by the International Energy Agency Solar Heating & Cooling Programme (*Mauthner & Weiss, 2013*), shows that the efficiency of a collector varies depending on aspects such as: systems fluid temperature, outdoor air temperature...

By applying the Ecotect software, it has been estimated that the incident radiation on the roof of the building is from 1211 kWh/(m^2·a). The panels will be protected flat solar collectors, with an efficiency of 50%, with an inclination of 45 degrees and oriented to the southeast. Finally, being a new system, it is proposed that the distribution elements will be thermally isolated.

In this way, after specifying these values, this study has calculated the surface of solar panels to be applied in each of the efficiency levels.

	Energy needs for DHW (kWh·a)	**Energy generated by thermal solar system (kWh·a)**			**Fraction covered by solar system (%)**		
		75 m²	**110 m²**	**140 m²**	**75 m²**	**110 m²**	**140 m²**
JAN	10033	1291	1894	2410	13	19	24
FEB	9173	1833	2689	3422	20	29	37
MAR	10319	2851	4181	5321	28	41	52
APR	9746	3588	5262	6697	37	54	69
MAY	10033	4299	6305	8025	43	63	80
JUN	10033	4647	6816	8675	46	68	86
JUL	10033	5093	7469	9506	51	74	**95**
AUG	10176	4458	6538	8321	44	64	82
SEP	9889	3267	4792	6099	33	48	62
OCT	10033	2352	3449	4390	23	34	44
NOV	9889	1468	2153	2740	15	22	28
DEC	10176	1157	1698	2161	11	17	21
TOTAL	119533	36304	53246	67767	**30**	**45**	57

Electricity generated by a grid connected Photovoltaic panel system

Based on equation 18, it has been calculated the annual electricity generated from radiation captured by photovoltaic solar panels

$$E_{el.pv.out\ [kWh/year]} = {(E_{sol.hor} \times f_{tit}) \times (K_{pk} \times A) \times f_{ef}} / {I_{ref}} \quad (18)$$

Kpk	Peak power coefficient depending on the type of building integration of the photovoltaic module	[kW/m^2]
I_{ref}	reference solar irradiance equal to 1 kW/m2	[-]

$E_{sol.hor}$ and f_{tit} values will be the same as those defined in the calculation of thermal solar panels (1211 kWh/(m^2·year) and 0.9 respectivamente). The selected PV collector is mono crystalline silicon, whose peak power coefficient (Kpk) is 0.15 and its efficiency factor (f_{ef}) is 0.8. In this way after specifying these values and apply these values in equation 18, it is estimated that the annual amount of power generated per m^2 of panel will be 167.1 kWh.

7.5.2. Section 5.4. Environmental impact information of each product and process applied during the case study assessment

	Unit	Density (kg/m^3)	Weight (kg/m^2)	GWP (Kg CO_2/unit)	NRPE (MJ/unit)
Energy refurbishment product and systems					
INIES – FDES SGG Climaplus	m^2	2450	-	3.15E+01	4.63E+02
INIES – FDES SGG Climaplus	m^2	2450	-	4.31E+01	6.21E+02
INIES – FDES SGG Climatop	m^2	2450	-	5.00E+01	7.89E+02
Ecoinvent. Window frame, aluminium, at plant	m^2	2700	-	4.64E+02	7.22E+03
Ecoinvent. Window frame, plastic (PVC), at plant	m^2	-	94.5	2.57E+02	5.63E+03
Ecoinvent. Window frame wood U=1.5 W/m^2K., at plant	m^2	-	80.2	1.32E+02	2.32E+03
CERTIFIED. Extruded aluminium industry-average	kg	-	50.7	6.57E+00	7.13E+01
IBU. FPX - Fachvereinigung Polystyrol-Extruderschaumstoff	m^2	34.6	-	9.54E+00	1.54E+02
IBU. GUTEX Holzfaserplattenwerk H.	m^3	173	-	-1.64E+02	2.54E+02
GaBi. Ceramic façade panels – NBK Ceramic PE (2008)	m^2	2000	-	1.67E+01	2.56E+02
Ecoinvent. Cement mortar, at plant	kg	1525	-	1.92E-01	1.49E+00
Ecoinvent. Gypsum plaster board, at plant	kg	825	-	3.50E-01	5.75E+00
Ecoinvent. Flat plate collector, at plant*	m^2	-	24.8	1.04E+02	1.50E+03
Ecoinvent. Photovoltaic panel single-Si, at plant*	m^2	-	11.23	1.92E+02	3.33E+03
Ecoinvent. Gas boiler. RER**	unit	-	866	3.81E+02	6.32E+03
Energy refurbishment processes					
GaBi. Articulated lorry (40t) incl. fuel ELCD (2005)	t.Km	-	-	6.16E-02	8.41E-01
GaBi. Landfill for inert matter (construction waste) (2010)	kg	-	-	1.36E-02	1.86E-01
Ecoinvent. Disposal hazardous waste. 0% water. to underground deposit	kg	-	-	1.85E-01	2.84E+00
Heat generation process					
Ecoinvent. Heat production, natural gas, at boiler modulating	MJ	-	-	6.89E-02	1.23E+00
Electricity generation processes					
Ecoinvent. Electricity production, hydro reservoir, non-alpine region (Spain)	kWh	-	-	1.62E-02	6.22E-02
Ecoinvent. Electricity production nuclear, pressure water reactor (Spain).	kWh	-	-	1.24E-02	1.25E+01
Ecoinvent. Electricity production nuclear, boiling water reactor (Spain).	kWh	-	-	1.31E-02	1.33E+01
Ecoinvent. Electricity production, hard coal	kWh	-	-	8.31E-01	1-07E+01
Ecoinvent. Electricity production, lignite (Rest Of the World - ROW)	kWh	-	-	1.08E+00	1-31E+01
Ecoinvent. Electricity production, natural gas, combined cycle power plant (ROW)	kWh	-	-	4.35E-01	8.60E+00
Ecoinvent, Electricity production, hydro, run-of-river (Spain)	kWh	-	-	4.04E-03	4.37E-02
Ecoinvent, Electricity production, wind,<	kWh	-	-	1.39E-02	1.91E-01

1MW turbine, onshore (Spain)					
Ecoinvent, Electricity production, wind, 1-3MW turbine, onshore (Spain)	kWh	-	-	1.46E-02	2.19E-01
Ecoinvent, Electricity production, photovoltaic, 570kWp open ground installation, multi-Si (Spain)	kWh	-	-	5.04E-02	8.35E-01
Electricity production, wind, 1-3MW turbine, onshore	kWh	-	-	2.60E-02	2.19E-01
Ecoinvent, Electricity, heat and power co-generation, wood chips, 6400kw thermal (Spain)	kWh	-	-	6.5E-03	1.16E-01
Ecoinvent, Electricity, heat and power co-generation, biogas, gas engine (Spain)	kWh	-	-	7.39E-02	5.24E-01
Ecoinvent, Electricity, treatment of municipal solid waste, incineration (Spain)	kWh	-	-	1.00E-01	2.67E+00
Ecoinvent, Electricity production, hard coal (Spain)	kWh	-	-	2.99E-01	3.87E+00
Ecoinvent, Heat and power co-generation, natural gas, 1MW electrical, lean burn (Europe)	kWh	-	-	2.31E-01	3.68E+00
Ecoinvent, Electricity production, oil (Spain)	kWh	-	-	3.14E-01	5.71E+00

** In the renewable systems only the environmental impact of the panel is quantified and is not considered the impact of other materials that are part of the system.*

*** Due to the lack of information in the current market, it has been impossible to obtain environmental impact data generated during the manufacturing process of a biomass boiler. Therefore, because its functional resemblance, it has been applied the process of manufacturing a natural gas boiler.*

7.5.3. Section 5.4. Environmental and economic assessment of each refurbishment strategy with life cycle approach

<u>Environmental</u>

Summary of Non Renewable Primary Energy use (MJ/(m^2·a) of the baseline and of the refurbished building applying different refurbishment strategies.

Strategy ID	IEE_{A1-3}	ITE_{A4}	ICE_{A5}	REE_{A1-3}	RTE_{A4}	RTE_{A5}	R_{B6_EN}	EL_{C1-4_EN}	RED_{B6_EN}
Baseline	0	0	0	0	0	0	7.3E+02	0	0.0E+00
1b	4.5E+00	5.7E-03	4.8E-04	4.5E+00	4.7E-03	3.2E-04	6.7E+02	2.7E-02	5.7E+01
1e	4.2E+00	9.2E-03	6.3E-04	4.2E+00	9.2E-03	6.3E-04	6.3E+02	4.2E-02	1.0E+02
1a	3.0E+00	2.7E-02	7.4E-04	3.0E+00	2.7E-02	7.4E-04	6.0E+02	4.9E-02	1.3E+02
2bl	5.3E+00	4.8E-02	1.9E-03	0.0E+00	0.0E+00	0.0E+00	6.4E+02	6.2E-02	9.2E+01
2bh	7.1E+00	1.5E-02	1.1E-03	0.0E+00	0.0E+00	0.0E+00	6.4E+02	3.1E-02	9.2E+01
2el	7.1E+00	8.4E-02	2.9E-03	0.0E+00	0.0E+00	0.0E+00	6.0E+02	9.8E-02	1.3E+02
2eh	1.1E+01	1.8E-02	1.5E-03	0.0E+00	0.0E+00	0.0E+00	6.0E+02	4.9E-02	1.3E+02
2al	1.1E+01	1.5E-01	4.8E-03	0.0E+00	0.0E+00	0.0E+00	5.8E+02	1.6E-01	1.5E+02
2ah	1.7E+01	2.4E-02	2.0E-03	0.0E+00	0.0E+00	0.0E+00	5.8E+02	6.8E-02	1.5E+02
3bl	3.6E-01	3.9E-02	1.7E-03	1.6E-01	4.6E-03	7.5E-04	6.4E+02	8.1E-02	9.2E+01
3bh	2.2E+00	5.8E-03	9.4E-04	1.6E-01	4.6E-03	7.5E-04	6.4E+02	5.6E-02	9.2E+01
3el	5.6E-01	7.3E-02	2.6E-03	1.6E-01	4.6E-03	7.5E-04	6.0E+02	1.1E-01	1.3E+02
3eh	4.2E+00	6.9E-03	1.1E-03	1.6E-01	4.6E-03	7.5E-04	6.0E+02	6.3E-02	1.3E+02
3al	8.9E-01	1.3E-01	4.1E-03	1.6E-01	4.6E-03	7.5E-04	5.8E+02	1.6E-01	1.5E+02
3ah	6.0E+00	8.8E-03	1.4E-03	1.6E-01	4.6E-03	7.5E-04	5.8E+02	7.3E-02	1.5E+02
4bl	8.4E-01	4.2E-02	1.6E-03	6.6E-01	1.2E-02	7.8E-04	6.7E+02	8.0E-02	6.1E+01
4bh	2.5E+00	1.3E-02	9.5E-04	6.6E-01	1.2E-02	7.8E-04	6.7E+02	5.8E-02	6.1E+01
4el	1.0E+00	7.3E-02	2.5E-03	6.6E-01	1.2E-02	7.8E-04	6.3E+02	1.1E-01	1.0E+02
4eh	4.3E+00	1.4E-02	1.1E-03	6.6E-01	1.2E-02	7.8E-04	6.3E+02	6.3E-02	1.0E+02
4al	1.3E+00	1.2E-01	3.8E-03	6.6E-01	1.2E-02	7.8E-04	6.1E+02	1.5E-01	1.2E+02
4ah	5.9E+00	1.5E-02	1.4E-03	6.6E-01	1.2E-02	7.8E-04	6.1E+02	7.3E-02	1.2E+02
5bl	1.8E-01	3.1E-02	8.3E-04	0.0E+00	0.0E+00	0.0E+00	6.7E+02	2.8E-02	5.5E+01
5bh	1.8E+00	1.0E-03	1.7E-04	0.0E+00	0.0E+00	0.0E+00	6.7E+02	5.6E-03	5.5E+01
5el	3.6E-01	6.1E-02	1.7E-03	0.0E+00	0.0E+00	0.0E+00	6.3E+02	5.6E-02	9.8E+01
5eh	3.6E+00	2.0E-03	3.3E-04	0.0E+00	0.0E+00	0.0E+00	6.3E+02	1.1E-02	9.8E+01
6b	2.6E-01	1.1E-03	5.2E-05	2.6E-01	1.1E-03	7.4E-04	7.0E+02	2.6E-02	2.7E+01
6e	3.8E-01	1.6E-03	7.6E-05	3.8E-01	1.6E-03	1.1E-03	6.9E+02	3.9E-02	3.9E+01
6a	4.9E-01	2.0E-03	9.6E-05	4.9E-01	2.0E-03	1.4E-03	6.8E+02	4.9E-02	5.0E+01
7e	9.3E-01	7.9E-04	3.7E-05	9.3E-01	7.9E-04	5.4E-04	7.2E+02	1.9E-02	1.2E+01
7a	3.1E+00	2.6E-03	1.2E-04	3.1E+00	2.6E-03	1.8E-03	6.9E+02	6.4E-02	3.9E+01
8	1.5E-02	2.0E-04	2.4E-05	1.5E-02	2.0E-04	3.5E-04	4.3E+02	1.2E-02	3.0E+02

Summary of Global Warming Potential ($kgCO_2/(m^2 \cdot a)$) of the baseline and of the refurbished building applying different r efurbishment strategies.

Strategy ID	IEE_{A1-3}	ITE_{A4}	ICE_{A5}	REE_{A1-3}	RTE_{A4}	RTE_{A5}	R_{B6_EN}	EL_{C1-4_EN}	RED_{B6_EN}
Baseline	0	0	0	0	0	0	3.3E+01	0	0.0E+00
1b	3.0E-01	4.2E-04	3.5E-05	3.0E-01	3.4E-04	2.3E-05	2.3E-05	1.9E-03	3.2E+00
1e	2.2E-01	6.8E-04	4.6E-05	2.2E-01	6.8E-04	4.6E-05	4.6E-05	3.0E-03	5.7E+00
1a	1.8E-01	2.0E-03	5.4E-05	1.8E-01	2.0E-03	5.4E-05	5.4E-05	3.6E-03	7.1E+00
2bl	2.7E-01	3.5E-03	1.4E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.5E-03	5.2E+00
2bh	5.2E-01	1.1E-03	8.2E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.2E-03	5.2E+00
2el	2.9E-01	6.2E-03	2.1E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.1E-03	7.2E+00
2eh	6.7E-01	1.3E-03	1.1E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.6E-03	7.2E+00
2al	4.5E-01	1.1E-02	3.5E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.2E-02	8.3E+00
2ah	1.0E+00	1.8E-03	1.5E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.9E-03	8.3E+00
3bl	-1.1E-01	2.8E-03	1.2E-04	2.1E-02	3.4E-04	5.5E-05	5.5E-05	5.9E-03	5.2E+00
3bh	1.5E-01	4.2E-04	6.8E-05	2.1E-02	3.4E-04	5.5E-05	5.5E-05	4.1E-03	5.2E+00
3el	-2.4E-01	5.3E-03	1.9E-04	2.1E-02	3.4E-04	5.5E-05	5.5E-05	8.1E-03	7.2E+00
3eh	1.5E-01	5.0E-04	8.2E-05	2.1E-02	3.4E-04	5.5E-05	5.5E-05	4.6E-03	7.2E+00
3al	-4.5E-01	9.5E-03	3.0E-04	2.1E-02	3.4E-04	5.5E-05	5.5E-05	1.2E-02	8.3E+00
3ah	1.5E-01	6.4E-04	1.0E-04	2.1E-02	3.4E-04	5.5E-05	5.5E-05	5.3E-03	8.3E+00
4bl	-7.5E-02	3.1E-03	1.2E-04	4.0E-02	8.5E-04	5.7E-05	5.7E-05	5.8E-03	3.4E+00
4bh	1.5E-01	9.2E-04	6.9E-05	4.0E-02	8.5E-04	5.7E-05	5.7E-05	4.2E-03	3.4E+00
4el	-1.9E-01	5.3E-03	1.8E-04	4.0E-02	8.5E-04	5.7E-05	5.7E-05	7.9E-03	5.7E+00
4eh	1.5E-01	1.0E-03	8.1E-05	4.0E-02	8.5E-04	5.7E-05	5.7E-05	4.6E-03	5.7E+00
4al	-3.8E-01	9.1E-03	2.8E-04	4.0E-02	8.5E-04	5.7E-05	5.7E-05	1.1E-02	6.9E+00
4ah	1.5E-01	1.1E-03	1.0E-04	4.0E-02	8.5E-04	5.7E-05	5.7E-05	5.3E-03	6.9E+00
5bl	-1.2E-01	2.2E-03	6.1E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.0E-03	3.1E+00
5bh	1.1E-01	7.5E-05	1.2E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.0E-04	3.1E+00
5el	-2.3E-01	4.5E-03	1.2E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.0E-03	5.5E+00
5eh	1.1E-01	1.5E-04	2.4E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00	8.1E-04	5.5E+00
6b	1.8E-02	8.0E-05	3.8E-06	1.8E-02	8.0E-05	4.8E-05	4.8E-05	1.7E-03	9.6E-01
6e	2.7E-02	1.2E-04	5.5E-06	2.7E-02	1.2E-04	7.1E-05	7.1E-05	2.6E-03	1.4E+00
6a	3.4E-02	1.5E-04	7.0E-06	3.4E-02	1.5E-04	9.0E-05	9.0E-05	3.2E-03	1.8E+00
7e	5.4E-02	5.8E-05	2.7E-06	5.4E-02	5.8E-05	3.5E-05	3.5E-05	1.3E-03	4.3E-01
7a	1.8E-01	1.9E-04	9.1E-06	1.8E-01	1.9E-04	1.2E-04	1.2E-04	4.2E-03	1.4E+00
8	8.9E-04	1.5E-05	1.8E-06	8.9E-04	1.5E-05	2.3E-05	2.3E-05	8.1E-04	1.6E+01

<u>Economic</u>

Summary of economic impact (€/(m^2·a) of the baseline and of the refurbished building applying different refurbishment strategies.

Strategy ID	IC_{A1-3}	ITC_{A4}	ICC_{A5}	MC_{B2}	RC_{B4_A1-3}	RTC_{B4-A4}	RCC_{B4-a5}	R_{B6_EC}	EL_{C1-4_EC}	RED_{B6}
Baseline	0	0	0	0	0	0	0	5.5E+01	0	0.0E+00
1b	4.7E-01	1.1E-03	2.5E-01	4.7E-02	7.3E-01	1.7E-03	3.9E-01	5.3E+01	1.2E-02	2.2E+00
1e	5.2E-01	1.4E-03	2.5E-01	4.7E-02	8.1E-01	2.2E-03	3.9E-01	5.1E+01	1.5E-02	3.9E+00
1a	9.0E-01	4.2E-03	2.5E-01	4.7E-02	1.4E+00	6.6E-03	3.9E-01	5.0E+01	1.8E-02	4.9E+00
2bl	1.9E+00	4.2E-03	5.8E-01	3.8E-01	0.0E+00	0.0E+00	0.0E+00	5.1E+01	2.2E-02	3.5E+00
2bh	1.8E+00	2.6E-03	5.8E-01	3.8E-01	0.0E+00	0.0E+00	0.0E+00	5.1E+01	1.3E-02	3.5E+00
2el	2.0E+00	6.7E-03	5.8E-01	3.8E-01	0.0E+00	0.0E+00	0.0E+00	5.0E+01	3.5E-02	5.0E+00
2eh	1.8E+00	3.3E-03	5.8E-01	3.8E-01	0.0E+00	0.0E+00	0.0E+00	5.0E+01	1.7E-02	5.0E+00
2al	2.5E+00	1.1E-02	6.4E-01	3.8E-01	0.0E+00	0.0E+00	0.0E+00	4.9E+01	5.7E-02	5.7E+00
2ah	2.3E+00	4.6E-03	6.4E-01	3.8E-01	0.0E+00	0.0E+00	0.0E+00	4.9E+01	2.4E-02	5.7E+00
3bl	1.0E+00	9.6E-03	3.3E-01	5.2E-01	1.7E+00	1.6E-02	5.5E-01	5.1E+01	4.0E-02	3.5E+00
3bh	9.4E-01	8.9E-04	3.3E-01	5.2E-01	1.6E+00	1.5E-03	5.5E-01	5.1E+01	2.2E-02	3.5E+00
3el	1.2E+00	1.5E-02	3.3E-01	5.2E-01	1.9E+00	2.5E-02	5.5E-01	5.0E+01	6.2E-02	5.0E+00
3eh	1.1E+00	1.1E-03	3.3E-01	5.2E-01	1.8E+00	1.8E-03	5.5E-01	5.0E+01	2.7E-02	5.0E+00
3al	1.8E+00	2.4E-02	3.7E-01	5.2E-01	3.0E+00	4.0E-02	6.2E-01	4.9E+01	9.9E-02	5.7E+00
3ah	1.6E+00	1.4E-03	3.7E-01	5.2E-01	2.7E+00	2.3E-03	6.2E-01	4.9E+01	3.4E-02	5.7E+00
4bl	4.4E-01	9.2E-03	1.3E-01	1.0E-01	4.4E-01	1.8E-04	2.6E-03	5.2E+01	3.8E-02	2.3E+00
4bh	4.0E-01	9.0E-04	1.3E-01	1.0E-01	4.0E-01	1.8E-05	2.6E-03	5.2E+01	2.3E-02	2.3E+00
4el	5.0E-01	1.4E-02	1.3E-01	1.0E-01	5.0E-01	2.8E-04	2.6E-03	5.1E+01	5.8E-02	3.9E+00
4eh	4.5E-01	1.1E-03	1.3E-01	1.0E-01	4.5E-01	2.1E-05	2.6E-03	5.1E+01	2.7E-02	3.9E+00
4al	7.2E-01	2.2E-02	1.3E-01	1.0E-01	7.2E-01	2.2E-02	2.6E-03	5.0E+01	9.1E-02	4.7E+00
4ah	6.2E-01	1.3E-03	1.3E-01	1.0E-01	6.2E-01	2.6E-05	2.6E-03	5.0E+01	3.3E-02	4.7E+00
5bl	3.5E-01	4.7E-03	1.3E-01	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.3E+01	9.9E-03	2.1E+00
5bh	9.5E-02	1.6E-04	1.3E-01	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.3E+01	2.0E-03	2.1E+00
5el	3.9E-01	9.5E-03	1.3E-01	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.1E+01	2.0E-02	3.7E+00
5eh	1.3E-01	3.2E-04	1.3E-01	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.1E+01	4.0E-03	3.7E+00
6b	7.6E-02	1.7E-04	2.0E-02	7.7E-02	1.2E-01	2.6E-04	3.1E-02	5.2E+01	2.0E-02	2.9E+00
6e	1.1E-01	2.5E-04	2.9E-02	5.6E-01	1.8E-01	3.9E-04	4.5E-02	5.1E+01	1.4E-03	4.3E+00
6a	1.4E-01	3.2E-04	3.7E-02	7.1E-01	2.2E-01	4.9E-04	5.8E-02	4.9E+01	1.7E-03	5.4E+00
7e	7.4E-02	1.2E-04	3.8E-03	1.4E-01	1.2E-01	1.9E-04	6.0E-03	5.4E+01	6.8E-04	1.3E+00
7a	2.5E-01	4.1E-04	1.3E-02	4.8E-01	3.9E-01	6.4E-04	2.0E-02	5.1E+01	2.3E-03	4.3E+00
8	8.2E-02	3.2E-05	3.1E-03	1.2E-01	1.3E-01	4.9E-05	4.9E-03	5.1E+01	4.3E-04	4.0E+00

7.5.4. Section 5.5. Optimization of the system boundary

Environmental (case study)

Non Renewable Primary Energy (NRPE) use impact percentage (%) of each life cycle stage respect to global NRPE use impact reduction during the refurbished buildings life cycle by the different rehabilitation strategies

	IEE_{A1-3}	ITE_{A4}	ICE_{A5}	REE_{A1-3}	RTE_{A4}	RCE_{A5}	RED_{B6}	EL_{C1-4_EN}
1b	6.91%	0.01%	0.00%	6.91%	0.01%	0.00%	86.13%	0.04%
1e	3.78%	0.01%	0.00%	3.78%	0.01%	0.00%	92.39%	0.04%
1a	2.25%	0.02%	0.00%	2.25%	0.02%	0.00%	95.43%	0.04%
2bl	5.42%	0.05%	0.00%	0.00%	0.00%	0.00%	94.47%	0.06%
2bh	7.14%	0.02%	0.00%	0.00%	0.00%	0.00%	92.81%	0.03%
2el	5.18%	0.06%	0.00%	0.00%	0.00%	0.00%	94.69%	0.07%
2eh	7.63%	0.01%	0.00%	0.00%	0.00%	0.00%	92.32%	0.03%
2al	7.14%	0.09%	0.00%	0.00%	0.00%	0.00%	92.67%	0.10%
2ah	10.03%	0.01%	0.00%	0.00%	0.00%	0.00%	89.91%	0.04%
3bl	0.39%	0.04%	0.00%	0.18%	0.00%	0.00%	99.30%	0.09%
3bh	2.29%	0.01%	0.00%	0.17%	0.00%	0.00%	97.46%	0.06%
3el	0.43%	0.06%	0.00%	0.13%	0.00%	0.00%	99.30%	0.09%
3eh	3.12%	0.01%	0.00%	0.12%	0.00%	0.00%	96.70%	0.05%
3al	0.59%	0.09%	0.00%	0.11%	0.00%	0.00%	99.09%	0.11%
3ah	3.89%	0.01%	0.00%	0.11%	0.00%	0.00%	95.95%	0.05%
4bl	1.34%	0.07%	0.00%	1.06%	0.02%	0.00%	97.38%	0.13%
4bh	3.86%	0.02%	0.00%	1.03%	0.02%	0.00%	94.98%	0.09%
4el	0.98%	0.07%	0.00%	0.63%	0.01%	0.00%	98.20%	0.10%
4eh	3.98%	0.01%	0.00%	0.61%	0.01%	0.00%	95.32%	0.06%
4al	1.04%	0.10%	0.00%	0.52%	0.01%	0.00%	98.20%	0.12%
4ah	4.55%	0.01%	0.00%	0.51%	0.01%	0.00%	94.87%	0.06%
5bl	0.32%	0.06%	0.00%	0.00%	0.00%	0.00%	99.57%	0.05%
5bh	3.17%	0.00%	0.00%	0.00%	0.00%	0.00%	96.82%	0.01%
5el	0.36%	0.06%	0.00%	0.00%	0.00%	0.00%	99.51%	0.06%
5eh	3.57%	0.00%	0.00%	0.00%	0.00%	0.00%	96.42%	0.01%
6b	0.97%	0.00%	0.00%	0.97%	0.00%	0.00%	97.95%	0.10%
6e	0.97%	0.00%	0.00%	0.97%	0.00%	0.00%	97.95%	0.10%
6a	0.97%	0.00%	0.00%	0.97%	0.00%	0.00%	97.95%	0.10%
7e	6.86%	0.01%	0.00%	6.86%	0.01%	0.00%	86.13%	0.14%
7a	6.86%	0.01%	0.00%	6.86%	0.01%	0.00%	86.13%	0.14%
8	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	99.99%	0.00%

Global Warming Potential (GWP) impact percentage (%) of each life cycle stage respect to global GWP impact reduction during the refurbished buildings life cycle by the different rehabilitation strategies

	IEE_{A1-3}	ITE_{A4}	ICE_{A5}	REE_{A1-3}	RTE_{A4}	RCE_{A5}	RED_{B6}	EL_{C1-4_EN}
1b	7.86%	0.01%	0.00%	7.86%	0.01%	0.00%	84.21%	0.05%
1e	3.66%	0.01%	0.00%	3.66%	0.01%	0.00%	92.62%	0.05%
1a	2.43%	0.03%	0.00%	2.43%	0.03%	0.00%	95.03%	0.05%
2bl	4.96%	0.06%	0.00%	0.00%	0.00%	0.00%	94.89%	0.08%
2bh	9.18%	0.02%	0.00%	0.00%	0.00%	0.00%	90.76%	0.04%
2el	3.82%	0.08%	0.00%	0.00%	0.00%	0.00%	96.01%	0.09%
2eh	8.44%	0.02%	0.00%	0.00%	0.00%	0.00%	91.49%	0.04%
2al	5.08%	0.12%	0.00%	0.00%	0.00%	0.00%	94.66%	0.13%
2ah	11.11%	0.02%	0.00%	0.00%	0.00%	0.00%	88.82%	0.05%
3bl	-2.11%	0.06%	0.00%	0.41%	0.01%	0.00%	101.51%	0.12%
3bh	2.72%	0.01%	0.00%	0.39%	0.01%	0.00%	96.79%	0.08%
3el	-3.34%	0.08%	0.00%	0.30%	0.00%	0.00%	102.84%	0.12%
3eh	1.96%	0.01%	0.00%	0.28%	0.00%	0.00%	97.68%	0.06%
3al	-5.67%	0.12%	0.00%	0.27%	0.00%	0.00%	105.13%	0.15%
3ah	1.71%	0.01%	0.00%	0.25%	0.00%	0.00%	97.97%	0.06%
4bl	-2.23%	0.09%	0.00%	1.19%	0.03%	0.00%	100.75%	0.17%
4bh	4.22%	0.03%	0.00%	1.12%	0.02%	0.00%	94.49%	0.12%
4el	-3.41%	0.10%	0.00%	0.72%	0.02%	0.00%	102.44%	0.14%
4eh	2.56%	0.02%	0.00%	0.68%	0.01%	0.00%	96.65%	0.08%
4al	-5.79%	0.14%	0.00%	0.61%	0.01%	0.00%	104.86%	0.17%
4ah	2.13%	0.02%	0.00%	0.56%	0.01%	0.00%	97.20%	0.07%
5bl	-3.87%	0.08%	0.00%	0.00%	0.00%	0.00%	103.73%	0.07%
5bh	3.49%	0.00%	0.00%	0.00%	0.00%	0.00%	96.50%	0.01%
5el	-4.40%	0.09%	0.00%	0.00%	0.00%	0.00%	104.24%	0.08%
5eh	2.00%	0.00%	0.00%	0.00%	0.00%	0.00%	97.98%	0.01%
6b	1.82%	0.01%	0.00%	1.82%	0.01%	0.00%	96.17%	0.17%
6e	1.82%	0.01%	0.00%	1.82%	0.01%	0.00%	96.17%	0.17%
6a	1.82%	0.01%	0.00%	1.82%	0.01%	0.00%	96.17%	0.17%
7e	10.04%	0.01%	0.00%	10.04%	0.01%	0.01%	79.65%	0.24%
7a	10.04%	0.01%	0.00%	10.04%	0.01%	0.01%	79.65%	0.24%
8	0.01%	0.00%	0.00%	0.01%	0.00%	0.00%	99.98%	0.00%

Economic (case study)

Economic (€) impact percentage (%) of each life cycle stage respect to global economic impact reduction during the refurbished buildings life cycle by the different rehabilitation strategies

	IC_{A1-3}	ITC_{A4}	ICC_{A5}	MC_{B2}	RC_{B4_A1-3}	RTC_{B4-A4}	RCC_{B4-A5}	RED_{B6}	EL_{C1-4_EC}
1b	11.56%	0.03%	6.07%	1.16%	18.07%	0.04%	9.49%	53.29%	0.28%
1e	8.71%	0.02%	4.18%	0.80%	13.62%	0.04%	6.53%	65.85%	0.25%
1a	11.46%	0.05%	3.14%	0.60%	17.92%	0.08%	4.90%	61.62%	0.22%
2bl	29.78%	0.07%	9.02%	5.84%	0.00%	0.00%	0.00%	54.95%	0.35%
2bh	28.34%	0.04%	9.23%	5.97%	0.00%	0.00%	0.00%	56.21%	0.21%
2el	24.72%	0.08%	7.34%	4.75%	0.00%	0.00%	0.00%	62.67%	0.44%
2eh	23.68%	0.04%	7.46%	4.83%	0.00%	0.00%	0.00%	63.76%	0.22%
2al	27.07%	0.12%	6.85%	4.04%	0.00%	0.00%	0.00%	61.31%	0.61%
2ah	25.48%	0.05%	7.04%	4.15%	0.00%	0.00%	0.00%	63.00%	0.27%
3bl	13.29%	0.12%	4.22%	6.71%	22.38%	0.21%	7.10%	45.45%	0.51%
3bh	12.53%	0.01%	4.39%	6.98%	21.10%	0.02%	7.39%	47.28%	0.30%
3el	12.06%	0.16%	3.43%	5.46%	20.30%	0.26%	5.78%	51.89%	0.65%
3eh	11.51%	0.01%	3.55%	5.65%	19.38%	0.02%	5.98%	53.63%	0.29%
3al	14.67%	0.19%	3.04%	4.29%	24.71%	0.33%	5.11%	46.85%	0.81%
3ah	14.01%	0.01%	3.18%	4.50%	23.59%	0.02%	5.35%	49.04%	0.29%
4bl	12.68%	0.26%	3.69%	2.97%	12.68%	0.01%	0.07%	66.53%	1.10%
4bh	11.87%	0.03%	3.81%	3.06%	11.87%	0.00%	0.08%	68.62%	0.67%
4el	9.54%	0.27%	2.47%	1.98%	9.54%	0.01%	0.05%	75.03%	1.12%
4eh	8.88%	0.02%	2.54%	2.04%	8.88%	0.00%	0.05%	77.08%	0.52%
4al	10.94%	0.33%	1.97%	1.58%	10.94%	0.33%	0.04%	72.46%	1.40%
4ah	9.96%	0.02%	2.06%	1.66%	9.96%	0.00%	0.04%	75.77%	0.53%
5bl	13.39%	0.18%	4.94%	0.00%	0.00%	0.00%	0.00%	81.10%	0.38%
5bh	4.07%	0.01%	5.51%	0.00%	0.00%	0.00%	0.00%	90.33%	0.08%
5el	9.08%	0.22%	3.01%	0.00%	0.00%	0.00%	0.00%	87.23%	0.46%
5eh	3.31%	0.01%	3.22%	0.00%	0.00%	0.00%	0.00%	93.37%	0.10%
6b	2.35%	0.01%	0.61%	2.36%	3.67%	0.01%	0.95%	89.43%	0.61%
6e	2.16%	0.00%	0.56%	10.77%	3.38%	0.01%	0.88%	82.22%	0.03%
6a	2.16%	0.00%	0.56%	10.77%	3.38%	0.01%	0.88%	82.22%	0.03%
7e	4.55%	0.01%	0.23%	8.80%	7.11%	0.01%	0.37%	78.88%	0.04%
7a	4.55%	0.01%	0.23%	8.80%	7.11%	0.01%	0.37%	78.88%	0.04%
8	1.86%	0.00%	0.07%	2.67%	2.91%	0.00%	0.11%	92.36%	0.01%

7.5.5. Section 5.5.2. Optimization of the system boundary: sensitivity and uncertainty evaluation.

Environmental and economic impact percentage (%) of each life cycle stage respect to global environmental and economic impact reduction during the refurbished buildings life cycle by the different rehabilitation strategies

Environmental (NRPE use) - Product stage (A1-3), (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	Hybrid	OE_-20%	OE_+20%	CF_-20%	CF_+20%	C1	C2	C3	C4	C5	C6	C7	C8
1b	6.9	13.8	3.6	6.7	7.4	7.3	7.3	7.3	7.2	2.7	20.0	3.7	22.9	8.9	6.2	8.9	6.2	16.0	9.3	72.7	40.0	3.3	0.9	13.4	3.7
1e	3.8	7.6	1.9	3.5	3.9	3.8	3.8	3.8	3.8	1.7	13.4	2.5	12.3	4.6	3.2	4.6	3.2	10.9	6.3	64.7	31.4	2.0	0.6	8.6	2.3
1a	2.2	4.5	1.1	2.1	2.3	2.2	2.2	2.2	2.2	1.0	9.5	1.5	7.9	2.8	1.9	2.8	1.9	9.6	4.8	53.8	22.5	1.3	0.4	5.5	1.4
2bl	5.4	10.3	2.	4.9	5.4	5.3	5.3	5.3	5.2	1.1	10.2	1.2	17.1	6.5	4.5	6.5	4.5	11.4	5.3	54.3	22.9	1.5	0.4	6.0	1.6
2bh	7.1	13.3	3.5	6.4	7.1	7.0	7.0	7.0	6.9	1.5	13.2	1.6	21.7	8.5	5.9	8.5	5.9	13.3	6.6	61.5	28.6	1.9	0.5	7.9	2.1
2el	5.2	9.8	2.5	4.7	5.2	5.0	5.0	5.0	5.0	1.1	8.8	1.2	16.2	6.2	4.3	6.2	4.3	10.4	4.7	50.6	20.4	1.4	0.4	5.8	1.5
2eh	7.6	14.	3.7	6.7	7.6	7.4	7.4	7.4	7.4	1.6	12.8	1.8	17.4	9.0	6.3	9.0	6.3	10.9	6.5	52.7	28.0	1.5	0.6	6.2	2.3
2al	7.1	13.3	3.4	6.1	7.1	6.8	6.8	6.8	6.7	1.4	10.7	1.7	20.1	8.3	5.8	8.3	5.8	10.9	5.4	56.5	24.5	1.8	0.5	7.5	2.0
2ah	10.0	18.2	4.8	8.4	10.0	9.6	9.6	9.6	9.5	2.1	14.8	2.4	21.2	11.5	8.2	11.5	8.2	11.3	7.2	58.2	32.1	1.9	0.7	7.9	2.9
3bl	0.4	0.8	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.1	0.8	0.1	1.5	0.5	0.3	0.5	0.3	1.8	0.5	7.5	2.0	0.1	0.0	0.4	0.1
3bh	2.3	4.5	1.1	2.2	2.3	2.3	2.3	2.3	2.3	0.5	4.7	0.5	8.5	2.9	1.9	2.9	1.9	8.1	2.7	32.9	10.9	0.6	0.2	2.5	0.6
3el	0.4	0.9	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.1	0.8	0.1	1.7	0.5	0.4	0.5	0.4	1.9	0.5	7.5	2.0	0.1	0.0	0.5	0.1
3eh	3.1	6.1	1.6	3.0	3.1	3.1	3.1	3.1	3.1	0.6	5.7	0.7	3.5	3.9	2.6	3.9	2.6	3.6	3.3	14.5	13.2	0.2	0.2	1.0	0.9
3al	0.6	1.2	0.3	0.6	0.6	0.6	0.6	0.6	0.6	0.1	1.0	0.1	2.3	0.7	0.5	0.7	0.5	2.3	0.6	9.2	2.5	0.2	0.0	0.6	0.2
3ah	3.9	7.5	1.9	3.7	3.9	3.9	3.9	3.9	3.9	0.8	6.4	0.9	4.2	4.8	3.3	4.8	3.3	3.9	3.7	15.7	14.7	0.3	0.3	1.1	1.1
4bl	1.3	2.7	0.7	1.3	1.4	1.3	1.3	1.3	1.3	0.2	2.5	0.2	5.0	1.7	1.1	1.7	1.1	4.5	1.4	20.4	6.0	0.1	0.1	0.5	0.3
4bh	3.9	7.5	1.9	3.7	3.9	3.9	3.9	3.9	3.8	0.7	6.9	0.7	13.4	4.8	3.2	4.8	3.2	9.9	3.8	43.1	15.9	0.7	0.2	3.0	1.0
4el	1.0	1.9	0.5	1.0	1.0	1.0	1.0	1.0	1.0	0.2	1.7	0.2	3.7	1.2	0.8	1.2	0.8	3.4	1.0	14.4	4.0	0.1	0.1	0.5	0.3
4eh	4.0	7.7	2.0	3.8	4.0	4.0	4.0	4.0	3.9	0.8	6.6	0.8	5.6	4.9	3.3	4.9	3.3	4.8	3.7	20.7	15.1	0.3	0.3	1.1	1.1
4al	1.0	2.1	0.5	1.0	1.0	1.0	1.0	1.0	1.0	0.2	1.6	0.2	4.0	1.3	0.9	1.3	0.9	3.3	1.0	13.9	3.9	0.2	0.1	0.6	0.3
4ah	4.5	8.7	2.3	4.3	4.6	4.5	4.5	4.5	4.5	0.8	6.8	1.0	5.9	5.6	3.8	5.6	3.8	4.7	3.8	19.7	15.5	0.3	0.3	1.1	1.1
5bl	0.3	0.6	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.1	0.6	0.1	1.3	0.4	0.3	0.4	0.3	1.4	0.4	5.5	1.4	0.1	0.0	0.3	0.1
5bh	3.2	6.1	1.6	3.1	3.2	3.2	3.2	3.2	3.2	0.5	5.6	0.5	11.6	3.9	2.7	3.9	2.7	9.3	3.2	37.2	12.9	0.7	0.2	2.9	0.7
5el	0.4	0.7	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.1	0.6	0.1	1.4	0.5	0.3	0.5	0.3	1.4	0.4	5.7	1.5	0.1	0.0	0.4	0.1
5eh	3.6	6.9	1.8	3.4	3.6	3.6	3.6	3.6	3.6	0.7	5.8	0.7	3.6	4.4	3.0	4.4	3.0	3.3	3.3	13.4	13.4	0.2	0.2	0.9	0.9
6b	1.0	1.9	0.5	0.9	1.0	1.0	1.0	1.0	1.0	1.3	0.7	1.1	3.7	1.0	1.0	1.2	0.8	1.5	0.4	6.3	1.6	2.0	0.6	8.4	2.2
6e	1.0	1.9	0.5	0.9	1.0	1.0	1.0	1.0	1.0	1.8	0.7	1.1	3.7	1.0	1.0	1.2	0.8	1.5	0.4	6.3	1.6	2.6	0.7	11.1	3.0
6a	1.0	1.9	0.5	0.9	1.0	1.0	1.0	1.0	1.0	1.3	0.7	1.1	3.7	1.0	1.0	1.2	0.8	1.5	0.4	6.3	1.6	2.0	0.6	8.4	2.2
7e	6.9	13.7	3.4	6.0	7.4	6.9	6.9	6.9	6.9	9.1	4.9	7.6	19.4	6.9	6.9	8.3	5.9	6.9	2.7	35.0	11.9	8.1	3.5	42.5	15.6
7a	6.9	13.7	3.4	6.0	7.4	6.9	6.9	6.9	6.9	9.1	4.9	8.2	19.4	6.9	6.9	8.3	5.9	6.9	2.7	35.0	11.9	8.1	3.5	42.5	15.6
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0

Environmental (GWP) - Product stage (A1-3), (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	Hybrid	OE_-20	OE_+20	CF_-20	CF_+20	C1	C2	C3	C4	C5	C6	C7	C8
1b	7.9	15.7	4.2	7.6	8.5	8.4	8.3	8.3	8.3	3.1	22.3	4.2	25.4	10.2	7.1	10.2	7.1	16.2	10.1	74.6	43.6	3.7	0.9	15.2	4.3
1e	3.7	7.3	1.8	3.4	3.8	3.7	3.7	3.7	3.6	1.6	13.1	2.4	12.0	4.5	3.1	4.5	3.1	10.5	6.2	62.6	30.6	2.0	0.6	8.4	2.2
1a	2.4	4.9	1.2	2.3	2.5	2.4	2.4	2.4	2.4	1.1	10.1	1.6	8.5	3.0	2.0	3.0	2.0	9.4	5.1	53.8	24.0	1.4	0.4	5.9	1.6
2bl	5.0	9.4	2.4	4.4	5.0	4.8	4.8	4.7	4.7	1.0	9.1	1.1	15.1	5.8	4.0	5.8	4.0	9.4	4.7	99.9	21.3	1.3	0.4	5.4	1.4
2bh	9.2	16.8	4.4	7.8	9.2	8.8	8.8	8.8	8.7	2.0	16.2	2.1	25.6	10.7	7.5	10.7	7.5	13.7	7.7	99.9	34.4	2.4	0.5	10.1	2.7
2el	3.8	7.3	1.8	3.3	3.8	3.6	3.6	3.6	3.6	0.8	6.4	0.9	11.6	4.5	3.1	4.5	3.1	7.2	3.4	99.9	15.7	1.0	0.4	4.2	1.1
2eh	8.4	15.6	4.0	7.2	8.4	8.1	8.1	8.0	8.0	1.8	13.7	2.0	23.4	9.8	6.9	9.8	6.9	12.4	6.7	99.9	30.2	2.2	0.6	9.3	2.5
2al	5.1	9.6	2.3	4.2	5.1	4.7	4.7	4.7	4.6	1.0	7.3	1.2	13.6	5.7	4.0	5.7	4.0	7.1	3.7	99.9	18.4	1.2	0.5	5.3	1.4
2ah	11.1	20.0	5.1	8.7	11.1	10.3	10.3	10.3	10.2	2.3	15.6	2.7	26.9	12.3	8.8	12.3	8.8	12.3	7.3	99.9	34.7	2.7	0.7	11.6	3.2
3bl	-2.1	-4.3	-1.1	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1	-0.4	-4.5	-0.4	-8.9	-2.6	-1.8	-2.6	-1.8	-15	-3.0	-65.0	-12	-0.6	0.0	-2.3	-0.6
3bh	2.7	5.3	1.4	2.6	2.7	2.7	2.7	2.7	2.7	0.6	5.5	0.6	10.0	3.4	2.3	3.4	2.3	8.7	3.2	36.1	12.8	0.8	0.2	3.0	0.8
3el	-3.3	-6.9	-1.7	-3.4	-3.4	-3.3	-3.3	-3.3	-3.3	-0.7	-6.5	-0.7	-14	-4.2	-2.8	-4.2	-2.8	-28	-4.4	-12	-17	-0.9	0.0	-3.7	-0.9
3eh	2.0	3.9	1.0	1.9	2.0	2.0	2.0	2.0	1.9	0.4	3.6	0.4	7.3	2.4	1.6	2.4	1.6	6.5	2.1	26.8	8.6	0.6	0.2	2.2	0.6
3al	-5.7	-12	-2.8	-6.0	-5.7	-5.7	-5.7	-5.6	-5.5	-1.0	-10	-1.2	-27	-7.2	-4.7	-7.2	-4.7	-9.1	-7.3	-41	-29	-1.5	0.0	-6.0	-1.4
3ah	1.7	3.4	0.9	1.7	1.7	1.7	1.7	1.7	1.7	0.3	2.9	0.4	6.5	2.1	1.4	2.1	1.4	5.5	1.7	22.4	6.9	0.5	0.3	1.8	0.5
4bl	-2.2	-4.6	-1.1	-2.2	-2.3	-2.2	-2.2	-2.2	-2.2	-0.4	-4.2	-0.4	-9.2	-2.8	-1.9	-2.8	-1.9	-11	-2.7	-57.4	-11	-0.5	0.1	-2.1	-0.5
4bh	4.2	8.2	2.1	4.0	4.3	4.2	4.2	4.2	4.1	0.8	7.5	0.8	14.6	5.2	3.6	5.2	3.6	9.9	4.2	44.0	17.2	1.0	0.2	4.1	1.1
4el	-3.4	-7.1	-1.7	-3.5	-3.4	-3.4	-3.4	-3.4	-3.3	-0.6	-5.9	-0.7	-14	-4.3	-2.8	-4.3	-2.8	-21	-4.0	-10	-16	-0.9	0.1	-3.5	-0.9
4eh	2.6	5.0	1.3	2.5	2.6	2.6	2.6	2.6	2.5	0.5	4.3	0.5	9.3	3.2	2.2	3.2	2.2	7.1	2.5	30.4	10.2	0.7	0.3	2.6	0.7
4al	-5.8	-12	-2.9	-6.1	-5.8	-5.8	-5.8	-5.8	-5.6	-1.0	-9.1	-1.1	-27	-7.3	-4.8	-7.3	-4.8	-5.6	-6.5	-28	-26	-1.4	0.1	-5.6	-1.3
4ah	2.1	4.2	1.1	2.1	2.1	2.1	2.1	2.1	2.1	0.4	3.2	0.4	7.9	2.6	1.8	2.6	1.8	5.8	1.9	24.5	7.7	0.5	0.3	2.1	0.5
5bl	-3.9	-8.0	-1.9	-4.0	-3.9	-3.9	-3.9	-3.9	-3.8	-0.6	-7.2	-0.6	-17	-4.9	-3.2	-4.9	-3.2	-4.1	-5.1	-16.5	-20	-0.9	0.0	-3.5	-0.9
5bh	3.5	6.7	1.7	3.4	3.5	3.5	3.5	3.5	3.5	0.6	6.1	0.6	12.6	4.3	2.9	4.3	2.9	9.8	3.5	39.4	14.1	0.8	0.2	3.2	0.8
5el	-4.4	-9.2	-2.2	-4.6	-4.4	-4.4	-4.4	-4.4	-4.3	-0.8	-7.6	-0.8	-20	-5.6	-3.6	-5.6	-3.6	-4.6	-5.3	-18	-21	-1.1	0.0	-4.4	-1.1
5eh	2.0	3.9	1.0	2.0	2.0	2.0	2.0	2.0	2.0	0.4	3.3	0.4	7.6	2.5	1.7	2.5	1.7	6.3	2.0	25.3	7.9	0.5	0.2	2.0	0.5
6b	1.8	3.6	0.9	1.8	1.9	1.8	1.8	1.8	1.8	2.5	1.2	2.0	6.6	1.8	1.8	2.3	1.5	2.1	0.6	9.1	2.5	3.2	0.6	14.5	4.2
6e	1.8	3.6	0.9	1.8	1.9	1.8	1.8	1.8	1.8	3.3	1.2	2.0	6.6	1.8	1.8	2.3	1.5	2.1	0.6	9.1	2.5	4.0	0.7	18.5	5.6
6a	1.8	3.6	0.9	1.8	1.9	1.8	1.8	1.8	1.8	2.5	1.2	2.0	6.6	1.8	1.8	2.3	1.5	2.1	0.6	9.1	2.5	3.2	0.6	14.5	4.2
7e	10.0	20.1	5.0	8.3	11.2	10.0	10.0	10.0	10.0	13.0	7.3	11.0	25.1	10.0	10.0	11.9	8.7	7.6	3.3	39.8	14.6	9.3	3.5	52.6	22.6
7a	10.0	20.1	5.0	8.3	11.2	10.0	10.0	10.0	10.0	13.0	7.3	11.8	25.1	10.0	10.0	11.9	8.7	7.6	3.3	39.8	14.6	9.3	3.5	52.6	22.6
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0

Environmental (NRPE use) - Transportation stage (A4), (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	Hybrid	OE_-20%	OE_+20%	CF_-20%	CF_+20%	C1	C2	C3	C4	C5	C6	C7	C8
1b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
1e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
1a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0
2bl	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.2	1.1	0.0	0.1	0.0	0.2	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0
2bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.7	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
2el	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.3	1.3	0.0	0.1	0.0	0.2	0.1	0.1	0.1	0.1	0.0	0.1	0.2	0.2	0.0	0.0	0.0	0.0
2eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2al	0.1	0.2	0.0	0.1	0.1	0.0	0.1	0.4	1.7	0.0	0.1	0.0	0.3	0.1	0.1	0.1	0.1	0.0	0.1	0.2	0.3	0.0	0.0	0.0	0.0
2ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3bl	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.2	1.1	0.0	0.1	0.0	0.2	0.1	0.0	0.1	0.0	0.0	0.1	0.2	0.2	0.0	0.0	0.0	0.0
3bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3el	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.3	1.2	0.0	0.1	0.0	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.0	0.0	0.0	0.0
3eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3al	0.1	0.2	0.0	0.1	0.1	0.0	0.1	0.3	1.7	0.0	0.2	0.0	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.4	0.0	0.0	0.0	0.0
3ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4bl	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.3	1.6	0.0	0.1	0.0	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.0	0.0	0.0	0.0
4bh	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.9	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
4el	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.3	1.4	0.0	0.1	0.0	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.0	0.0	0.0	0.0
4eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.6	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4al	0.1	0.2	0.0	0.1	0.1	0.0	0.1	0.4	1.8	0.0	0.2	0.0	0.4	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.4	0.0	0.0	0.0	0.0
4ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.7	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5bl	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.2	0.9	0.0	0.1	0.0	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.0	0.0	0.0	0.0
5bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5el	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.2	1.0	0.0	0.1	0.0	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.0	0.0	0.0	0.0
5eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Environmental (GWP) - Transportation stage (A4), (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	Hybrid	OE_-20	OE_+20	CF_-20	CF_+20	C1	C2	C3	C4	C5	C6	C7	C8
1b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.4	0.1	0.0	0.0	0.1	0.0
1e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.6	0.1	0.0	0.0	0.1	0.0
1a	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.1	2.0	0.3	0.1	0.0	0.2	0.0
2bl	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.3	1.5	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.4	0.1	0.0	0.3	0.1	0.0	0.2	0.0
2bh	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0
2el	0.1	0.2	0.0	0.1	0.1	0.0	0.1	0.3	1.6	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.5	0.1	0.0	0.3	0.1	0.0	0.3	0.0
2eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0
2al	0.1	0.2	0.1	0.1	0.1	0.0	0.1	0.4	2.2	0.0	0.2	0.0	0.1	0.1	0.1	0.1	0.1	0.6	0.1	0.0	0.4	0.1	0.0	0.4	0.0
2ah	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0
3bl	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.3	1.5	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	1.4	0.1	2.9	0.3	0.1	0.0	0.2	0.0
3bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.4	0.0	0.0	0.0	0.0	0.0
3el	0.1	0.2	0.0	0.1	0.1	0.0	0.1	0.3	1.6	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	2.2	0.1	3.6	0.4	0.1	0.0	0.3	0.0
3eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.3	0.0	0.0	0.0	0.0	0.0
3al	0.1	0.3	0.1	0.1	0.1	0.0	0.1	0.5	2.3	0.0	0.2	0.0	0.1	0.2	0.1	0.2	0.1	1.6	0.2	3.1	0.6	0.1	0.0	0.4	0.0
3ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.3	0.0	0.0	0.0	0.0	0.0
4bl	0.1	0.2	0.0	0.1	0.1	0.0	0.1	0.4	2.1	0.0	0.2	0.0	0.1	0.1	0.1	0.1	0.1	1.6	0.1	3.1	0.5	0.1	0.0	0.3	0.0
4bh	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.9	0.1	0.0	0.0	0.1	0.0
4el	0.1	0.2	0.0	0.1	0.1	0.0	0.1	0.4	1.9	0.0	0.2	0.0	0.1	0.1	0.1	0.1	0.1	2.1	0.1	4.9	0.5	0.1	0.0	0.3	0.0
4eh	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.7	0.1	0.0	0.0	0.1	0.0
4al	0.1	0.3	0.1	0.1	0.1	0.0	0.2	0.5	2.5	0.0	0.2	0.0	0.2	0.2	0.1	0.2	0.1	2.6	0.2	2.3	0.6	0.1	0.0	0.5	0.0
4ah	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.6	0.1	0.0	0.0	0.1	0.0
5bl	0.1	0.2	0.0	0.1	0.1	0.0	0.1	0.3	1.2	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	2.7	0.1	1.0	0.4	0.1	0.0	0.2	0.0
5bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
5el	0.1	0.2	0.0	0.1	0.1	0.0	0.1	0.3	1.4	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	3.1	0.1	1.2	0.4	0.1	0.0	0.3	0.0
5eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
6b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.2	0.0
6e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.3	0.0
6a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.2	0.0
7e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.0
7a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Environmental (NRPE use) – Construction process stage (A5), (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	Hybrid	OE_-20%	OE_+20%	CF_-20%	CF_+20%	C1	C2	C3	C4	C5	C6	C7	C8
1b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2bl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2el	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2al	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3bl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3el	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3al	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4bl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4el	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4al	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5bl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5el	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Environmental (GWP) - Construction process stage (A5), (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	Hybrid	OE_-20	OE_+20	CF_-20	CF_+20	C1	C2	C3	C4	C5	C6	C7	C8
1b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2bl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2el	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2al	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3bl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3el	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3al	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4bl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4el	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4al	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5bl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5el	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Environmental (NRPE) - Replacement stage ($B4_{A1-3}$) – product, (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	Hybrid	OE_-20%	OE_+20%	CF_-20%	CF_+20%	C1	C2	C3	C4	C5	C6	C7	C8
1b	6.9	0.0	5.4	9.9	0.0	1.8	1.8	1.8	1.8	0.7	4.9	0.9	5.6	2.2	1.5	2.2	1.5	59.8	34.7	0.0	0.0	12.2	3.5	0.0	0.0
1e	3.8	0.0	5.7	10.5	0.0	3.8	3.8	3.8	3.8	1.7	13.4	2.5	12.3	4.6	3.2	4.6	3.2	65.3	38.1	0.0	0.0	12.2	3.4	0.0	0.0
1a	2.2	0.0	3.4	6.4	0.0	2.2	2.2	2.2	2.2	1.0	9.5	1.5	7.9	2.8	1.9	2.8	1.9	57.4	28.8	0.0	0.0	7.9	2.1	0.0	0.0
2bl	0.0	0.0	5.1	9.5	0.0	2.5	2.5	2.5	2.4	0.5	4.7	0.6	7.9	3.0	2.1	3.0	2.1	50.1	23.3	0.0	0.0	6.4	1.7	0.0	0.0
2bh	0.0	0.0	5.9	10.8	0.0	2.4	2.4	2.4	2.4	0.5	4.6	0.6	7.5	3.0	2.0	3.0	2.0	53.6	26.8	0.0	0.0	7.8	2.1	0.0	0.0
2el	0.0	0.0	5.4	10.0	0.0	2.9	2.9	2.9	2.8	0.6	5.1	0.7	9.3	3.5	2.4	3.5	2.4	49.0	22.1	0.0	0.0	6.6	1.8	0.0	0.0
2eh	0.0	0.0	6.5	11.8	0.0	2.8	2.8	2.8	2.8	0.6	4.8	0.7	9.2	3.4	2.4	3.4	2.4	50.0	26.8	0.0	0.0	6.9	2.3	0.0	0.0
2al	0.0	0.0	8.2	14.7	0.0	4.8	4.8	4.8	4.7	1.0	7.6	1.2	14.2	5.8	4.1	5.8	4.1	55.7	27.8	0.0	0.0	9.2	2.5	0.0	0.0
2ah	0.0	0.0	9.4	16.5	0.0	4.7	4.7	4.7	4.6	1.0	7.2	1.2	14.1	5.6	4.0	5.6	4.0	56.3	32.1	0.0	0.0	9.5	3.1	0.0	0.0
3bl	0.2	0.0	0.3	0.6	0.0	0.2	0.2	0.2	0.2	0.0	0.4	0.0	0.7	0.2	0.2	0.2	0.2	7.2	1.9	0.0	0.0	0.4	0.1	0.0	0.0
3bh	0.2	0.0	1.2	2.4	0.0	0.2	0.2	0.2	0.2	0.0	0.4	0.0	0.6	0.2	0.1	0.2	0.1	25.6	8.5	0.0	0.0	2.0	0.5	0.0	0.0
3el	0.1	0.0	0.3	0.6	0.0	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.5	0.2	0.1	0.2	0.1	6.7	1.8	0.0	0.0	0.4	0.1	0.0	0.0
3eh	0.1	0.0	1.6	3.1	0.0	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.5	0.2	0.1	0.2	0.1	11.8	10.1	0.0	0.0	0.8	0.7	0.0	0.0
3al	0.1	0.0	0.4	0.7	0.0	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.4	0.1	0.1	0.1	0.1	7.7	2.1	0.0	0.0	0.5	0.1	0.0	0.0
3ah	0.1	0.0	2.0	3.8	0.0	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.4	0.1	0.1	0.1	0.1	12.5	11.2	0.0	0.0	0.9	0.8	0.0	0.0
4bl	1.1	0.0	1.7	3.4	0.0	1.1	1.1	1.1	1.0	0.2	1.9	0.2	3.9	1.3	0.9	1.3	0.9	24.3	7.8	0.0	0.0	0.6	0.4	0.0	0.0
4bh	1.0	0.0	3.0	5.6	0.0	1.0	1.0	1.0	1.0	0.2	1.9	0.2	3.6	1.3	0.9	1.3	0.9	37.6	14.6	0.0	0.0	2.4	0.9	0.0	0.0
4el	0.6	0.0	1.1	2.2	0.0	0.6	0.6	0.6	0.6	0.1	1.1	0.1	2.4	0.8	0.5	0.8	0.5	16.7	4.9	0.0	0.0	0.5	0.3	0.0	0.0
4eh	0.6	0.0	2.6	5.0	0.0	0.6	0.6	0.6	0.6	0.1	1.0	0.1	2.4	0.8	0.5	0.8	0.5	20.7	12.8	0.0	0.0	0.9	0.9	0.0	0.0
4al	0.5	0.0	1.0	2.1	0.0	0.5	0.5	0.5	0.5	0.1	0.8	0.1	2.0	0.7	0.4	0.7	0.4	14.9	4.3	0.0	0.0	0.6	0.3	0.0	0.0
4ah	0.5	0.0	2.8	5.3	0.0	0.5	0.5	0.5	0.5	0.1	0.8	0.1	2.0	0.6	0.4	0.6	0.4	18.7	12.7	0.0	0.0	0.9	0.9	0.0	0.0
5bl	0.0	0.0	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1	1.1	0.0	0.0	0.2	0.1	0.0	0.0
5bh	0.0	0.0	1.6	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.9	9.7	0.0	0.0	2.2	0.6	0.0	0.0
5el	0.0	0.0	0.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.3	1.1	0.0	0.0	0.3	0.1	0.0	0.0
5eh	0.0	0.0	1.8	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	10.0	0.0	0.0	0.7	0.7	0.0	0.0
6b	1.0	0.0	1.5	2.8	0.0	1.0	1.0	1.0	1.0	1.3	0.7	1.1	3.7	1.0	1.0	1.2	0.8	9.0	2.4	0.0	0.0	11.9	3.3	0.0	0.0
6e	1.0	0.0	1.5	2.8	0.0	1.0	1.0	1.0	1.0	1.8	0.7	1.1	3.7	1.0	1.0	1.2	0.8	9.0	2.4	0.0	0.0	15.3	4.4	0.0	0.0
6a	1.0	0.0	1.5	2.8	0.0	1.0	1.0	1.0	1.0	1.3	0.7	1.1	3.7	1.0	1.0	1.2	0.8	9.0	2.4	0.0	0.0	11.9	3.3	0.0	0.0
7e	6.9	0.0	10.3	18.1	0.0	6.9	6.9	6.9	6.9	9.1	4.9	7.6	19.4	6.9	6.9	8.3	5.9	41.6	16.3	0.0	0.0	48.3	20.9	0.0	0.0
7a	6.9	0.0	10.3	18.1	0.0	6.9	6.9	6.9	6.9	9.1	4.9	8.2	19.4	6.9	6.9	8.3	5.9	41.6	16.3	0.0	0.0	48.3	20.9	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Environmental (GWP) - Replacement stage ($B4_{A1-3}$) - product, (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	Hybrid	OE_-20	OE_+20	CF_-20	CF_+20	C1	C2	C3	C4	C5	C6	C7	C8
1b	7.9	0.0	6.3	11.4	0.0	2.1	2.1	2.1	2.1	0.8	5.7	1.1	6.4	2.6	1.8	2.6	1.8	61.0	37.8	0.0	0.0	13.9	3.5	0.0	0.0
1e	3.7	0.0	5.5	10.2	0.0	3.7	3.7	3.7	3.6	1.6	13.1	2.4	12.0	4.5	3.1	4.5	3.1	63.2	37.3	0.0	0.0	11.8	3.4	0.0	0.0
1a	2.4	0.0	3.6	7.0	0.0	2.4	2.4	2.4	2.4	1.1	10.1	1.6	8.5	3.0	2.0	3.0	2.0	56.3	30.4	0.0	0.0	8.5	2.1	0.0	0.0
2bl	0.0	0.0	6.4	11.7	0.0	4.0	4.0	4.0	3.9	0.9	7.6	0.9	12.6	4.9	3.4	4.9	3.4	51.9	25.9	0.0	0.0	7.3	1.7	0.0	0.0
2bh	0.0	0.0	8.2	14.6	0.0	3.8	3.8	3.8	3.8	0.8	7.0	0.9	11.1	4.6	3.3	4.6	3.3	58.9	33.3	0.0	0.0	10.5	2.1	0.0	0.0
2el	0.0	0.0	6.5	12.0	0.0	4.7	4.7	4.7	4.6	1.0	8.2	1.1	15.0	5.8	4.0	5.8	4.0	49.4	23.4	0.0	0.0	7.0	1.8	0.0	0.0
2eh	0.0	0.0	8.5	15.1	0.0	4.5	4.5	4.5	4.4	1.0	7.6	1.1	13.1	5.4	3.8	5.4	3.8	57.7	31.3	0.0	0.0	10.5	2.3	0.0	0.0
2al	0.0	0.0	10.2	18.0	0.0	7.8	7.8	7.8	7.6	1.7	12.2	1.9	22.7	9.5	6.7	9.5	6.7	56.6	29.9	0.0	0.0	9.9	2.5	0.0	0.0
2ah	0.0	0.0	12.5	21.2	0.0	7.4	7.4	7.3	7.3	1.6	11.1	1.9	19.3	8.8	6.3	8.8	6.3	63.2	37.6	0.0	0.0	14.0	3.2	0.0	0.0
3bl	0.4	0.0	-0.8	-1.7	0.0	0.4	0.4	0.4	0.4	0.1	0.9	0.1	1.7	0.5	0.3	0.5	0.3	-39	-7.7	0.0	0.0	-1.5	0.1	0.0	0.0
3bh	0.4	0.0	1.6	3.0	0.0	0.4	0.4	0.4	0.4	0.1	0.8	0.1	1.4	0.5	0.3	0.5	0.3	28.7	10.4	0.0	0.0	2.5	0.5	0.0	0.0
3el	0.3	0.0	-1.5	-3.1	0.0	0.3	0.3	0.3	0.3	0.1	0.6	0.1	1.3	0.4	0.3	0.4	0.3	-81	-12	0.0	0.0	-2.6	0.1	0.0	0.0
3eh	0.3	0.0	1.1	2.2	0.0	0.3	0.3	0.3	0.3	0.1	0.5	0.1	1.1	0.4	0.2	0.4	0.2	21.5	7.0	0.0	0.0	1.8	0.7	0.0	0.0
3al	0.3	0.0	-2.7	-5.7	0.0	0.3	0.3	0.3	0.3	0.0	0.5	0.1	1.3	0.3	0.2	0.3	0.2	-26	-21	0.0	0.0	-4.3	0.1	0.0	0.0
3ah	0.2	0.0	1.0	1.9	0.0	0.2	0.2	0.2	0.2	0.0	0.4	0.1	0.9	0.3	0.2	0.3	0.2	18.0	5.7	0.0	0.0	1.5	0.8	0.0	0.0
4bl	1.2	0.0	0.1	0.1	0.0	1.2	1.2	1.2	1.2	0.2	2.2	0.2	4.9	1.5	1.0	1.5	1.0	-15	-3.8	0.0	0.0	-0.7	0.4	0.0	0.0
4bh	1.1	0.0	3.2	6.1	0.0	1.1	1.1	1.1	1.1	0.2	2.0	0.2	3.9	1.4	0.9	1.4	0.9	37.7	15.7	0.0	0.0	3.8	0.9	0.0	0.0
4el	0.7	0.0	-1.0	-2.0	0.0	0.7	0.7	0.7	0.7	0.1	1.2	0.1	3.1	0.9	0.6	0.9	0.6	-5.0	-9.5	0.0	0.0	-2.1	0.3	0.0	0.0
4eh	0.7	0.0	2.0	3.8	0.0	0.7	0.7	0.7	0.7	0.1	1.1	0.1	2.5	0.8	0.6	0.8	0.6	26.8	9.4	0.0	0.0	2.5	0.9	0.0	0.0
4al	0.6	0.0	-2.3	-4.8	0.0	0.6	0.6	0.6	0.6	0.1	1.0	0.1	2.9	0.8	0.5	0.8	0.5	-15	-17	0.0	0.0	-3.7	0.3	0.0	0.0
4ah	0.6	0.0	1.6	3.2	0.0	0.6	0.6	0.6	0.6	0.1	0.9	0.1	2.1	0.7	0.5	0.7	0.5	21.9	7.2	0.0	0.0	1.9	1.0	0.0	0.0
5bl	0.0	0.0	-1.9	-4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-12	-15	0.0	0.0	-2.6	0.1	0.0	0.0
5bh	0.0	0.0	1.7	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.5	10.6	0.0	0.0	2.4	0.6	0.0	0.0
5el	0.0	0.0	-2.2	-4.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-13	-16	0.0	0.0	-3.3	0.1	0.0	0.0
5eh	0.0	0.0	1.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.0	5.9	0.0	0.0	1.5	0.7	0.0	0.0
6b	1.8	0.0	2.7	5.3	0.0	1.8	1.8	1.8	1.8	2.5	1.2	2.0	6.6	1.8	1.8	2.3	1.5	12.7	3.7	0.0	0.0	19.3	3.3	0.0	0.0
6e	1.8	0.0	2.7	5.3	0.0	1.8	1.8	1.8	1.8	3.3	1.2	2.0	6.6	1.8	1.8	2.3	1.5	12.7	3.7	0.0	0.0	23.8	4.4	0.0	0.0
6a	1.8	0.0	2.7	5.3	0.0	1.8	1.8	1.8	1.8	2.5	1.2	2.0	6.6	1.8	1.8	2.3	1.5	12.7	3.7	0.0	0.0	19.3	3.3	0.0	0.0
7e	10.0	0.0	15.1	25.0	0.0	10.0	10.0	10.0	10.0	13.0	7.3	11.0	25.1	10.0	10.0	11.9	8.7	45.5	19.7	0.0	0.0	55.8	20.9	0.0	0.0
7a	10.0	0.0	15.1	25.0	0.0	10.0	10.0	10.0	10.0	13.0	7.3	11.8	25.1	10.0	10.0	11.9	8.7	45.5	19.7	0.0	0.0	55.8	20.9	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0

Environmental (NRPE) - Replacement stage (B4 $_{A4}$) - transportation, (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	Hybrid	OE_-20%	OE_+20%	CF_-20%	CF_+20%	C1	C2	C3	C4	C5	C6	C7	C8
1b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
1e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
1a	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.3	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0
2bl	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
2bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
2el	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
2eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2al	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
2ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3bl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0
3bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3el	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0
3eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3al	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0
3ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4bl	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.2	0.8	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0
4bh	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.2	0.7	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
4el	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0
4eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
4al	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0
4ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
5bl	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0
5bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5el	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0
5eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Environmental (GWP) - Replacement stage (B4 $_{A4}$) - transportation, (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	Hybrid	OE_-20	OE_+20	CF_-20	CF_+20	C1	C2	C3	C4	C5	C6	C7	C8
1b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.1	0.0	0.0	0.1	0.0	0.0	0.0
1e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.1	0.0	0.0	0.1	0.0	0.0	0.0
1a	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.3	0.0	0.0	0.3	0.0	0.0	0.0
2bl	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.2	0.0	0.0	0.2	0.0	0.0	0.0
2bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.1	0.0	0.0	0.1	0.0	0.0	0.0
2el	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.2	0.0	0.0	0.2	0.0	0.0	0.0
2eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.1	0.0	0.0	0.0
2al	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.3	0.0	0.0	0.3	0.0	0.0	0.0
2ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.1	0.0	0.0	0.0
3bl	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	0.3	0.0	0.0	0.2	0.0	0.0	0.0
3bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3el	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	0.3	0.0	0.0	0.2	0.0	0.0	0.0
3eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3al	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.4	0.5	0.0	0.0	0.3	0.0	0.0	0.0
3ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4bl	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.2	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.4	0.0	0.0	0.3	0.0	0.0	0.0
4bh	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.2	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.1	0.0	0.0	0.1	0.0	0.0	0.0
4el	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.2	0.4	0.0	0.0	0.3	0.0	0.0	0.0
4eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.1	0.0	0.0	0.1	0.0	0.0	0.0
4al	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.9	0.5	0.0	0.0	0.4	0.0	0.0	0.0
4ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.1	0.0	0.0	0.1	0.0	0.0	0.0
5bl	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.2	0.3	0.0	0.0	0.2	0.0	0.0	0.0
5bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5el	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.2	0.3	0.0	0.0	0.2	0.0	0.0	0.0
5eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.3	0.0	0.0	0.0
6e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.4	0.0	0.0	0.0
6a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.3	0.0	0.0	0.0
7e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0
7a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Environmental (NRPE) - Replacement stage ($B4_{A5}$) – construction process, (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	Hybrid	OE_-20%	OE_+20%	CF_-20%	CF_+20%	C1	C2	C3	C4	C5	C6	C7	C8
1b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2bl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2el	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2al	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3bl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3el	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3al	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4bl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4el	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4al	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5bl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5el	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Environmental (GWP) - Replacement stage ($B4_{A5}$) - construction process, (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	Hybrid	OE_-20	OE_+20	CF_-20	CF_+20	C1	C2	C3	C4	C5	C6	C7	C8
1b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2bl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2el	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2al	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3bl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3el	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3al	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4bl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4el	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4al	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5bl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5el	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.0
6e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.2	0.0	0.1	0.0
6a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.0
7e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0
7a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Environmental (NRPE) – Reduction of the operational energy use stage (RED_{B6}), (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	Hybrid	OE_-20%	OE_+20%	CF_-20%	CF_+20%	C1	C2	C3	C4	C5	C6	C7	C8
1b	86.1	86.1	90.9	83.3	92.5	90.9	90.9	90.8	90.2	96.6	75.0	95.4	71.4	88.9	92.3	88.9	92.3	24.0	55.7	27.2	59.8	84.5	95.6	86.6	96.3
1e	92.4	92.4	92.4	85.9	96.0	92.4	92.4	92.3	91.8	96.7	73.0	95.1	75.2	90.7	93.6	90.7	93.6	23.7	55.3	35.2	68.4	85.8	96.0	91.3	97.7
1a	95.4	95.4	95.4	91.3	97.7	95.5	95.4	95.3	94.8	97.9	80.8	97.0	83.9	94.4	96.2	94.4	96.2	32.7	65.8	46.0	77.1	90.7	97.5	94.5	98.5
2bl	94.5	89.5	92.1	85.4	94.5	92.2	92.1	92.0	91.0	98.3	84.9	98.2	74.6	90.4	93.4	90.4	93.4	38.2	70.9	45.4	76.6	92.1	97.9	94.0	98.4
2bh	92.8	86.6	90.6	82.8	92.8	90.6	90.5	90.4	89.8	98.0	82.2	97.8	70.6	88.5	92.0	88.5	92.0	33.1	66.3	38.4	71.2	90.3	97.4	92.1	97.9
2el	94.7	89.9	92.0	85.1	94.7	92.0	91.9	91.7	90.7	98.3	85.9	98.1	74.1	90.1	93.2	90.1	93.2	40.3	72.7	49.1	79.1	91.9	97.8	94.2	98.5
2eh	92.3	85.7	89.7	81.4	92.3	89.7	89.7	89.6	89.0	97.8	82.3	97.5	73.3	87.5	91.3	87.5	91.3	39.0	66.6	47.1	71.9	91.5	97.1	93.8	97.7
2al	92.7	86.3	88.2	78.9	92.7	88.3	88.2	87.9	86.5	97.5	81.5	97.1	65.1	85.7	90.0	85.7	90.0	33.2	66.2	43.1	74.8	88.9	96.9	92.5	98.0
2ah	89.9	81.7	85.7	75.0	89.9	85.7	85.7	85.5	84.9	96.9	77.9	96.4	64.6	82.7	87.8	82.7	87.8	32.3	60.5	41.7	67.7	88.5	96.1	92.0	97.1
3bl	99.3	99.0	99.4	98.8	99.5	99.3	99.3	99.0	97.8	99.9	98.6	99.9	97.3	99.1	99.4	99.1	99.4	90.4	97.0	92.0	97.5	99.4	99.8	99.5	99.9
3bh	97.5	95.4	97.6	95.2	97.7	97.5	97.4	97.3	96.4	99.5	94.9	99.4	90.6	96.9	97.9	96.9	97.9	66.1	88.5	67.0	88.9	97.4	99.3	97.4	99.3
3el	99.3	98.9	99.4	98.7	99.4	99.3	99.3	99.0	97.8	99.9	98.7	99.8	97.2	99.1	99.4	99.1	99.4	90.9	97.1	91.9	97.4	99.4	99.8	99.5	99.8
3eh	96.7	93.9	96.8	93.7	96.8	96.7	96.7	96.5	95.9	99.3	94.0	99.3	95.8	95.9	97.2	95.9	97.2	84.5	86.4	85.4	86.7	98.9	99.1	99.0	99.1
3al	99.1	98.5	99.2	98.3	99.2	99.2	99.1	98.8	97.2	99.8	98.5	99.8	96.5	98.9	99.2	98.9	99.2	89.3	96.5	90.1	96.8	99.3	99.8	99.3	99.8
3ah	95.9	92.4	96.0	92.3	96.1	95.9	95.9	95.8	95.1	99.2	93.3	99.1	95.2	95.0	96.6	95.0	96.6	83.5	85.0	84.1	85.2	98.8	98.9	98.8	98.9
4bl	97.4	97.0	97.4	94.9	98.5	97.4	97.3	97.0	95.2	99.5	95.2	99.5	90.3	96.7	97.8	96.7	97.8	70.4	89.9	79.0	93.3	99.2	99.4	99.4	99.6
4bh	95.0	92.4	95.0	90.4	96.0	95.0	94.9	94.7	93.5	99.1	91.0	99.1	82.5	93.8	95.8	93.8	95.8	52.2	81.1	56.7	83.8	96.8	98.8	97.0	99.0
4el	98.2	97.8	98.2	96.5	98.9	98.3	98.2	97.9	96.4	99.7	97.0	99.6	93.2	97.8	98.5	97.8	98.5	79.4	93.4	85.0	95.3	99.3	99.6	99.4	99.7
4eh	95.3	92.2	95.3	91.1	95.9	95.3	95.3	95.1	94.3	99.1	92.3	99.1	91.7	94.2	96.1	94.2	96.1	74.2	83.2	79.2	84.7	98.8	98.8	98.9	98.9
4al	98.2	97.5	98.2	96.5	98.7	98.3	98.2	97.9	96.1	99.7	97.3	99.6	93.2	97.8	98.5	97.8	98.5	81.1	93.9	85.4	95.4	99.2	99.6	99.3	99.7
4ah	94.9	91.2	94.9	90.2	95.4	94.9	94.8	94.7	93.9	99.1	92.3	98.9	91.9	93.7	95.7	93.7	95.7	76.4	83.2	80.2	84.3	98.7	98.7	98.8	98.8
5bl	99.6	99.1	99.6	99.1	99.6	99.6	99.6	99.4	98.7	99.9	99.2	99.9	98.3	99.5	99.6	99.5	99.6	94.0	98.1	94.0	98.1	99.7	99.9	99.7	99.9
5bh	96.8	93.8	96.8	93.8	96.8	96.8	96.8	96.8	96.7	99.5	94.4	99.5	88.4	96.1	97.3	96.1	97.3	62.8	87.0	62.8	87.0	97.1	99.3	97.1	99.3
5el	99.5	99.0	99.5	99.0	99.5	99.6	99.5	99.4	98.6	99.9	99.2	99.9	98.1	99.4	99.6	99.4	99.6	93.8	98.0	93.8	98.0	99.6	99.9	99.6	99.9
5eh	96.4	93.1	96.4	93.1	96.4	96.4	96.4	96.4	96.2	99.3	94.2	99.3	96.4	95.6	97.0	95.6	97.0	86.6	86.6	86.6	86.6	99.1	99.1	99.1	99.1
6b	98.0	98.0	98.0	96.0	99.0	98.0	98.0	97.9	97.8	97.2	98.6	97.7	92.3	98.0	98.0	97.5	98.3	89.4	97.0	93.6	98.3	86.0	95.9	91.5	97.6
6e	98.0	98.0	98.0	96.0	99.0	98.0	98.0	97.9	97.8	96.2	98.6	97.7	92.3	98.0	98.0	97.5	98.3	89.4	97.0	93.6	98.3	81.9	94.6	88.8	96.8
6a	98.0	98.0	98.0	96.0	99.0	98.0	98.0	97.9	97.8	97.2	98.6	97.7	92.3	98.0	98.0	97.5	98.3	89.4	97.0	93.6	98.3	86.0	95.9	91.5	97.6
7e	86.1	86.1	86.1	75.6	92.5	86.1	86.1	86.1	86.0	81.7	90.2	84.6	60.8	86.1	86.1	83.2	88.2	51.3	80.7	64.9	88.0	43.5	75.3	57.4	84.2
7a	86.1	86.1	86.1	75.6	92.5	86.1	86.1	86.1	86.0	81.7	90.2	83.5	60.8	86.1	86.1	83.2	88.2	51.3	80.7	64.9	88.0	43.5	75.3	57.4	84.2
8	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Environmental (GWP) - Reduction of the operational energy use stage (RED_{B6}), (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	Hybrid	OE_-20%	OE_+20%	CF_-20%	CF_+20%	C1	C2	C3	C4	C5	C6	C7	C8
1b	84.2	84.2	89.5	80.9	91.4	89.5	89.4	89.3	88.6	96.1	71.8	94.7	68.1	87.2	91.1	87.2	91.1	20.9	51.8	24.0	56.1	82.0	95.6	84.5	95
1e	92.6	92.6	92.6	86.2	96.2	92.6	92.6	92.5	91.8	96.8	73.6	95.2	76.0	90.9	93.8	90.9	93.8	23.8	56.1	35.3	69.1	85.8	96.0	91.4	98
1a	95.0	95.0	95.0	90.5	97.5	95.1	95.0	94.9	94.2	97.7	79.4	96.8	82.9	93.9	95.8	93.9	95.8	29.5	63.8	42.3	75.5	89.4	97.5	93.6	98
2bl	94.9	90.3	91.1	83.6	94.9	91.1	91.1	90.8	89.7	98.1	83.1	97.9	72.1	89.1	92.5	89.1	92.5	34.5	68.8	0.1	78.1	90.9	97.9	94.0	98
2bh	90.8	83.1	87.3	77.4	90.8	87.3	87.2	87.1	86.4	97.2	76.7	97.0	63.3	84.6	89.2	84.6	89.2	26.0	58.8	0.1	65.3	86.9	97.4	89.7	97
2el	96.0	92.3	91.5	84.3	96.0	91.5	91.4	91.2	89.8	98.2	85.1	98.0	73.2	89.6	92.8	89.6	92.8	38.4	72.6	0.1	83.6	91.3	97.8	95.1	99
2eh	91.5	84.3	87.4	77.6	91.5	87.4	87.3	87.2	86.5	97.2	78.6	96.9	63.5	84.7	89.3	84.7	89.3	28.4	61.7	0.1	69.6	87.0	97.1	90.5	97
2al	94.7	89.9	87.2	77.4	94.7	87.3	87.2	86.9	85.1	97.3	80.1	96.8	63.5	84.6	89.1	84.6	89.1	31.0	65.5	0.1	80.6	87.9	96.9	93.8	98
2ah	88.8	79.9	82.3	69.9	88.8	82.3	82.2	82.1	81.3	96.1	73.1	95.4	53.8	78.8	84.8	78.8	84.8	23.1	54.9	0.1	65.1	82.9	96.1	88.1	97
3bl	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
3bh	96.8	94.6	97.0	94.2	97.2	96.8	96.7	96.5	95.4	99.3	93.5	99.3	88.5	96.0	97.3	96.0	97.3	59.5	86.1	61.6	87.0	96.5	99.3	96.8	99.2
3el	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
3eh	97.7	96.1	97.8	95.8	98.0	97.7	97.6	97.5	96.6	99.5	95.7	99.5	91.5	97.1	98.1	97.1	98.1	69.2	90.6	71.1	91.2	97.4	99.1	97.6	99.4
3al	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99.8	100	100
3ah	98.0	96.5	98.1	96.3	98.2	98.0	97.9	97.8	96.9	99.6	96.6	99.5	92.5	97.5	98.3	97.5	98.3	73.7	92.4	75.4	92.9	97.9	98.9	98.0	99.5
4bl	100	100	100	100	100	100	100	100	97.7	100	100	100	100	100	100	100	100	100	100	100	100	100	99.4	100	100
4bh	94.5	91.6	94.5	89.6	95.6	94.5	94.4	94.1	92.5	99.0	90.2	99.0	81.4	93.2	95.4	93.2	95.4	47.6	79.5	52.7	82.4	94.7	98.8	95.6	98.9
4el	100	100	100	100	100	100	100	100	99.9	100	100	100	100	100	100	100	100	100	100	100	100	100	99.6	100	100
4eh	96.6	94.8	96.6	93.5	97.4	96.7	96.6	96.4	95.3	99.4	94.4	99.3	88.1	95.9	97.2	95.9	97.2	62.4	87.7	67.0	89.6	96.5	98.8	97.2	99.3
4al	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99.6	100	100
4ah	97.2	95.7	97.2	94.6	97.8	97.2	97.2	97.0	95.9	99.5	95.8	99.4	89.9	96.5	97.7	96.5	97.7	68.8	90.6	72.9	92.0	97.2	98.8	97.7	99.5
5bl	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99.9	100	100
5bh	96.5	93.2	96.5	93.2	96.5	96.5	96.5	96.5	96.3	99.4	93.8	99.4	87.4	95.7	97.1	95.7	97.1	60.1	85.9	60.1	85.9	96.8	99.3	96.8	99.2
5el	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99.9	100	100
5eh	98.0	96.0	98.0	96.0	98.0	98.0	98.0	97.9	97.7	99.6	96.7	99.6	92.4	97.5	98.3	97.5	98.3	73.9	92.1	73.9	92.1	97.9	99.1	97.9	99.5
6b	96.2	96.2	96.2	92.6	98.0	96.2	96.2	96.1	95.9	94.7	97.4	95.7	86.7	96.2	96.2	95.3	96.8	82.3	95.5	89.0	97.4	73.0	95.9	82.6	95.6
6e	96.2	96.2	96.2	92.6	98.0	96.2	96.2	96.1	95.9	93.0	97.4	95.7	86.7	96.2	96.2	95.3	96.8	82.3	95.5	89.0	97.4	66.6	94.6	77.7	94.1
6a	96.2	96.2	96.2	92.6	98.0	96.2	96.2	96.1	95.9	94.7	97.4	95.7	86.7	96.2	96.2	95.3	96.8	82.3	95.5	89.0	97.4	73.0	95.9	82.6	95.6
7e	79.7	79.7	79.7	66.2	88.7	79.7	79.7	79.6	79.4	73.7	85.2	77.6	49.7	79.7	79.7	75.8	82.5	44.3	76.7	58.2	85.2	31.7	75.3	44.8	77.1
7a	79.7	79.7	79.7	66.2	88.7	79.7	79.7	79.6	79.4	73.7	85.2	76.1	49.7	79.7	79.7	75.8	82.5	44.3	76.7	58.2	85.2	31.7	75.3	44.8	77.1
8	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Environmental (NRPE) – End of life stage (C1-4), (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	Hybrid	OE_-20%	OE_+20%	CF_-20%	CF_+20%	C1	C2	C3	C4	C5	C6	C7	C8
1b	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.0	0.1	0.0	0.1	0.2	0.1	0.1	0.0	0.0	0.0	0.0
1e	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.0	0.1	0.0	0.1	0.2	0.1	0.2	0.0	0.0	0.0	0.0
1a	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.1	0.1	0.0	0.1	0.0	0.1	0.3	0.1	0.2	0.0	0.0	0.0	0.0
2bl	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.2	0.1	0.1	0.1	0.1	0.1	0.3	0.2	0.3	0.0	0.0	0.0	0.0
2bh	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
2el	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.3	0.1	0.1	0.1	0.1	0.2	0.3	0.2	0.3	0.0	0.0	0.0	0.0
2eh	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
2al	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.3	0.1	0.1	0.1	0.1	0.2	0.3	0.2	0.3	0.0	0.0	0.0	0.0
2ah	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.0	0.0	0.0	0.0
3bl	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.3	0.1	0.1	0.1	0.1	0.3	0.4	0.3	0.3	0.0	0.0	0.0	0.0
3bh	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.2	0.0	0.0	0.0	0.0
3el	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.3	0.1	0.1	0.1	0.1	0.3	0.4	0.3	0.3	0.0	0.0	0.0	0.0
3eh	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.0	0.2	0.1	0.0	0.1	0.0	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0
3al	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.4	0.1	0.1	0.1	0.1	0.4	0.4	0.4	0.4	0.0	0.0	0.0	0.0
3ah	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.0	0.2	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
4bl	0.1	0.2	0.1	0.3	0.1	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.5	0.2	0.1	0.2	0.1	0.4	0.5	0.3	0.4	0.0	0.0	0.0	0.0
4bh	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.3	0.1	0.1	0.1	0.1	0.2	0.3	0.1	0.2	0.0	0.0	0.0	0.0
4el	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.4	0.1	0.1	0.1	0.1	0.3	0.4	0.3	0.3	0.0	0.0	0.0	0.0
4eh	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0
4al	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.5	0.2	0.1	0.2	0.1	0.4	0.4	0.3	0.4	0.0	0.0	0.0	0.0
4ah	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0
5bl	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.2	0.1	0.0	0.1	0.0	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0
5bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5el	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0
5eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6b	0.1	0.1	0.1	0.2	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1
6e	0.1	0.1	0.1	0.2	0.0	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.1	0.2
6a	0.1	0.1	0.1	0.2	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1
7e	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.4	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.3	0.1	0.2
7a	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.4	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.3	0.1	0.2
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Environmental (GWP) - End of life stage (C1-4), (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	Hybrid	OE_-20%	OE_+20%	CF_-20%	CF_+20%	C1	C2	C3	C4	C5	C6	C7	C8
1b	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.1	0.1	0.1	0.1	1.3	0.2	1.0	0.2	0.3	0.0	0.2	0.0
1e	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.1	0.0	1.7	0.3	1.5	0.2	0.3	0.0	0.2	0.0
1a	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.1	0.0	2.2	0.4	1.8	0.2	0.3	0.0	0.2	0.0
2bl	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.1	0.1	0.1	0.1	0.1	2.4	0.3	0.0	0.4	0.3	0.0	0.3	0.0
2bh	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.1	0.0	0.9	0.2	0.0	0.2	0.2	0.0	0.2	0.0
2el	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.1	0.1	0.1	0.1	0.1	2.7	0.4	0.0	0.4	0.4	0.0	0.4	0.0
2eh	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.1	0.1	0.1	0.1	1.1	0.2	0.0	0.2	0.2	0.0	0.2	0.0
2al	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.1	0.2	0.1	0.2	0.1	2.8	0.4	0.0	0.5	0.5	0.0	0.5	0.0
2ah	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.1	0.1	0.1	0.1	1.0	0.2	0.0	0.2	0.2	0.0	0.2	0.0
3bl	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.1	0.2	0.1	0.2	0.1	9.6	0.6	8.5	0.5	0.4	0.0	0.3	0.0
3bh	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.1	0.1	0.1	0.1	0.1	2.6	0.3	1.9	0.2	0.2	0.0	0.2	0.0
3el	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.1	0.2	0.1	0.2	0.1	12.2	0.6	11.4	0.5	0.4	0.0	0.3	0.0
3eh	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	2.3	0.2	1.7	0.2	0.2	0.0	0.1	0.0
3al	0.2	0.3	0.1	0.3	0.1	0.2	0.2	0.1	0.1	0.0	0.3	0.0	0.2	0.2	0.1	0.2	0.1	30.9	0.7	32.1	0.7	0.5	0.0	0.5	0.0
3ah	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	2.3	0.2	1.8	0.2	0.2	0.0	0.2	0.0
4bl	0.2	0.2	0.2	0.3	0.1	0.2	0.2	0.2	0.2	0.0	0.3	0.0	0.2	0.2	0.1	0.2	0.1	10.9	0.8	10.3	0.6	0.5	0.0	0.4	0.0
4bh	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.1	0.1	0.1	0.1	0.1	3.4	0.4	2.3	0.3	0.3	0.0	0.2	0.0
4el	0.1	0.2	0.1	0.3	0.1	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.2	0.2	0.1	0.2	0.1	11.5	0.6	11.1	0.5	0.5	0.0	0.4	0.0
4eh	0.1	0.1	0.1	0.2	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	2.7	0.3	1.9	0.2	0.2	0.0	0.2	0.0
4al	0.2	0.3	0.2	0.4	0.1	0.2	0.2	0.2	0.2	0.0	0.3	0.0	0.2	0.2	0.1	0.2	0.1	21.7	0.7	24.1	0.7	0.5	0.0	0.5	0.0
4ah	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	2.5	0.2	1.9	0.2	0.2	0.0	0.2	0.0
5bl	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	9.9	0.4	9.9	0.4	0.2	0.0	0.2	0.0
5bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.1	0.5	0.1	0.0	0.0	0.0	0.0
5el	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	11.1	0.4	11.1	0.4	0.3	0.0	0.3	0.0
5eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.1	0.6	0.1	0.1	0.0	0.1	0.0
6b	0.2	0.2	0.2	0.3	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2	2.7	0.2	1.7	0.1	4.1	0.2	2.6	0.2
6e	0.2	0.2	0.2	0.3	0.1	0.2	0.2	0.2	0.2	0.3	0.1	0.2	0.2	0.2	0.2	0.2	0.2	2.7	0.2	1.7	0.1	5.1	0.3	3.4	0.3
6a	0.2	0.2	0.2	0.3	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2	2.7	0.2	1.7	0.1	4.1	0.2	2.6	0.2
7e	0.2	0.2	0.2	0.4	0.1	0.2	0.2	0.2	0.2	0.3	0.2	0.3	0.2	0.2	0.2	0.3	0.2	2.4	0.3	1.8	0.2	2.9	0.3	2.4	0.3
7a	0.2	0.2	0.2	0.4	0.1	0.2	0.2	0.2	0.2	0.3	0.2	0.3	0.2	0.2	0.2	0.3	0.2	2.4	0.3	1.8	0.2	2.9	0.3	2.4	0.3
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.2	0.0	0.0	0.0	0.0	0.0

Economic - Product stage (A1-3), (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	OE_-20%	OE_+20%	EPI_0%	EPI_double	DR_0%	DR_3%	C1	C3	C5	C7
1b	11.6	32.5	3.0	7.4	16.0	11.6	11.6	11.5	11.2	5.8	18.4	7.3	12.9	10.5	16.4	6.3	12.9	10.0	8.4	55.0	0.1	10.7
1e	8.7	25.1	2.0	6.2	10.9	8.7	8.7	8.7	8.5	4.5	17.9	6.3	10.0	7.7	13.8	4.3	9.4	7.8	8.5	54.8	0.1	8.2
1a	11.5	32.8	2.8	7.8	14.9	11.5	11.5	11.5	11.5	6.5	22.6	8.5	13.1	10.2	17.4	5.8	12.5	10.1	10.1	66.8	0.1	11.9
2bl	29.8	49.7	8.2	25.8	29.8	25.9	25.9	25.8	25.3	8.9	34.5	9.5	28.6	23.6	35.3	14.8	26.3	25.2	36.4	48.9	0.2	13.6
2bh	28.3	48.1	7.8	26.1	28.3	26.1	26.1	26.0	25.7	8.5	35.7	9.1	29.1	23.7	36.7	14.4	26.6	25.4	38.2	53.2	0.2	13.1
2el	24.7	44.8	6.3	21.9	24.7	22.0	22.0	21.9	21.3	6.8	29.8	7.5	24.8	19.8	31.9	11.7	22.3	21.5	32.4	47.0	0.1	10.7
2eh	23.7	43.5	6.0	21.1	23.7	21.2	21.2	21.1	20.8	6.5	28.9	7.1	23.9	19.0	31.0	11.2	21.5	20.7	31.8	46.4	0.1	10.2
2al	27.1	47.9	7.0	23.7	27.1	23.8	23.8	23.7	22.9	7.2	30.7	8.3	26.7	21.5	34.1	12.9	24.1	23.4	33.4	48.3	0.1	11.3
2ah	25.5	46.1	6.5	22.5	25.5	22.6	22.6	22.5	22.2	6.7	29.4	7.7	25.4	20.3	32.8	12.0	22.9	22.2	32.5	47.5	0.1	10.5
3bl	13.3	37.0	4.0	10.2	19.0	13.3	13.3	13.2	12.6	4.7	17.4	5.0	14.6	12.2	17.8	7.7	15.5	10.8	10.1	55.3	0.1	8.5
3bh	12.5	35.0	3.7	9.7	17.6	12.5	12.5	12.5	12.2	4.3	16.6	4.6	13.8	11.5	17.0	7.2	14.5	10.2	9.8	53.4	0.1	7.8
3el	12.1	34.0	3.4	9.5	16.4	12.1	12.1	11.9	11.3	3.9	15.9	4.3	13.5	10.9	17.0	6.6	13.8	10.0	9.8	53.1	0.1	7.1
3eh	11.5	32.5	3.1	9.2	15.4	11.5	11.5	11.4	11.2	3.7	15.4	4.0	12.9	10.4	16.4	6.2	13.1	9.6	9.7	51.9	0.1	6.6
3al	14.7	41.2	4.3	11.2	21.1	14.7	14.7	14.5	13.6	4.9	18.2	5.6	16.2	13.4	19.8	8.4	17.0	12.0	10.9	59.5	0.1	8.8
3ah	14.0	39.5	4.0	10.9	19.8	14.0	14.0	13.9	13.6	4.5	17.6	5.2	15.5	12.8	19.3	7.9	16.1	11.5	10.7	58.4	0.1	8.2
4bl	12.7	31.6	3.3	13.5	14.6	13.7	13.6	13.5	13.0	3.1	20.4	3.1	15.9	11.9	22.6	6.4	13.8	13.4	23.3	41.0	0.1	5.0
4bh	11.9	29.9	3.0	13.0	13.5	13.1	13.1	13.0	12.7	2.8	20.2	2.8	15.4	11.4	22.6	6.0	13.2	12.9	23.6	44.6	0.0	4.6
4el	9.5	25.0	2.2	10.0	10.6	10.1	10.1	10.0	9.7	2.2	15.0	2.4	12.0	8.7	18.0	4.5	10.1	10.0	18.0	36.5	0.0	3.7
4eh	8.9	23.6	2.1	9.7	9.8	9.7	9.7	9.6	9.5	2.0	14.9	2.2	11.6	8.3	18.2	4.2	9.7	9.6	18.4	41.7	0.0	3.4
4al	10.9	28.7	2.6	11.6	12.4	11.7	11.7	11.5	10.8	2.5	16.0	2.9	13.8	10.1	20.5	5.3	11.7	11.6	19.1	38.3	0.0	4.1
4ah	10.0	26.5	2.3	10.9	11.1	11.0	11.0	10.9	10.7	2.2	15.5	2.6	13.2	9.4	20.5	4.7	11.0	10.9	19.4	44.0	0.0	3.7
5bl	13.4	29.7	2.9	11.8	13.4	13.4	13.4	13.3	13.0	2.6	21.1	2.6	16.0	11.5	24.4	5.9	13.4	13.4	14.5	49.9	0.0	4.4
5bh	4.1	10.5	0.8	3.9	4.1	4.1	4.1	4.1	4.1	0.7	6.9	0.7	5.0	3.5	8.2	1.7	4.1	4.1	7.1	22.0	0.0	1.2
5el	9.1	22.2	1.8	8.3	9.1	9.1	9.1	9.0	8.8	1.8	14.0	1.9	11.0	7.7	17.6	3.8	9.1	9.1	11.6	41.2	0.0	3.1
5eh	3.3	9.0	0.6	3.2	3.3	3.3	3.3	3.3	3.3	0.6	5.3	0.7	4.1	2.8	6.9	1.3	3.3	3.3	5.9	20.0	0.0	1.1
6b	2.4	8.1	0.3	2.2	2.5	2.4	2.4	2.4	2.4	3.2	1.7	2.6	2.4	2.4	5.9	0.7	2.4	2.3	2.1	9.0	0.0	6.5
6e	2.2	7.1	0.3	2.0	2.3	2.2	2.2	2.2	2.2	3.5	1.6	2.4	2.2	2.2	4.8	0.7	2.3	2.0	1.9	8.2	0.0	6.8
6a	2.2	7.1	0.3	2.0	2.3	2.2	2.2	2.2	2.2	2.8	1.6	2.4	2.2	2.2	4.8	0.7	2.3	2.0	1.9	8.2	0.0	5.5
7e	4.6	14.8	0.7	4.0	4.9	4.6	4.6	4.6	4.5	5.9	3.3	5.0	4.6	4.6	9.7	1.4	4.8	4.2	3.7	17.0	0.0	11.8
7a	4.6	14.8	0.7	4.0	4.9	4.6	4.6	4.6	4.5	5.9	3.3	5.3	4.6	4.6	9.7	1.4	4.8	4.2	3.7	17.0	0.0	11.8
8	1.9	4.1	0.2	1.2	1.2	1.2	1.2	1.2	1.2	0.3	2.8	0.4	1.5	1.0	3.1	0.4	1.2	1.2	3.6	16.2	0.0	0.6

Economic - Transportation stage (A4), (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	OE_-20%	OE_+20%	EPI_0%	EPI_double	DR_0%	DR_3%	C1	C3	C5	C7
1b	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.2	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
1e	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.2	1.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
1a	0.1	0.2	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.3	0.0	0.1
2bl	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.5	2.3	0.0	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.0
2bh	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.3	1.5	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.0
2el	0.1	0.2	0.0	0.1	0.1	0.0	0.2	0.6	3.1	0.0	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.2	0.0	0.0
2eh	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.3	1.6	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.0
2al	0.1	0.2	0.0	0.1	0.1	0.0	0.3	0.9	4.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.0	0.0
2ah	0.1	0.1	0.0	0.0	0.1	0.0	0.1	0.4	1.9	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.0
3bl	0.1	0.3	0.0	0.1	0.2	0.0	0.1	0.4	2.0	0.0	0.2	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.5	0.0	0.1
3bh	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
3el	0.2	0.4	0.0	0.1	0.2	0.0	0.2	0.5	2.4	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.1	0.7	0.0	0.1
3eh	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
3al	0.2	0.5	0.1	0.1	0.3	0.0	0.2	0.6	3.0	0.1	0.2	0.1	0.2	0.2	0.3	0.1	0.2	0.2	0.1	0.8	0.0	0.1
3ah	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4bl	0.3	0.7	0.1	0.3	0.3	0.0	0.3	0.9	4.5	0.1	0.4	0.1	0.3	0.3	0.5	0.1	0.3	0.3	0.5	0.9	0.0	0.1
4bh	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.6	2.9	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.0
4el	0.3	0.7	0.1	0.3	0.3	0.0	0.3	0.9	4.5	0.1	0.4	0.1	0.3	0.2	0.5	0.1	0.3	0.3	0.5	1.0	0.0	0.1
4eh	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.5	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
4al	0.3	0.9	0.1	0.4	0.4	0.1	0.4	1.2	5.5	0.1	0.5	0.1	0.4	0.3	0.6	0.2	0.4	0.4	0.6	1.2	0.0	0.1
4ah	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.5	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
5bl	0.2	0.4	0.0	0.2	0.2	0.0	0.2	0.6	3.0	0.0	0.3	0.0	0.2	0.2	0.3	0.1	0.2	0.2	0.2	0.7	0.0	0.1
5bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5el	0.2	0.5	0.0	0.2	0.2	0.0	0.2	0.7	3.6	0.0	0.3	0.1	0.3	0.2	0.4	0.1	0.2	0.2	0.3	1.0	0.0	0.1
5eh	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Economic – Construction process stage (A5), (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	OE_-20%	OE_+20%	EPI_0%	EPI_double	DR_0%	DR_3%	C1	C3	C5	C7
1b	6.1	17.1	1.6	3.9	8.4	6.1	6.1	6.0	5.9	3.0	9.7	3.8	6.8	5.5	8.6	3.3	6.8	5.2	4.4	28.9	0.1	5.6
1e	4.2	12.0	1.0	3.0	5.2	4.2	4.2	4.2	4.1	2.2	8.6	3.0	4.8	3.7	6.6	2.1	4.5	3.7	4.1	26.2	0.0	3.9
1a	3.1	9.0	0.8	2.1	4.1	3.1	3.1	3.1	3.1	1.8	6.2	2.3	3.6	2.8	4.8	1.6	3.4	2.8	2.8	18.3	0.0	3.3
2bl	9.0	15.1	2.5	7.8	9.0	7.8	7.8	7.8	7.7	2.7	10.4	2.9	8.7	7.2	10.7	4.5	8.0	7.6	11.0	14.8	0.1	4.1
2bh	9.2	15.6	2.6	8.5	9.2	8.5	8.5	8.5	8.4	2.8	11.6	3.0	9.5	7.7	11.9	4.7	8.7	8.3	12.4	17.3	0.1	4.3
2el	7.3	13.3	1.9	6.5	7.3	6.5	6.5	6.5	6.3	2.0	8.8	2.2	7.3	5.9	9.5	3.5	6.6	6.4	9.6	13.9	0.0	3.2
2eh	7.5	13.7	1.9	6.7	7.5	6.7	6.7	6.7	6.6	2.0	9.1	2.2	7.5	6.0	9.8	3.5	6.8	6.5	10.0	14.6	0.0	3.2
2al	6.9	12.1	1.8	6.0	6.9	6.0	6.0	6.0	5.8	1.8	7.8	2.1	6.8	5.4	8.6	3.3	6.1	5.9	8.5	12.2	0.0	2.9
2ah	7.0	12.7	1.8	6.2	7.0	6.2	6.2	6.2	6.1	1.8	8.1	2.1	7.0	5.6	9.1	3.3	6.3	6.1	9.0	13.1	0.0	2.9
3bl	4.2	11.7	1.3	3.2	6.0	4.2	4.2	4.2	4.0	1.5	5.5	1.6	4.6	3.9	5.6	2.5	4.9	3.4	3.2	17.6	0.0	2.7
3bh	4.4	12.2	1.3	3.4	6.2	4.4	4.4	4.4	4.3	1.5	5.8	1.6	4.9	4.0	6.0	2.5	5.1	3.6	3.4	18.7	0.0	2.7
3el	3.4	9.7	1.0	2.7	4.7	3.4	3.4	3.4	3.2	1.1	4.5	1.2	3.8	3.1	4.8	1.9	3.9	2.8	2.8	15.1	0.0	2.0
3eh	3.5	10.0	1.0	2.8	4.8	3.5	3.5	3.5	3.4	1.1	4.7	1.2	4.0	3.2	5.1	1.9	4.0	3.0	3.0	16.0	0.0	2.0
3al	3.0	8.5	0.9	2.3	4.4	3.0	3.0	3.0	2.8	1.0	3.8	1.2	3.4	2.8	4.1	1.7	3.5	2.5	2.2	12.3	0.0	1.8
3ah	3.2	9.0	0.9	2.5	4.5	3.2	3.2	3.2	3.1	1.0	4.0	1.2	3.5	2.9	4.4	1.8	3.7	2.6	2.4	13.3	0.0	1.8
4bl	3.7	9.2	1.0	3.9	4.3	4.0	4.0	3.9	3.8	0.9	5.9	0.9	4.6	3.5	6.6	1.9	4.0	3.9	6.8	11.9	0.0	1.5
4bh	3.8	9.6	1.0	4.2	4.3	4.2	4.2	4.2	4.1	0.9	6.5	0.9	4.9	3.6	7.2	1.9	4.2	4.1	7.6	14.3	0.0	1.5
4el	2.5	6.5	0.6	2.6	2.7	2.6	2.6	2.6	2.5	0.6	3.9	0.6	3.1	2.3	4.7	1.2	2.6	2.6	4.6	9.5	0.0	1.0
4eh	2.5	6.7	0.6	2.8	2.8	2.8	2.8	2.8	2.7	0.6	4.3	0.6	3.3	2.4	5.2	1.2	2.8	2.7	5.3	11.9	0.0	1.0
4al	2.0	5.2	0.5	2.1	2.2	2.1	2.1	2.1	1.9	0.5	2.9	0.5	2.5	1.8	3.7	0.9	2.1	2.1	3.4	6.9	0.0	0.7
4ah	2.1	5.5	0.5	2.3	2.3	2.3	2.3	2.3	2.2	0.5	3.2	0.5	2.7	1.9	4.2	1.0	2.3	2.2	4.0	9.1	0.0	0.8
5bl	4.9	11.0	1.1	4.3	4.9	5.0	4.9	4.9	4.8	1.0	7.8	1.0	5.9	4.3	9.0	2.2	4.9	4.9	5.4	18.4	0.0	1.6
5bh	5.5	14.2	1.1	5.3	5.5	5.5	5.5	5.5	5.5	1.0	9.3	1.0	6.7	4.7	11.1	2.3	5.5	5.5	9.6	29.8	0.0	1.7
5el	3.0	7.3	0.6	2.7	3.0	3.0	3.0	3.0	2.9	0.6	4.6	0.6	3.6	2.6	5.8	1.3	3.0	3.0	3.8	13.7	0.0	1.0
5eh	3.2	8.7	0.6	3.1	3.2	3.2	3.2	3.2	3.2	0.6	5.2	0.7	4.0	2.7	6.7	1.3	3.2	3.2	5.7	19.5	0.0	1.0
6b	0.6	2.1	0.1	0.6	0.6	0.6	0.6	0.6	0.6	0.8	0.4	0.7	0.6	0.6	1.5	0.2	0.6	0.6	0.5	2.3	0.0	1.7
6e	0.6	1.8	0.1	0.5	0.6	0.6	0.6	0.6	0.6	0.9	0.4	0.6	0.6	0.6	1.3	0.2	0.6	0.5	0.5	2.1	0.0	1.8
6a	0.6	1.8	0.1	0.5	0.6	0.6	0.6	0.6	0.6	0.7	0.4	0.6	0.6	0.6	1.3	0.2	0.6	0.5	0.5	2.1	0.0	1.4
7e	0.2	0.8	0.0	0.2	0.3	0.2	0.2	0.2	0.2	0.3	0.2	0.3	0.2	0.2	0.5	0.1	0.2	0.2	0.2	0.9	0.0	0.6
7a	0.2	0.8	0.0	0.2	0.3	0.2	0.2	0.2	0.2	0.3	0.2	0.3	0.2	0.2	0.5	0.1	0.2	0.2	0.2	0.9	0.0	0.6
8	0.1	0.2	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.1	0.1	0.2	0.0	0.1	0.1	0.2	1.0	0.0	0.0

Economic - Maintenance stage (B2), (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	OE_-20%	OE_+20%	EPI_0%	EPI_double	DR_0%	DR_3%	C1	C3	C5	C7
1b	1.2	1.6	0.6	0.7	1.6	1.2	1.2	1.2	1.1	0.6	1.9	0.7	1.3	1.1	1.7	0.6	0.9	1.5	1.1	1.9	0.0	0.8
1e	0.8	1.2	0.4	0.6	1.0	0.8	0.8	0.8	0.8	0.4	1.6	0.6	0.9	0.7	1.3	0.4	0.6	1.1	1.1	1.7	0.0	0.6
1a	0.6	0.9	0.3	0.4	0.8	0.6	0.6	0.6	0.6	0.3	1.2	0.5	0.7	0.5	0.9	0.3	0.4	0.8	0.7	1.2	0.0	0.5
2bl	5.8	4.9	3.2	5.1	5.8	5.1	5.1	5.1	5.0	1.7	6.8	1.9	5.6	4.6	6.9	2.9	3.5	7.6	9.7	3.2	0.1	2.0
2bh	6.0	5.1	3.3	5.5	6.0	5.5	5.5	5.5	5.4	1.8	7.5	1.9	6.1	5.0	7.7	3.0	3.8	8.2	10.9	3.8	0.1	2.1
2el	4.7	4.3	2.4	4.2	4.7	4.2	4.2	4.2	4.1	1.3	5.7	1.4	4.8	3.8	6.1	2.2	2.9	6.3	8.4	3.1	0.1	1.6
2eh	4.8	4.4	2.4	4.3	4.8	4.3	4.3	4.3	4.3	1.3	5.9	1.4	4.9	3.9	6.3	2.3	3.0	6.5	8.8	3.2	0.1	1.6
2al	4.0	3.6	2.1	3.5	4.0	3.6	3.6	3.5	3.4	1.1	4.6	1.2	4.0	3.2	5.1	1.9	2.4	5.3	6.8	2.4	0.1	1.3
2ah	4.2	3.8	2.1	3.7	4.2	3.7	3.7	3.7	3.6	1.1	4.8	1.3	4.2	3.3	5.3	2.0	2.5	5.5	7.2	2.6	0.1	1.3
3bl	6.7	9.3	4.0	5.2	9.6	6.7	6.7	6.7	6.4	2.4	8.8	2.5	7.4	6.2	9.0	3.9	5.3	8.3	6.9	9.5	0.1	3.3
3bh	7.0	9.7	4.1	5.4	9.8	7.0	7.0	6.9	6.8	2.4	9.3	2.6	7.7	6.4	9.5	4.0	5.5	8.7	7.4	10.1	0.1	3.3
3el	5.5	7.7	3.0	4.3	7.5	5.5	5.5	5.4	5.1	1.8	7.2	1.9	6.1	5.0	7.7	3.0	4.2	6.9	6.0	8.2	0.1	2.4
3eh	5.6	8.0	3.1	4.5	7.6	5.6	5.6	5.6	5.5	1.8	7.5	2.0	6.3	5.1	8.0	3.1	4.4	7.2	6.4	8.6	0.1	2.5
3al	4.3	6.0	2.5	3.3	6.2	4.3	4.3	4.2	4.0	1.4	5.3	1.6	4.7	3.9	5.8	2.5	3.4	5.4	4.3	5.9	0.1	2.0
3ah	4.5	6.3	2.6	3.5	6.3	4.5	4.5	4.5	4.4	1.5	5.6	1.7	5.0	4.1	6.2	2.5	3.5	5.6	4.7	6.4	0.1	2.0
4bl	3.0	3.7	1.5	3.2	3.4	3.2	3.2	3.2	3.1	0.7	4.8	0.7	3.7	2.8	5.3	1.5	2.2	4.8	7.4	3.3	0.0	0.9
4bh	3.1	3.8	1.5	3.4	3.5	3.4	3.4	3.4	3.3	0.7	5.2	0.7	4.0	2.9	5.8	1.5	2.3	5.1	8.3	3.9	0.0	0.9
4el	2.0	2.6	0.9	2.1	2.2	2.1	2.1	2.1	2.0	0.5	3.1	0.5	2.5	1.8	3.8	0.9	1.4	3.2	5.1	2.6	0.0	0.6
4eh	2.0	2.7	0.9	2.2	2.2	2.2	2.2	2.2	2.2	0.5	3.4	0.5	2.7	1.9	4.2	1.0	1.5	3.4	5.7	3.2	0.0	0.6
4al	1.6	2.1	0.8	1.7	1.8	1.7	1.7	1.7	1.6	0.4	2.3	0.4	2.0	1.5	3.0	0.8	1.2	2.6	3.7	1.9	0.0	0.5
4ah	1.7	2.2	0.8	1.8	1.8	1.8	1.8	1.8	1.8	0.4	2.6	0.4	2.2	1.6	3.4	0.8	1.2	2.8	4.4	2.5	0.0	0.5
5bl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5el	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6b	2.4	4.0	0.6	2.2	2.5	2.4	2.4	2.4	2.4	3.2	1.7	2.6	2.4	2.4	5.9	0.7	1.6	3.5	2.9	3.1	0.1	5.0
6e	10.8	17.6	3.1	9.9	11.2	10.8	10.8	10.8	10.8	17.6	7.7	11.9	10.8	10.8	24.1	3.3	7.7	15.3	12.9	13.9	0.4	25.9
6a	10.8	17.6	3.1	9.9	11.2	10.8	10.8	10.8	10.8	14.0	7.7	11.9	10.8	10.8	24.1	3.3	7.7	15.3	12.9	13.9	0.3	21.0
7e	8.8	14.3	2.6	7.6	9.5	8.8	8.8	8.8	8.8	11.3	6.4	9.7	8.8	8.8	18.7	2.8	6.3	12.4	9.8	11.1	0.3	17.4
7a	8.8	14.3	2.6	7.6	9.5	8.8	8.8	8.8	8.8	11.3	6.4	10.3	8.8	8.8	18.7	2.8	6.3	12.4	9.8	11.1	0.3	17.4
8	2.7	4.6	0.8	2.6	2.8	2.7	2.7	2.7	2.7	0.7	6.2	0.9	3.3	2.3	7.0	0.9	1.9	4.1	11.0	12.4	0.0	1.0

Economic - Replacement stage ($B4_{A1\text{-}3}$) - product, (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	OE_-20%	OE_+20%	EPI_0%	EPI_double	DR_0%	DR_3%	C1	C3	C5	C7
1b	18.1	0.0	13.9	34.9	0.0	18.1	18.1	18.0	17.6	9.0	28.8	11.4	20.2	16.3	25.7	9.8	12.9	24.2	50.4	0.0	1.8	0.0
1e	13.6	0.0	9.5	29.1	0.0	13.6	13.6	13.6	13.3	7.1	27.9	9.8	15.7	12.0	21.5	6.7	9.4	19.0	50.9	0.0	1.3	0.0
1a	17.9	0.0	12.9	36.8	0.0	17.9	17.9	17.9	17.9	10.1	35.3	13.3	20.4	16.0	27.3	9.1	12.5	24.6	60.9	0.0	2.0	0.0
2bl	0.0	0.0	4.1	12.9	0.0	13.0	12.9	12.9	12.7	4.4	17.2	4.7	14.3	11.8	17.6	7.4	13.2	12.6	18.2	24.4	0.1	6.8
2bh	0.0	0.0	2.4	7.8	0.0	7.8	7.8	7.8	7.7	2.5	10.7	2.7	8.7	7.1	11.0	4.3	8.0	7.6	11.5	16.0	0.1	3.9
2el	0.0	0.0	3.2	11.0	0.0	11.0	11.0	10.9	10.7	3.4	14.9	3.7	12.4	9.9	15.9	5.9	11.1	10.8	16.2	23.5	0.1	5.4
2eh	0.0	0.0	3.0	10.6	0.0	10.6	10.6	10.6	10.4	3.2	14.4	3.5	11.9	9.5	15.5	5.6	10.7	10.3	15.9	23.2	0.1	5.1
2al	0.0	0.0	3.5	11.9	0.0	11.9	11.9	11.8	11.4	3.6	15.3	4.2	13.4	10.8	17.0	6.4	12.1	11.7	16.7	24.1	0.1	5.6
2ah	0.0	0.0	3.2	11.3	0.0	11.3	11.3	11.3	11.1	3.3	14.7	3.9	12.7	10.2	16.4	6.0	11.4	11.1	16.3	23.7	0.1	5.2
3bl	22.4	0.0	13.3	34.4	0.0	22.4	22.4	22.2	21.3	7.9	29.3	8.4	24.6	20.5	30.0	13.0	15.5	30.3	50.4	0.0	1.3	0.0
3bh	21.1	0.0	12.3	32.8	0.0	21.1	21.1	21.0	20.5	7.3	28.0	7.8	23.3	19.3	28.6	12.1	14.5	28.7	48.9	0.0	1.2	0.0
3el	20.3	0.0	11.3	32.1	0.0	20.4	20.3	20.1	19.1	6.6	26.8	7.2	22.7	18.4	28.6	11.2	13.8	28.1	49.1	0.0	1.1	0.0
3eh	19.4	0.0	10.6	30.9	0.0	19.4	19.4	19.3	18.8	6.2	25.9	6.7	21.7	17.5	27.6	10.5	13.1	27.0	48.3	0.0	1.0	0.0
3al	24.7	0.0	14.5	37.8	0.0	24.8	24.7	24.4	22.8	8.2	30.6	9.4	27.3	22.6	33.4	14.2	17.0	33.7	54.3	0.0	1.4	0.0
3ah	23.6	0.0	13.5	36.5	0.0	23.6	23.6	23.5	22.9	7.6	29.6	8.7	26.2	21.5	32.5	13.3	16.1	32.4	53.6	0.0	1.2	0.0
4bl	12.7	0.0	1.6	6.8	0.0	6.8	6.8	6.8	6.5	1.5	10.2	1.6	8.0	6.0	11.3	3.2	6.9	6.7	11.6	20.5	0.0	2.5
4bh	11.9	0.0	0.8	3.3	0.0	3.3	3.3	3.3	3.2	0.7	5.0	0.7	3.9	2.8	5.7	1.5	3.3	3.2	5.9	11.2	0.0	1.2
4el	9.5	0.0	1.1	5.0	0.0	5.1	5.0	5.0	4.8	1.1	7.5	1.2	6.0	4.4	9.0	2.2	5.1	5.0	9.0	18.3	0.0	1.8
4eh	8.9	0.0	0.2	1.0	0.0	1.0	1.0	1.0	1.0	0.2	1.5	0.2	1.2	0.8	1.8	0.4	1.0	1.0	1.8	4.2	0.0	0.3
4al	10.9	0.0	1.3	5.8	0.0	5.9	5.8	5.8	5.4	1.2	8.0	1.4	6.9	5.1	10.3	2.6	5.9	5.8	9.5	19.2	0.0	2.1
4ah	10.0	0.0	0.2	1.1	0.0	1.1	1.1	1.1	1.1	0.2	1.6	0.3	1.3	0.9	2.1	0.5	1.1	1.1	1.9	4.4	0.0	0.4
5bl	0.0	0.0	2.9	11.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	43.6	0.0	0.1	0.0
5bh	0.0	0.0	0.8	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.2	0.0	0.0	0.0
5el	0.0	0.0	1.8	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	34.7	0.0	0.1	0.0
5eh	0.0	0.0	0.6	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.6	0.0	0.0	0.0
6b	3.7	0.0	1.5	10.1	0.0	3.7	3.7	3.7	3.7	4.9	2.6	4.1	3.7	3.7	9.2	1.1	2.4	5.5	12.7	0.0	0.3	0.0
6e	3.4	0.0	1.4	9.3	0.0	3.4	3.4	3.4	3.4	5.5	2.4	3.7	3.4	3.4	7.6	1.0	2.3	4.9	11.5	0.0	0.4	0.0
6a	3.4	0.0	1.4	9.3	0.0	3.4	3.4	3.4	3.4	4.4	2.4	3.7	3.4	3.4	7.6	1.0	2.3	4.9	11.5	0.0	0.3	0.0
7e	7.1	0.0	3.1	18.6	0.0	7.1	7.1	7.1	7.1	9.2	5.2	7.8	7.1	7.1	15.2	2.2	4.8	10.2	22.4	0.0	0.6	0.0
7a	7.1	0.0	3.1	18.6	0.0	7.1	7.1	7.1	7.1	9.2	5.2	8.4	7.1	7.1	15.2	2.2	4.8	10.2	22.4	0.0	0.6	0.0
8	2.9	0.0	0.9	5.4	0.0	1.9	1.9	1.9	1.9	0.5	4.3	0.7	2.3	1.6	4.9	0.6	1.2	2.9	21.6	0.0	0.0	0.0

Economic - Replacement stage ($B4_{A4}$) - transportation, (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	OE_-20%	OE_+20%	EPI_0%	EPI_double	DR_0%	DR_3%	C1	C3	C5	C7
1b	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.4	1.7	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0
1e	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.3	1.5	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0
1a	0.1	0.0	0.1	0.2	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.3	0.0	0.0	0.0
2bl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2el	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2al	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3bl	0.2	0.0	0.1	0.3	0.0	0.0	0.2	0.7	3.3	0.1	0.3	0.1	0.2	0.2	0.3	0.1	0.1	0.3	0.5	0.0	0.0	0.0
3bh	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3el	0.3	0.0	0.1	0.4	0.0	0.0	0.3	0.9	4.1	0.1	0.4	0.1	0.3	0.2	0.4	0.1	0.2	0.4	0.6	0.0	0.0	0.0
3eh	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3al	0.3	0.0	0.2	0.5	0.0	0.1	0.3	1.1	5.0	0.1	0.4	0.1	0.4	0.3	0.4	0.2	0.2	0.4	0.7	0.0	0.0	0.0
3ah	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4bl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4el	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4al	0.3	0.0	0.0	0.2	0.0	0.0	0.2	0.6	2.7	0.0	0.2	0.0	0.2	0.2	0.3	0.1	0.2	0.2	0.3	0.6	0.0	0.1
4ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5bl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5bh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5el	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5eh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6b	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Economic - Replacement stage ($B4_{A5}$) – construction process, (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	OE_-20%	OE_+20%	EPI_0%	EPI_double	DR_0%	DR_3%	C1	C3	C5	C7
1b	9.5	0.0	7.3	18.3	0.0	9.5	9.5	9.4	9.2	4.8	15.1	6.0	10.6	8.6	13.5	5.2	6.8	12.7	26.5	0.0	0.9	0.0
1e	6.5	0.0	4.6	13.9	0.0	6.5	6.5	6.5	6.4	3.4	13.4	4.7	7.5	5.8	10.3	3.2	4.5	9.1	24.4	0.0	0.6	0.0
1a	4.9	0.0	3.5	10.1	0.0	4.9	4.9	4.9	4.9	2.8	9.7	3.6	5.6	4.4	7.5	2.5	3.4	6.7	16.7	0.0	0.5	0.0
2bl	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.3	0.0	0.1
2bh	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.2	0.0	0.1
2el	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.0	0.3	0.0	0.1
2eh	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.3	0.0	0.1
2al	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.0	0.2	0.0	0.1
2ah	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.0	0.3	0.0	0.1
3bl	7.1	0.0	4.2	10.9	0.0	7.1	7.1	7.1	6.8	2.5	9.3	2.7	7.8	6.5	9.5	4.1	4.9	9.6	16.0	0.0	0.4	0.0
3bh	7.4	0.0	4.3	11.5	0.0	7.4	7.4	7.3	7.2	2.6	9.8	2.7	8.2	6.8	10.0	4.2	5.1	10.1	17.1	0.0	0.4	0.0
3el	5.8	0.0	3.2	9.1	0.0	5.8	5.8	5.7	5.4	1.9	7.6	2.1	6.5	5.2	8.1	3.2	3.9	8.0	14.0	0.0	0.3	0.0
3eh	6.0	0.0	3.3	9.5	0.0	6.0	6.0	5.9	5.8	1.9	8.0	2.1	6.7	5.4	8.5	3.2	4.0	8.3	14.9	0.0	0.3	0.0
3al	5.1	0.0	3.0	7.8	0.0	5.1	5.1	5.1	4.7	1.7	6.3	2.0	5.6	4.7	6.9	2.9	3.5	7.0	11.2	0.0	0.3	0.0
3ah	5.4	0.0	3.1	8.3	0.0	5.4	5.3	5.3	5.2	1.7	6.7	2.0	5.9	4.9	7.4	3.0	3.7	7.3	12.2	0.0	0.3	0.0
4bl	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0	0.0
4bh	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
4el	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
4eh	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4al	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
4ah	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5bl	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
5bh	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
5el	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
5eh	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
6b	1.0	0.0	0.4	2.6	0.0	1.0	1.0	1.0	1.0	1.3	0.7	1.1	1.0	1.0	2.4	0.3	0.6	1.4	3.3	0.0	0.1	0.0
6e	0.9	0.0	0.4	2.4	0.0	0.9	0.9	0.9	0.9	1.4	0.6	1.0	0.9	0.9	2.0	0.3	0.6	1.3	3.0	0.0	0.1	0.0
6a	0.9	0.0	0.4	2.4	0.0	0.9	0.9	0.9	0.9	1.1	0.6	1.0	0.9	0.9	2.0	0.3	0.6	1.3	3.0	0.0	0.1	0.0
7e	0.4	0.0	0.2	1.0	0.0	0.4	0.4	0.4	0.4	0.5	0.3	0.4	0.4	0.4	0.8	0.1	0.2	0.5	1.2	0.0	0.0	0.0
7a	0.4	0.0	0.2	1.0	0.0	0.4	0.4	0.4	0.4	0.5	0.3	0.4	0.4	0.4	0.8	0.1	0.2	0.5	1.2	0.0	0.0	0.0
8	0.1	0.0	0.1	0.3	0.0	0.1	0.1	0.1	0.1	0.0	0.3	0.0	0.1	0.1	0.3	0.0	0.1	0.2	1.3	0.0	0.0	0.0

Economic – Reduction of the operational energy use stage (RED_{B6}), (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	OE_-20%	OE_+20%	EPI_0%	EPI_double	DR_0%	DR_3%	C1	C3	C5	C7
1b	53.3	48.4	73.5	34.3	73.8	53.3	53.2	53.0	51.8	76.6	25.5	70.4	47.7	57.8	33.6	74.6	59.4	46.0	8.2	13.5	97.0	82.7
1e	65.9	61.3	82.4	46.8	82.6	65.9	65.8	65.6	64.2	82.2	30.0	75.3	60.7	69.8	46.1	83.2	71.2	59.0	10.1	16.3	97.9	87.1
1a	61.6	56.9	79.6	42.2	80.0	61.6	61.6	61.6	61.6	78.3	24.4	71.5	56.2	65.8	41.6	80.5	67.3	54.5	7.8	12.8	97.3	84.2
2bl	55.0	29.7	81.7	47.6	55.0	47.8	47.8	47.6	46.7	82.1	30.5	80.9	42.3	52.4	28.9	70.2	48.6	46.5	22.9	7.7	99.6	73.3
2bh	56.2	30.8	83.8	51.7	56.2	51.8	51.8	51.6	51.0	84.3	34.0	83.3	46.2	56.3	32.3	73.4	52.7	50.3	25.8	9.0	99.6	76.3
2el	62.7	36.7	86.0	55.5	62.7	55.8	55.7	55.4	54.1	86.2	40.1	85.0	50.2	60.2	35.8	76.4	56.5	54.5	30.9	11.2	99.7	78.9
2eh	63.8	37.9	86.6	56.9	63.8	57.0	56.9	56.8	56.1	86.8	41.3	85.6	51.4	61.4	37.0	77.3	57.8	55.7	32.2	11.8	99.7	79.7
2al	61.3	35.1	85.3	53.7	61.3	54.0	53.9	53.6	51.8	86.1	40.8	84.0	48.4	58.5	34.2	75.1	54.6	53.0	31.5	11.4	99.7	78.6
2ah	63.0	36.8	86.2	55.7	63.0	55.9	55.8	55.7	54.8	87.0	42.6	85.0	50.3	60.3	35.9	76.5	56.5	54.8	33.5	12.2	99.7	79.9
3bl	45.4	40.9	72.8	35.0	64.9	45.6	45.5	45.1	43.2	80.7	28.6	79.5	40.0	50.0	27.0	68.2	53.0	36.8	11.7	16.1	97.9	85.2
3bh	47.3	42.6	74.2	36.7	66.3	47.3	47.2	47.0	45.8	81.8	30.1	80.6	41.8	51.8	28.4	69.8	54.9	38.5	12.6	17.1	98.1	86.1
3el	51.9	47.3	77.7	41.0	70.8	52.1	51.9	51.4	48.7	84.3	36.4	82.9	46.3	56.4	32.3	73.5	59.3	43.0	15.9	21.5	98.4	88.2
3eh	53.6	49.0	78.8	42.7	72.0	53.6	53.5	53.3	52.0	85.2	38.0	83.9	48.1	58.1	33.9	74.9	61.0	44.7	16.9	22.8	98.5	88.9
3al	46.8	42.5	74.1	35.9	67.5	47.0	46.9	46.3	43.3	82.3	34.1	79.7	41.4	51.4	28.1	69.4	54.2	38.2	14.4	19.8	98.1	87.0
3ah	49.0	44.7	75.7	38.0	69.2	49.0	49.0	48.8	47.6	83.6	36.1	81.1	43.5	53.6	29.9	71.2	56.5	40.3	15.6	21.3	98.3	87.9
4bl	66.5	53.5	92.3	71.1	76.8	71.7	71.5	71.0	68.4	93.6	57.3	93.5	66.7	75.1	52.6	86.6	72.2	70.3	46.4	20.4	99.9	89.8
4bh	68.6	55.8	93.6	75.4	78.2	75.7	75.5	75.2	73.5	94.8	62.5	94.7	71.3	78.9	57.9	88.9	76.5	74.3	51.9	24.5	99.9	91.6
4el	75.0	63.7	94.8	78.8	83.5	79.5	79.3	78.8	75.9	95.4	69.1	95.1	75.4	82.1	62.9	90.8	79.8	78.4	58.6	29.8	99.9	92.6
4eh	77.1	66.2	96.1	83.8	84.9	84.1	84.0	83.7	82.2	96.6	75.5	96.4	80.8	86.4	70.0	93.1	84.7	83.1	66.5	37.6	99.9	94.5
4al	72.5	61.4	94.3	76.8	82.4	77.7	77.4	76.4	71.4	95.2	69.0	94.4	73.2	80.4	60.3	89.8	77.8	76.7	58.4	29.4	99.9	92.1
4ah	75.8	65.1	96.0	83.3	84.4	83.5	83.4	83.1	81.6	96.7	76.8	96.2	80.2	85.9	69.2	92.9	84.0	82.7	68.2	38.7	99.9	94.6
5bl	81.1	58.1	93.0	71.2	81.1	81.2	81.1	80.8	78.9	96.3	70.3	96.3	77.4	83.7	65.5	91.7	81.1	81.1	34.5	29.6	99.8	93.8
5bh	90.3	75.1	97.2	86.6	90.3	90.3	90.3	90.2	89.7	98.3	83.7	98.3	88.2	91.8	80.5	96.0	90.3	90.3	61.3	47.7	99.9	97.1
5el	87.2	68.8	95.5	79.6	87.2	87.4	87.2	86.8	84.3	97.4	80.3	97.3	84.5	89.1	75.2	94.6	87.2	87.2	47.1	42.0	99.9	95.7
5eh	93.4	82.0	98.0	90.2	93.4	93.4	93.3	93.2	92.6	98.7	89.4	98.7	91.8	94.4	86.2	97.3	93.4	93.4	70.0	59.9	99.9	97.9
6b	89.4	83.7	97.0	81.8	93.8	89.4	89.4	89.4	89.2	85.9	92.6	88.3	89.4	89.4	73.5	97.0	91.7	86.1	77.9	83.2	99.5	85.1
6e	82.2	73.4	94.7	75.7	85.9	82.2	82.2	82.2	82.1	71.0	87.2	80.4	82.2	82.2	60.2	94.6	86.5	76.1	70.2	75.6	99.0	65.5
6a	82.2	73.4	94.7	75.7	85.9	82.2	82.2	82.2	82.1	76.8	87.2	80.4	82.2	82.2	60.2	94.6	86.5	76.1	70.2	75.6	99.3	72.0
7e	78.9	70.0	93.4	68.6	85.3	78.9	78.9	78.8	78.6	72.8	84.6	76.8	78.9	78.9	55.0	93.3	83.5	72.5	62.5	71.0	99.0	70.1
7a	78.9	70.0	93.4	68.6	85.3	78.9	78.9	78.8	78.6	72.8	84.6	75.2	78.9	78.9	55.0	93.3	83.5	72.5	62.5	71.0	99.0	70.1
8	92.4	91.0	98.0	90.4	95.9	94.0	94.0	94.0	94.0	98.4	86.2	97.9	92.6	94.9	84.5	98.0	95.5	91.7	62.2	70.3	99.9	98.4

Economic – End of life stage (C1-4), (%)

	Baseline	RSLb_25	RSLb_100	ESL_half	ESL_double	Dm_50	Dm_300	Dm_1000	Dm_5000	Norway	SouthItaly	Stuttgart	OE_-20%	OE_+20%	EPI_0%	EPI_double	DR_0%	DR_3%	C1	C3	C5	C7
1b	0.3	0.4	0.1	0.4	0.2	0.3	0.3	0.3	0.3	0.1	0.5	0.2	0.3	0.3	0.4	0.2	0.3	0.2	0.7	0.7	0.0	0.1
1e	0.3	0.4	0.1	0.4	0.2	0.3	0.3	0.3	0.3	0.1	0.5	0.2	0.3	0.2	0.4	0.1	0.3	0.2	0.9	0.8	0.0	0.1
1a	0.2	0.3	0.1	0.3	0.1	0.2	0.2	0.2	0.2	0.1	0.4	0.2	0.3	0.2	0.3	0.1	0.2	0.2	0.7	0.7	0.0	0.1
2bl	0.3	0.6	0.2	0.6	0.3	0.3	0.3	0.3	0.3	0.1	0.4	0.1	0.3	0.3	0.4	0.2	0.3	0.3	1.7	0.6	0.0	0.2
2bh	0.2	0.4	0.1	0.4	0.2	0.2	0.2	0.2	0.2	0.1	0.3	0.1	0.2	0.2	0.3	0.1	0.2	0.2	1.1	0.4	0.0	0.1
2el	0.4	0.8	0.2	0.8	0.4	0.4	0.4	0.4	0.4	0.1	0.5	0.1	0.4	0.4	0.6	0.2	0.4	0.4	2.3	0.8	0.0	0.2
2eh	0.2	0.4	0.1	0.4	0.2	0.2	0.2	0.2	0.2	0.1	0.3	0.1	0.2	0.2	0.3	0.1	0.2	0.2	1.2	0.4	0.0	0.1
2al	0.6	1.1	0.3	1.1	0.6	0.5	0.5	0.5	0.5	0.2	0.7	0.2	0.6	0.5	0.8	0.3	0.5	0.5	3.0	1.1	0.0	0.3
2ah	0.3	0.5	0.1	0.5	0.3	0.2	0.2	0.2	0.2	0.1	0.3	0.1	0.3	0.2	0.3	0.1	0.2	0.2	1.4	0.5	0.0	0.1
3bl	0.5	0.7	0.2	0.6	0.4	0.5	0.5	0.5	0.5	0.2	0.7	0.2	0.6	0.5	0.7	0.3	0.6	0.4	1.2	1.1	0.0	0.2
3bh	0.3	0.4	0.1	0.3	0.2	0.3	0.3	0.3	0.3	0.1	0.4	0.1	0.3	0.3	0.4	0.2	0.3	0.2	0.7	0.6	0.0	0.1
3el	0.6	0.9	0.3	0.8	0.4	0.7	0.7	0.6	0.6	0.2	0.9	0.2	0.7	0.6	0.9	0.4	0.7	0.5	1.6	1.4	0.0	0.2
3eh	0.3	0.4	0.1	0.3	0.2	0.3	0.3	0.3	0.3	0.1	0.4	0.1	0.3	0.3	0.4	0.2	0.3	0.2	0.7	0.7	0.0	0.1
3al	0.8	1.1	0.4	0.9	0.6	0.8	0.8	0.8	0.8	0.3	1.0	0.3	0.9	0.7	1.1	0.5	0.9	0.7	1.8	1.6	0.0	0.2
3ah	0.3	0.4	0.1	0.3	0.2	0.3	0.3	0.3	0.3	0.1	0.4	0.1	0.3	0.3	0.4	0.2	0.3	0.2	0.7	0.6	0.0	0.1
4bl	1.1	1.4	0.3	1.2	0.6	0.6	0.6	0.6	0.6	0.1	0.9	0.1	0.7	0.5	1.0	0.3	0.6	0.6	4.0	1.8	0.0	0.2
4bh	0.7	0.8	0.2	0.7	0.4	0.4	0.4	0.4	0.4	0.1	0.6	0.1	0.4	0.3	0.6	0.2	0.4	0.4	2.7	1.3	0.0	0.1
4el	1.1	1.5	0.3	1.2	0.6	0.6	0.6	0.6	0.6	0.1	0.9	0.1	0.7	0.5	1.1	0.3	0.6	0.6	4.2	2.1	0.0	0.2
4eh	0.5	0.7	0.1	0.6	0.3	0.3	0.3	0.3	0.3	0.1	0.4	0.1	0.3	0.2	0.5	0.1	0.3	0.3	2.2	1.2	0.0	0.1
4al	1.4	1.8	0.3	1.5	0.8	0.7	0.8	0.7	0.7	0.2	1.0	0.2	0.9	0.7	1.3	0.3	0.7	0.7	4.9	2.4	0.0	0.3
4ah	0.5	0.7	0.1	0.6	0.3	0.3	0.3	0.3	0.3	0.1	0.4	0.1	0.4	0.3	0.5	0.1	0.3	0.3	2.1	1.2	0.0	0.1
5bl	0.4	0.8	0.2	0.7	0.4	0.4	0.4	0.4	0.4	0.1	0.6	0.1	0.5	0.3	0.7	0.2	0.4	0.4	1.7	1.4	0.0	0.1
5bh	0.1	0.2	0.0	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.0	0.1	0.1	0.6	0.5	0.0	0.0
5el	0.5	1.1	0.2	0.8	0.5	0.5	0.5	0.5	0.5	0.1	0.7	0.1	0.6	0.4	0.9	0.2	0.5	0.5	2.4	2.1	0.0	0.2
5eh	0.1	0.3	0.0	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.1	0.1	0.2	0.0	0.1	0.1	0.7	0.6	0.0	0.0
6b	0.6	2.1	0.1	0.6	0.6	0.6	0.6	0.6	0.6	0.8	0.4	0.7	0.6	0.6	1.5	0.2	0.6	0.6	0.5	2.3	0.0	1.7
6e	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.0
6a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.0
7e	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.1
7a	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.1
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0

7.5.6. Sections 5.6. Techno-economic assessment

Donostia (case study)

	NRPE reduction ($MJ/m^2 \cdot a$)	NRPE reduction (%)	NER	LC_PB (years)	IRR (%)
1b	4.74E+01	7%	6.21	46	0.42%
1e	9.32E+01	13%	12.14	33.5	2.33%
1a	1.20E+02	17%	20.88	37.5	1.62%
2bl	8.68E+01	12%	17.07	51.7	-0.34%
2bh	8.50E+01	12%	12.91	47.2	0.23%
2el	1.22E+02	17%	17.82	43	0.81%
2eh	1.19E+02	16%	12.02	41.7	1.00%
2al	1.37E+02	19%	12.64	45	0.54%
2ah	1.32E+02	18%	8.91	43	0.82%
3bl	9.15E+01	13%	141.28	54.5	-0.69%
3bh	8.98E+01	12%	38.40	52.3	-0.43%
3el	1.28E+02	18%	141.01	47	0.25%
3eh	1.25E+02	17%	29.29	45	0.51%
3al	1.47E+02	20%	109.38	53	-0.47%
3ah	1.42E+02	19%	23.66	50.2	-0.16%
4bl	5.90E+01	8%	37.14	27	3.65%
4bh	5.74E+01	8%	18.91	23	4.77%
4el	1.00E+02	14%	54.65	20	5.71%
4eh	9.72E+01	13%	20.37	15	7.84%
4al	1.21E+02	17%	54.58	22	5.02%
4ah	1.17E+02	16%	18.49	16	7.42%
5bl	5.49E+01	8%	231.84	19.2	5.92%
5bh	5.33E+01	7%	30.45	10.2	11.34%
5el	9.70E+01	13%	204.95	13.4	8.81%
5eh	9.39E+01	13%	26.92	7.1	15.81%
6b	2.60E+01	4%	47.85	11.5	10.80%
6e	3.81E+01	5%	47.85	12.8	10.00%
6a	4.85E+01	7%	47.85	12.6	10.00%
7e	9.83E+00	1%	6.21	19	6.60%
7a	3.28E+01	4%	6.21	19.1	6.60%
8	2.96E+02	41%	169.00	38	1.52%
1b-1e	4.58E+01	6%	20.00	7	16.20%
1e-1a	2.72E+01	4%	10.80	50.7	-0.18%
2bl-2el	3.52E+01	5%	19.99	5.5	20.15%
2el-2al	1.47E+01	2%	4.27	55.1	-0.73%
2bh-2eh	3.35E+01	5%	10.27	24.2	4.36%
2eh-2ah	1.33E+01	2%	3.25	50.1	-0.12%
3bl-3el	3.68E+01	5%	140.34	20.2	5.60%
3el-3al	1.88E+01	3%	43.57	75.5	-2.80%
3bh-3eh	3.51E+01	5%	18.43	20	5.71%
3eh-3ah	1.73E+01	2%	10.31	71.5	-2.40%
4bl-4el	4.13E+01	6%	174.79	6.2	17.90%
4el-4al	2.11E+01	3%	54.26	30.2	2.96%
4bh-4eh	3.98E+01	5%	22.96	3	20.00%
4eh-4ah	1.98E+01	3%	12.84	19.4	5.96%
5bl-5el	4.21E+01	6%	178.06	3.5	30.20%
5bh-5eh	4.05E+01	6%	23.39	2.5	40.80%
6b-6e	1.21E+01	2%	47.85	20.5	6.18%
6e-6a	1.04E+01	1%	47.85	13.5	8.70%
7e-7a	2.29E+01	3%	6.21	21	5.40%

Methodology application in the same building which is located in other climatic zones

Following the framework defined during this study, 2 new scenarios will be evaluated:

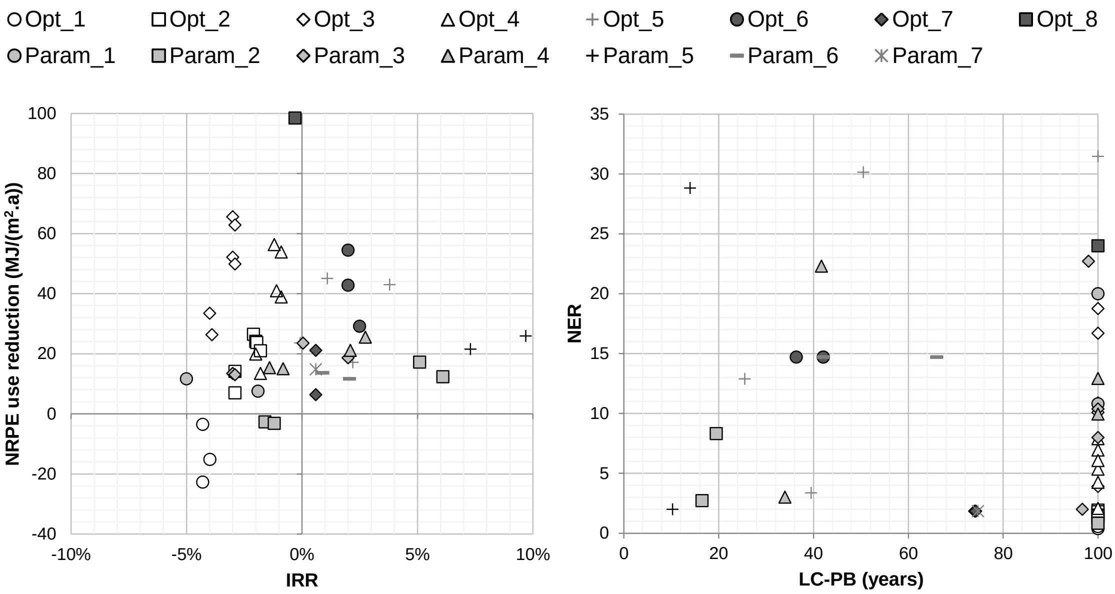
1. "**C1**". Combination where among other features, the building is located in a warm climate zone (Palermo), the ESLm values of the rehabilitation strategies are reduced and LCA hybrid data are applied
2. "**C6**". Combination where among other features, the building is located in a cold climate zone (Oslo), LCA process data are applied and the scenario of the variation of the energy price

**For more information about these combinations, see 5.5.1.*

Maintaining the same framework carried out during the initial assessment of the case studio, for both of these new scenarios also it is proposed a simplifying of the life cycle methodology boundary. After obtaining the necessary values during the 5.5.2 section, the different stages of the life cycle to be evaluated in these two new scenarios are shown.

	A1-3	**A4**	**A5**	**B2**	**B4**			**B6**	**C1-4**
					A1-3	**A4**	**A5**		
				"C1" scenario					
Environmental	X	Omitted	Omitted	-	X	Omitted	Omitted	X	Omitted
Economic	X	Omitted	X	X	X	Omitted	X	X	Omitted
				"C6" scenario					
Environmental	No	Omitted	Omitted	-	No	Omitted	Omitted	X	Omitted
Economic	No	Omitted	No	No	No	Omitted	No	X	Omitted

The results obtained in each of these two scenarios are quite different. On the one hand is the scenario "C1", which due to its low energy demand, or null energy price increases, the values of the different impact indicators reflect a high difficulty to justify the application of this type rehabilitation strategies. The NRPE use reduction is lower compared to the initial scenario (Donostia). Therefore, the NER values are also much lower, obtaining values close to 1 in strategies such as "1" and "2". Otherwise, on strategies where low amount of materials ("3-4-5") are applied, NER values increase, reaching values of up to 31 ("5bl"). However, when the technician begins to combine these environmental results with economic results, the strategy priority process changes dramatically. The results show that except for the strategy "5eh", which has an IRR value of 3.8%, in all other passive rehabilitation strategies ("1-2-3-4-5"), the value of IRR is almost null or negative. In these cases, the LC-PB overcomes the value of 100 years.

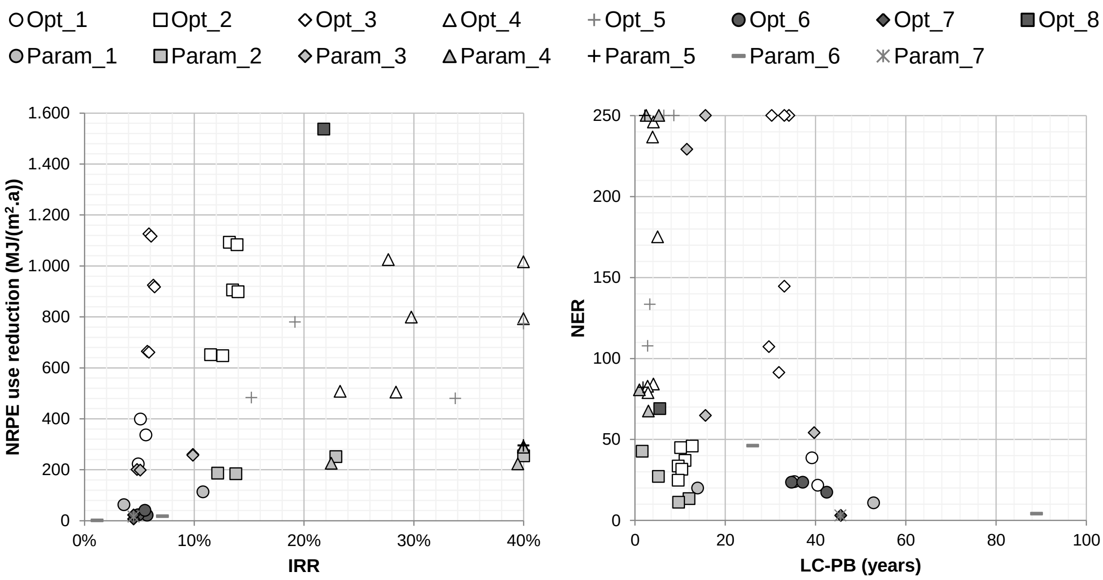


“C1” scenario

For renewable systems, the values obtained are better. The high potential of sunlight of Palermo enables to improve the economic performance of these strategies. However, in a scenario where the price of electricity is moderate and no increase in the price of electricity is proposed, it is difficult to increase the profitability of this kind of strategies. Regarding the biomass strategy ("8"), although environmentally his behaviour is right, getting to reduce up to 25% of NRPE use by the baseline during its life cycle, due to the reduced amount of thermal energy consumed during the use stage of the building and the high economic investment to be made during the different stages of the life cycle, its profitability (IRR) will be negative (-0.3%) and the value of LC-PB (114 years) exceeds the reference service life value of the refurbished building. Finally, the parameterized results show that although the NRPE use reduction and NER environmental indicators reflect positive values in both efficiency level changes, economic indicators show that in all rehabilitation strategies (except "5-6") their profitability values will be negatives and LC-PB values will exceed the 100 years (RSLb value proposed for this scenario). For example, in the "4eh-4ah" parametric assessment, the NER value is 9.9, while its IRR value will be -0.8%.

Otherwise, when the scenario to evaluate ("C6") is based in a building with high potential for reducing its energy demand and due to different economic-political reasons, the rising price of the energy increases, the results show good environmental and economic performance of many of the refurbishment strategies evaluated. The results show that there are rehabilitation strategies as "3al" which reduces the NRPE use of baseline up to 47%, while its profitability is 5.9% and the return on investment of 33 years. That is, in a scenario with these conditions where the reduction potential of

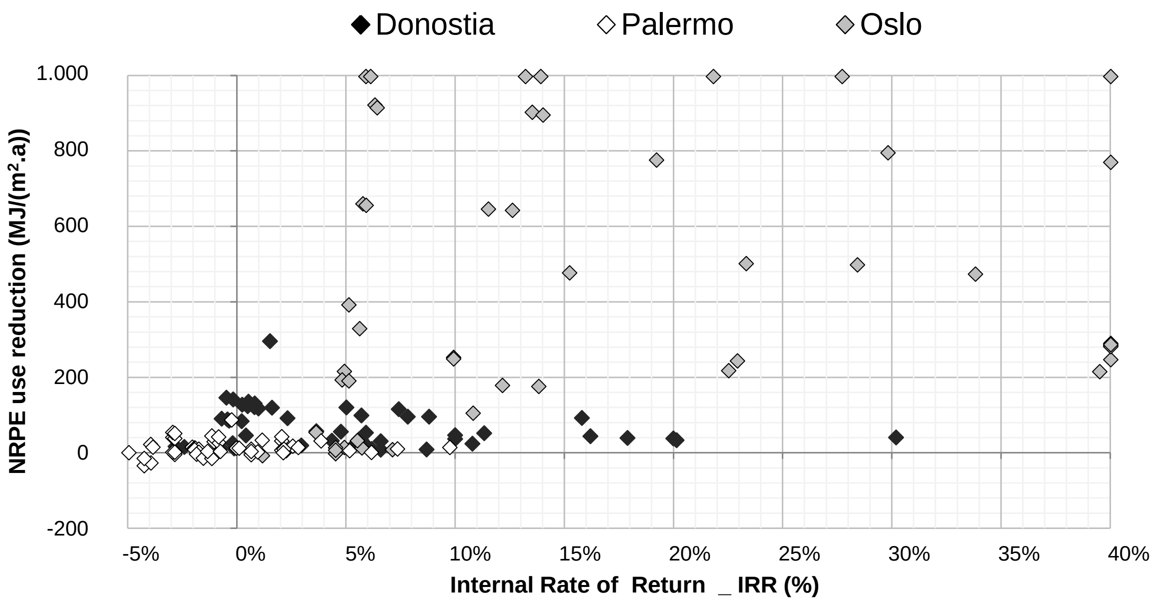
NRPE use is high, the profitability values range between 6 and 41% and LC-PB value is greatly reduced, reaching values up to only three years ("4eh"). These values confirm the results obtained during the section "optimization of the system boundary", showing that in scenarios like the "C6" the operational energy use is the stage that will mark the prioritization between different strategies.

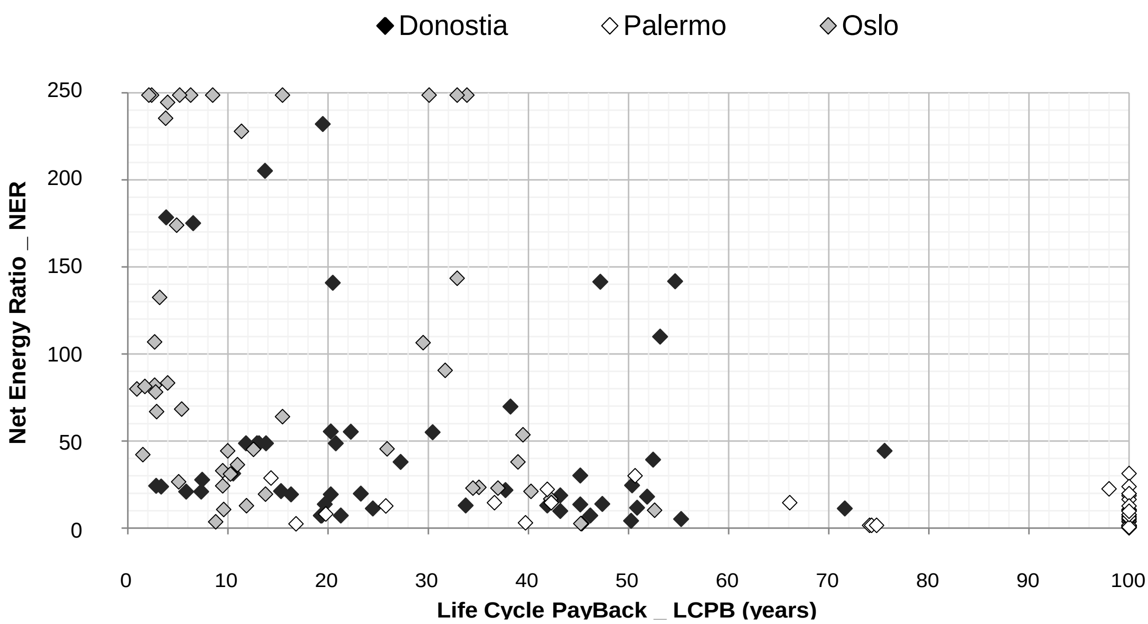


“C6” escenario. *In order to facilitate the reading of the results, this study has considered the following maximum limit values: IRR 40% and NER 250.*

After applying different strategies renewable systems ("6-7"), the price increase of the energy makes economic profitability of such a strategy will be positive. However, compared to other climates with more solar radiation, the value of LC-PB will be much higher, reaching values of up to 45 years ("7"). Regarding the biomass boiler, while greater the amount of energy consumed during the operational energy use stage of the building, greater will be the reduction of NRPE use and economic viability of such systems will be very positive (21.8%). Finally, the parameterized analysis shows that in scenarios similar to "C6" characteristics, the increment of the efficiency levels from basic to efficient has an adequate performance, increasing the reduction of NRPE use in about 10-12%, its profitability will be higher than 9.9%, while its LC-PB value is limited to 15 years. That is, it is verified that this level increment is necessary in such conditions. Regarding the increased level of efficiency between efficient and advanced, the results show that the reduction of NRPE use will be about 8-9%. Therefore, the different impact indicators (environmental and economic) show that in such conditions or scenarios can integrate passive strategies with very high efficiency levels (similar to the passive house standard), maintaining a positive environmental and economic performance throughout the lifecycle of the refurbished building.

Summary of results





Graphics values

"C1" (Palermo)

	NRPE reduction ($MJ/m^2 \cdot a$)	NRPE reduction (%)	NER	LC_PB (years)	IRR (%)
1b	-2.27E+01	-5%	0.4	>100	-4.3%
1e	-1.52E+01	-4%	0.5	>100	-4.0%
1a	-3.56E+00	-1%	0.9	>100	-4.3%
2bl	1.41E+01	3%	1.7	>100	-2.9%
2bh	6.96E+00	2%	1.2	>100	-2.9%
2el	2.64E+01	6%	1.9	>100	-2.1%
2eh	2.41E+01	6%	1.8	>100	-2.0%
2al	2.37E+01	6%	1.5	>100	-2.0%
2ah	2.10E+01	5%	1.4	>100	-1.8%
3bl	3.35E+01	8%	18.7	>100	-4.0%
3bh	2.63E+01	6%	3.9	>100	-3.9%
3el	5.21E+01	13%	20.0	>100	-3.0%
3eh	4.98E+01	12%	10.9	>100	-2.9%
3al	6.56E+01	16%	16.7	>100	-3.0%
3ah	6.28E+01	15%	10.1	>100	-2.9%
4bl	1.99E+01	5%	4.2	>100	-2.0%
4bh	1.34E+01	3%	2.1	>100	-1.8%
4el	4.10E+01	10%	6.9	>100	-1.1%
4eh	3.89E+01	9%	5.3	>100	-0.9%
4al	5.63E+01	14%	7.9	>100	-1.2%
4ah	5.39E+01	13%	6.1	>100	-0.9%
5bl	2.36E+01	6%	31.5	>100	-0.1%
5bh	1.71E+01	4%	3.4	39.5	2.2%
5el	4.51E+01	11%	30.1	50.5	1.1%
5eh	4.30E+01	10%	12.9	25.5	3.8%
6b	2.92E+01	7%	14.7	36.4	2.5%
6e	4.28E+01	10%	14.7	42.1	2.0%
6a	5.44E+01	13%	14.7	42.1	2.0%
7e	6.34E+00	2%	1.8	74	0.6%
7a	2.11E+01	5%	1.8	74.2	0.6%
8	9.84E+01	24%	125.0	>100	-0.3%
1b-1e	7.54E+00	2%	20.0	>100	-1.9%
1e-1a	1.16E+01	3%	10.8	>100	-5.5%
2bl-2el	1.23E+01	3%	2.7	16.5	6.1%
2el-2al	-2.74E+00	-1%	0.8	>100	-1.6%
2bh-2eh	1.72E+01	4%	8.3	19.5	5.1%
2eh-2ah	-3.17E+00	-1%	0.8	>100	-1.2%
3bl-3el	1.87E+01	5%	22.7	98	2.0%
3el-3al	1.34E+01	3%	10.4	>100	-3.0%
3bh-3eh	2.35E+01	6%	1.9	96.7	0.1%
3eh-3ah	1.30E+01	3%	8.0	>100	-2.9%
4bl-4el	2.11E+01	5%	28.3	41.7	2.1%
4el-4al	1.54E+01	4%	12.9	>100	-1.4%
4bh-4eh	2.55E+01	6%	3.1	34	2.8%
4eh-4ah	1.50E+01	4%	9.9	>100	-0.8%
5bl-5el	2.15E+01	5%	28.8	14	7.3%
5bh-5eh	2.59E+01	6%	4.2	10.3	9.7%
6b-6e	1.36E+01	3%	14.7	66	0.9%
6e-6a	1.17E+01	3%	14.7	42.1	2.1%
7e-7a	1.48E+01	4%	1.8	74.7	0.6%

"C6" (Oslo)

	NRPE reduction ($MJ/m^2 \cdot a$)	NRPE reduction (%)	NER	LC_PB (years)	IRR (%)
1b	2.23E+02	9%	21.70	40.5	4.90%
1e	3.36E+02	14%	23.97	35.3	5.60%
1a	3.99E+02	17%	38.63	39.2	5.10%
2bl	6.51E+02	27%	45.93	12.7	11.50%
2bh	6.48E+02	27%	37.04	11.1	12.60%
2el	9.06E+02	38%	44.98	10.1	13.50%
2eh	8.99E+02	37%	33.58	9.6	14.00%
2al	1.09E+03	45%	31.63	10.4	13.20%
2ah	1.08E+03	45%	24.80	9.6	13.90%
3bl	6.65E+02	28%	599.42	34.1	5.75%
3bh	6.61E+02	28%	144.52	33.1	5.90%
3el	9.25E+02	39%	565.14	30.3	6.30%
3eh	9.18E+02	38%	107.33	29.7	6.40%
3al	1.13E+03	47%	447.68	33.1	5.89%
3ah	1.12E+03	46%	91.33	31.9	6.10%
4bl	5.07E+02	21%	175.05	5	23.30%
4bh	5.04E+02	21%	84.20	4.1	28.40%
4el	7.99E+02	33%	236.65	3.9	29.80%
4eh	7.93E+02	33%	82.87	2.8	41.30%
4al	1.02E+03	43%	245.89	4.1	27.70%
4ah	1.02E+03	42%	78.94	2.9	40.80%
5bl	4.83E+02	20%	1016.25	8.6	15.22%
5bh	4.80E+02	20%	133.48	3.3	33.80%
5el	7.80E+02	32%	820.94	6.4	19.20%
5eh	7.74E+02	32%	107.83	2.8	40.50%
6b	2.18E+01	1%	23.52	34.7	5.70%
6e	2.33E+01	1%	17.36	42.5	4.90%
6a	4.08E+01	2%	23.52	37.2	5.50%
7e	6.78E+00	0%	3.05	45.6	4.50%
7a	2.26E+01	1%	3.05	45.6	4.50%
8	1.54E+03	68%	369.00	5.5	21.80%
1b-1e	1.13E+02	5%	20.00	13.9	10.80%
1e-1a	6.26E+01	3%	10.80	52.9	3.60%
2bl-2el	2.55E+02	11%	42.74	1.6	74.60%
2el-2al	1.87E+02	8%	13.39	12	12.14%
2bh-2eh	2.51E+02	10%	27.12	5.2	22.90%
2eh-2ah	1.84E+02	8%	11.27	9.7	13.80%
3bl-3el	2.60E+02	11%	493.11	15.6	9.90%
3el-3al	2.01E+02	8%	229.13	11.5	4.80%
3bh-3eh	2.57E+02	11%	64.77	15.6	9.90%
3eh-3ah	1.98E+02	8%	54.23	39.7	5.10%
4bl-4el	2.92E+02	12%	614.16	2.5	75.10%
4el-4al	2.25E+02	9%	285.37	5.3	22.50%
4bh-4eh	2.89E+02	12%	80.67	1	80.00%
4eh-4ah	2.23E+02	9%	67.55	3	39.50%
5bl-5el	2.97E+02	12%	625.64	2.2	49.80%
5bh-5eh	2.94E+02	12%	82.17	1.8	63.20%
6b-6e	1.43E+00	0%	4.15	89	1.15%
6e-6a	1.75E+01	1%	46.11	26.1	7.10%
7e-7a	1.58E+01	1%	3.05	45.5	4.50%

Uncertainty of data. Sensitivity evaluation

Non Renewable Primary Energy use reduction - NRPE (MJ/m^2 year).

	Current	RSLb_25	RSLb_100	ESL_half	ESL_double	Hybrid	OE-20%	OE_+20%	CF-20%	CF+20%
1b	47.4	47.4	47.4	38.3	52.0	20.2	36.1	58.7	36.1	58.7
1e	93.2	93.2	93.2	84.9	97.4	68.3	72.9	114.0	72.9	114.0
1a	120.5	120.0	120.0	114.0	124.0	103.0	95.2	146.0	95.2	146.0
2bl	86.8	81.4	86.8	81.4	86.8	70.9	68.3	105.0	68.3	105.0
2bh	85.0	77.9	85.0	77.9	85.0	63.7	66.6	103.0	66.6	103.0
2el	122.0	115.0	122.0	115.0	122.0	101.0	96.2	148.0	96.2	148.0
2eh	118.5	108.0	119.0	108.0	119.0	98.5	92.7	144.0	92.7	144.0
2al	136.7	125.0	137.0	125.0	137.0	102.0	107.0	166.0	107.0	166.0
2ah	131.8	115.0	132.0	115.0	132.0	99.7	102.0	161.0	102.0	161.0
3bl	91.5	91.2	91.6	91.1	91.7	89.9	73.1	110.0	73.1	110.0
3bh	89.8	87.8	89.9	87.6	90.0	82.8	71.3	108.0	71.3	108.0
3el	128.3	128.0	128.0	128.0	129.0	126.0	102.0	154.0	102.0	154.0
3eh	124.8	121.0	125.0	121.0	125.0	124.0	99.0	151.0	99.0	151.0
3al	147.1	146.0	147.0	146.0	147.0	144.0	117.0	177.0	117.0	177.0
3ah	142.2	136.0	142.0	136.0	142.0	141.0	112.0	172.0	112.0	172.0
4bl	59.0	58.7	59.0	57.4	59.7	54.5	46.9	71.1	46.9	71.1
4bh	57.4	55.6	57.4	54.2	58.1	48.0	45.3	69.5	45.3	69.5
4el	100.3	99.8	100.0	98.5	101.0	95.3	79.9	121.0	79.9	121.0
4eh	97.2	93.6	97.2	92.2	97.9	93.2	76.7	118.0	76.7	118.0
4al	121.4	121.0	121.0	119.0	122.0	116.0	96.7	146.0	96.7	146.0
4ah	117.0	112.0	117.0	110.0	118.0	113.0	92.3	142.0	92.3	142.0
5bl	54.9	54.7	54.9	54.7	54.9	54.4	43.9	65.9	43.9	65.9
5bh	53.3	51.5	53.3	51.5	53.3	47.9	42.3	64.4	42.3	64.4
5el	97.0	96.6	97.0	96.6	97.0	96.0	77.5	117.0	77.5	117.0
5eh	93.9	90.3	93.9	90.3	93.9	93.9	74.4	113.0	74.4	113.0
6b	26.0	26.0	26.0	25.4	26.2	24.4	26.0	26.0	20.7	31.3
6e	38.1	38.1	38.1	37.3	38.5	35.8	38.1	38.1	30.3	45.9
6a	48.5	48.5	48.5	47.4	49.0	45.5	48.5	48.5	38.6	58.4
7e	9.8	9.8	9.8	7.9	10.8	4.2	9.8	9.8	7.5	12.2
7a	32.8	32.8	32.8	26.5	35.9	14.1	32.8	32.8	25.0	40.6
8	296.2	296.0	296.0	296.0	296.0	296.0	237.0	356.0	237.0	356.0
1b-1e	45.8	45.8	45.8	46.5	45.4	48.1	36.8	54.8	36.8	54.8
1e-1a	27.2	27.2	27.2	29.6	26.1	34.3	22.3	32.2	22.3	32.2
2bl-2el	35.2	33.4	35.2	33.4	35.2	29.9	27.8	42.7	27.8	42.7
2el-2al	14.7	10.2	14.7	10.2	14.7	1.6	10.9	18.5	10.9	18.5
2bh-2eh	33.5	29.9	33.5	29.9	33.5	34.7	26.1	40.9	26.1	40.9
2eh-2ah	13.3	7.4	13.3	7.4	13.3	1.2	9.4	17.1	9.4	17.1
3bl-3el	36.8	36.6	36.8	36.6	36.8	36.2	29.4	44.2	29.4	44.2
3el-3al	18.8	18.3	18.8	18.3	18.8	17.8	14.9	22.6	14.9	22.6
3bh-3eh	35.1	33.1	35.1	33.1	35.1	41.1	27.7	42.5	27.7	42.5
3eh-3ah	17.3	15.5	17.3	15.5	17.3	17.3	13.5	21.2	13.5	21.2
4bl-4el	41.3	41.1	41.3	41.1	41.3	40.8	33.0	49.7	33.0	49.7
4el-4al	21.1	20.7	21.1	20.7	21.1	20.2	16.8	25.4	16.8	25.4
4bh-4eh	39.8	38.0	39.8	38.0	39.8	45.2	31.5	48.1	31.5	48.1
4eh-4ah	19.8	18.2	19.8	18.2	19.8	19.8	15.5	24.1	15.5	24.1
5bl-5el	42.1	41.9	42.1	41.9	42.1	41.6	33.6	50.6	33.6	50.6
5bh-5eh	40.5	38.7	40.5	38.7	40.5	46.0	32.1	49.0	32.1	49.0
6b-6e	12.1	12.1	12.1	11.9	12.2	11.4	12.1	12.1	9.6	14.6
6e-6a	10.4	10.4	10.4	10.2	10.5	9.8	10.4	10.4	8.3	12.5
7e-7a	22.9	22.9	22.9	18.5	25.1	9.9	22.9	22.9	17.5	28.4

Variation of the NRPE use reduction with respect to the original scenario, (%)

	Current	RSLb_25	RSLb_100	ESL_half	ESL_double	Hybrid	OE-20%	OE_+20%	CF-20%	CF+20%
1b	0.0%	-0.1%	-0.1%	-19.3%	9.6%	-57.4%	-23.9%	23.8%	-23.9%	23.8%
1e	0.0%	0.0%	0.0%	-8.9%	4.5%	-26.7%	-21.8%	22.3%	-21.8%	22.3%
1a	0.0%	-0.4%	-0.4%	-5.4%	2.9%	-14.5%	-21.0%	21.2%	-21.0%	21.2%
2bl	0.0%	-6.2%	0.0%	-6.2%	0.0%	-18.3%	-21.3%	21.0%	-21.3%	21.0%
2bh	0.0%	-8.4%	0.0%	-8.4%	0.0%	-25.1%	-21.7%	21.1%	-21.7%	21.1%
2el	0.0%	-5.7%	0.0%	-5.7%	0.0%	-17.2%	-21.2%	21.3%	-21.2%	21.3%
2eh	0.0%	-8.9%	0.4%	-8.9%	0.4%	-16.9%	-21.8%	21.5%	-21.8%	21.5%
2al	0.0%	-8.6%	0.2%	-8.6%	0.2%	-25.4%	-21.7%	21.4%	-21.7%	21.4%
2ah	0.0%	-12.7%	0.2%	-12.7%	0.2%	-24.3%	-22.6%	22.2%	-22.6%	22.2%
3bl	0.0%	-0.3%	0.1%	-0.5%	0.2%	-1.8%	-20.1%	20.2%	-20.1%	20.2%
3bh	0.0%	-2.2%	0.1%	-2.4%	0.3%	-7.8%	-20.6%	20.3%	-20.6%	20.3%
3el	0.0%	-0.3%	-0.3%	-0.3%	0.5%	-1.8%	-20.5%	20.0%	-20.5%	20.0%
3eh	0.0%	-3.1%	0.1%	-3.1%	0.1%	-0.7%	-20.7%	20.9%	-20.7%	20.9%
3al	0.0%	-0.7%	-0.1%	-0.7%	-0.1%	-2.1%	-20.5%	20.3%	-20.5%	20.3%
3ah	0.0%	-4.3%	-0.1%	-4.3%	-0.1%	-0.8%	-21.2%	21.0%	-21.2%	21.0%
4bl	0.0%	-0.5%	0.0%	-2.7%	1.2%	-7.6%	-20.5%	20.5%	-20.5%	20.5%
4bh	0.0%	-3.2%	0.0%	-5.6%	1.2%	-16.4%	-21.1%	21.1%	-21.1%	21.1%
4el	0.0%	-0.5%	-0.3%	-1.8%	0.7%	-5.0%	-20.4%	20.6%	-20.4%	20.6%
4eh	0.0%	-3.7%	0.0%	-5.1%	0.7%	-4.1%	-21.1%	21.4%	-21.1%	21.4%
4al	0.0%	-0.4%	-0.4%	-2.0%	0.5%	-4.5%	-20.4%	20.2%	-20.4%	20.2%
4ah	0.0%	-4.3%	0.0%	-6.0%	0.8%	-3.4%	-21.1%	21.3%	-21.1%	21.3%
5bl	0.0%	-0.4%	0.0%	-0.4%	0.0%	-0.9%	-20.1%	20.0%	-20.1%	20.0%
5bh	0.0%	-3.4%	-0.1%	-3.4%	-0.1%	-10.2%	-20.7%	20.7%	-20.7%	20.7%
5el	0.0%	-0.4%	0.0%	-0.4%	0.0%	-1.1%	-20.1%	20.6%	-20.1%	20.6%
5eh	0.0%	-3.8%	0.0%	-3.8%	0.0%	0.0%	-20.8%	20.4%	-20.8%	20.4%
6b	0.0%	0.1%	0.1%	-2.2%	0.9%	-6.0%	0.1%	0.1%	-20.3%	20.5%
6e	0.0%	0.0%	0.0%	-2.1%	1.1%	-6.0%	0.0%	0.0%	-20.4%	20.5%
6a	0.0%	0.1%	0.1%	-2.2%	1.1%	-6.1%	0.1%	0.1%	-20.4%	20.5%
7e	0.0%	0.0%	0.0%	-19.2%	9.8%	-57.0%	0.0%	0.0%	-23.8%	24.1%
7a	0.0%	0.1%	0.1%	-19.1%	9.5%	-57.0%	0.1%	0.1%	-23.7%	23.9%
8	0.0%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-20.0%	20.2%	-20.0%	20.2%
1b-1e	0.0%	0.0%	0.0%	1.6%	-0.9%	5.0%	-19.6%	19.7%	-19.6%	19.7%
1e-1a	0.0%	-0.2%	-0.2%	8.6%	-4.2%	25.9%	-18.2%	18.2%	-18.2%	18.2%
2bl-2el	0.0%	-5.2%	-0.1%	-5.2%	-0.1%	-15.1%	-21.1%	21.2%	-21.1%	21.2%
2el-2al	0.0%	-30.6%	0.0%	-30.6%	0.0%	-89.2%	-25.9%	25.8%	-25.9%	25.8%
2bh-2eh	0.0%	-10.7%	0.1%	-10.7%	0.1%	3.6%	-22.0%	22.2%	-22.0%	22.2%
2eh-2ah	0.0%	-44.5%	0.2%	-44.5%	0.2%	-91.3%	-28.9%	28.8%	-28.9%	28.8%
3bl-3el	0.0%	-0.6%	-0.1%	-0.6%	-0.1%	-1.7%	-20.2%	20.0%	-20.2%	20.0%
3el-3al	0.0%	-2.4%	0.3%	-2.4%	0.3%	-5.1%	-20.5%	20.5%	-20.5%	20.5%
3bh-3eh	0.0%	-5.6%	0.1%	-5.6%	0.1%	17.2%	-21.0%	21.2%	-21.0%	21.2%
3eh-3ah	0.0%	-10.6%	-0.2%	-10.6%	-0.2%	-0.2%	-22.1%	22.3%	-22.1%	22.3%
4bl-4el	0.0%	-0.6%	-0.1%	-0.6%	-0.1%	-1.3%	-20.2%	20.2%	-20.2%	20.2%
4el-4al	0.0%	-2.0%	-0.1%	-2.0%	-0.1%	-4.3%	-20.4%	20.3%	-20.4%	20.3%
4bh-4eh	0.0%	-4.4%	0.1%	-4.4%	0.1%	13.7%	-20.8%	21.0%	-20.8%	21.0%
4eh-4ah	0.0%	-8.3%	-0.2%	-8.3%	-0.2%	-0.2%	-21.9%	21.5%	-21.9%	21.5%
5bl-5el	0.0%	-0.5%	0.0%	-0.5%	0.0%	-1.2%	-20.2%	20.1%	-20.2%	20.1%
5bh-5eh	0.0%	-4.6%	-0.1%	-4.6%	-0.1%	13.5%	-20.8%	20.9%	-20.8%	20.9%
6b-6e	0.0%	-0.2%	-0.2%	-1.8%	0.7%	-5.9%	-0.2%	-0.2%	-20.5%	20.5%
6e-6a	0.0%	0.1%	0.1%	-1.8%	1.1%	-6.0%	0.1%	0.1%	-20.4%	20.3%
7e-7a	0.0%	-0.2%	-0.2%	-19.4%	9.4%	-56.9%	-0.2%	-0.2%	-23.7%	23.8%

Net Energy Ratio value – NER

	Current	RSLb_25	RSLb_100	ESL_half	ESL_double	Hybrid	OE-20%	OE_+20%	CF-20%	CF+20%
1b	6.2	6.2	6.2	3.1	12.4	1.6	5.0	7.5	5.0	7.5
1e	12.1	12.1	12.1	6.1	24.3	3.1	9.7	14.6	9.7	14.6
1a	20.9	20.9	20.9	10.4	41.8	5.3	16.7	25.1	16.7	25.1
2bl	17.1	8.5	17.1	8.5	17.1	4.3	13.7	20.5	13.7	20.5
2bh	12.9	6.5	12.9	6.5	12.9	3.2	10.3	15.5	10.3	15.5
2el	17.8	8.9	17.8	8.9	17.8	4.5	14.3	21.4	14.3	21.4
2eh	12.0	6.0	12.0	6.0	12.0	4.2	9.6	14.4	9.6	14.4
2al	12.6	6.3	12.6	6.3	12.6	3.2	10.1	15.2	10.1	15.2
2ah	8.9	4.5	8.9	4.5	8.9	3.0	7.1	10.7	7.1	10.7
3bl	141.3	100.5	166.0	83.0	201.1	41.4	113.0	169.5	113.0	169.5
3bh	38.4	20.9	40.0	20.0	41.8	9.8	30.7	46.1	30.7	46.1
3el	141.0	89.4	157.7	78.9	178.9	41.9	112.8	169.2	112.8	169.2
3eh	29.3	15.3	30.0	15.0	30.6	24.0	23.4	35.2	23.4	35.2
3al	109.4	63.8	117.8	58.9	127.6	32.8	87.5	131.3	87.5	131.3
3ah	23.7	12.2	24.0	12.0	24.4	20.5	18.9	28.4	18.9	28.4
4bl	37.1	32.4	37.1	18.6	64.8	9.9	29.7	44.6	29.7	44.6
4bh	18.9	12.1	18.9	9.5	24.2	4.8	15.1	22.7	15.1	22.7
4el	54.6	43.6	54.7	27.3	87.1	14.8	43.7	65.6	43.7	65.6
4eh	20.4	11.8	20.4	10.2	23.7	11.4	16.3	24.5	16.3	24.5
4al	54.6	39.4	54.6	27.3	78.8	15.1	43.7	65.5	43.7	65.5
4ah	18.5	10.3	18.5	9.2	20.6	11.6	14.8	22.2	14.8	22.2
5bl	231.8	115.9	231.8	115.9	231.8	71.3	185.5	278.2	185.5	278.2
5bh	30.5	15.2	30.5	15.2	30.5	7.6	24.4	36.5	24.4	36.5
5el	205.0	102.5	205.0	102.5	205.0	63.0	164.0	245.9	164.0	245.9
5eh	26.9	13.5	26.9	13.5	26.9	26.9	21.5	32.3	21.5	32.3
6b	47.8	47.9	47.9	23.9	95.7	12.5	47.9	47.9	38.3	57.4
6e	47.8	47.9	47.9	23.9	95.7	12.5	47.9	47.9	38.3	57.4
6a	47.8	47.9	47.9	23.9	95.7	12.5	47.9	47.9	38.3	57.4
7e	6.2	6.2	6.2	3.1	12.4	1.6	6.2	6.2	5.0	7.5
7a	6.2	6.2	6.2	3.1	12.4	1.6	6.2	6.2	5.0	7.5
8	69.0	69.0	69.0	69.0	69.0	69.0	69.0	69.0	69.0	69.0
1b-1e	20.0	10.1	20.2	10.1	32.3	5.1	13.3	23.7	16.1	23.1
1e-1a	10.8	5.4	10.8	5.4	15.1	2.3	10.8	10.8	7.6	13.5
2bl-2el	20.0	10.0	20.0	10.0	20.0	5.2	16.0	24.0	16.0	24.0
2el-2al	4.3	2.1	4.3	2.1	4.3	1.1	3.4	5.1	3.4	5.1
2bh-2eh	10.3	5.1	10.3	5.1	10.3	15.8	8.2	12.3	8.2	12.3
2eh-2ah	3.2	1.6	3.3	1.6	3.3	1.1	2.6	3.9	2.6	3.9
3bl-3el	140.3	70.2	140.3	70.2	140.3	43.2	112.3	168.4	112.3	168.4
3el-3al	43.6	21.8	43.6	21.8	43.6	13.4	34.9	52.3	34.9	52.3
3bh-3eh	18.4	9.2	18.4	9.2	18.4	3.0	14.8	22.1	14.8	22.1
3eh-3ah	10.3	5.2	10.3	5.2	10.3	10.3	8.3	12.4	8.3	12.4
4bl-4el	174.8	87.4	174.8	87.4	174.8	53.8	139.8	209.8	139.8	209.8
4el-4al	54.3	27.1	54.3	27.1	54.3	16.7	43.4	65.1	43.4	65.1
4bh-4eh	23.0	11.5	23.0	11.5	23.0	3.0	18.4	27.6	18.4	27.6
4eh-4ah	12.8	6.4	12.8	6.4	12.8	12.8	10.3	15.4	10.3	15.4
5bl-5el	178.1	89.0	178.1	89.0	178.1	54.8	142.5	213.7	142.5	213.7
5bh-5eh	23.4	11.7	23.4	11.7	23.4	3.0	18.7	28.1	18.7	28.1
6b-6e	47.9	47.9	47.9	23.9	95.7	12.5	47.9	47.9	38.3	57.4
6e-6a	47.8	47.9	47.9	23.9	95.7	12.5	47.9	47.9	38.3	57.4
7e-7a	6.2	6.2	6.2	3.1	12.4	1.6	6.2	6.2	5.0	7.5

Variation of the NER value with respect to the original scenario, (%)

	Current	RSLb_25	RSLb_100	ESL_half	ESL_double	Hybrid	OE-20%	OE_+20%	CF-20%	CF+20%
1b	0.0%	0.0%	0.0%	-50.1%	99.8%	-74.9%	-20.0%	20.0%	-20.0%	20.0%
1e	0.0%	0.0%	0.0%	-50.0%	100.0%	-74.9%	-20.0%	20.0%	-20.0%	20.0%
1a	0.0%	0.0%	0.0%	-50.0%	100.0%	-74.7%	-20.0%	20.0%	-20.0%	20.0%
2bl	0.0%	-50.0%	0.0%	-50.0%	0.0%	-74.6%	-20.0%	20.0%	-20.0%	20.0%
2bh	0.0%	-50.0%	0.0%	-50.0%	0.0%	-74.9%	-20.0%	20.0%	-20.0%	20.0%
2el	0.0%	-50.0%	0.0%	-50.0%	0.0%	-74.5%	-20.0%	20.0%	-20.0%	20.0%
2eh	0.0%	-50.0%	0.0%	-50.0%	0.0%	-65.1%	-20.0%	20.0%	-20.0%	20.0%
2al	0.0%	-50.0%	0.0%	-50.0%	0.0%	-74.5%	-20.0%	20.0%	-20.0%	20.0%
2ah	0.0%	-50.1%	0.0%	-50.1%	0.0%	-65.9%	-20.0%	20.0%	-20.0%	20.0%
3bl	0.0%	-28.8%	17.5%	-41.3%	42.3%	-70.7%	-20.0%	20.0%	-20.0%	20.0%
3bh	0.0%	-45.6%	4.2%	-47.9%	8.8%	-74.5%	-20.0%	20.0%	-20.0%	20.0%
3el	0.0%	-36.6%	11.8%	-44.1%	26.9%	-70.3%	-20.0%	20.0%	-20.0%	20.0%
3eh	0.0%	-47.7%	2.2%	-48.9%	4.6%	-18.2%	-20.0%	20.0%	-20.0%	20.0%
3al	0.0%	-41.7%	7.7%	-46.2%	16.7%	-70.0%	-20.0%	20.0%	-20.0%	20.0%
3ah	0.0%	-48.4%	1.6%	-49.2%	3.2%	-13.5%	-20.0%	20.0%	-20.0%	20.0%
4bl	0.0%	-12.7%	0.0%	-50.0%	74.6%	-73.3%	-20.0%	20.0%	-20.0%	20.0%
4bh	0.0%	-36.1%	0.0%	-50.0%	27.8%	-74.5%	-20.0%	20.0%	-20.0%	20.0%
4el	0.0%	-20.3%	0.0%	-50.0%	59.4%	-72.9%	-20.0%	20.0%	-20.0%	20.0%
4eh	0.0%	-41.9%	0.0%	-50.0%	16.1%	-44.0%	-20.0%	20.0%	-20.0%	20.0%
4al	0.0%	-27.8%	0.0%	-50.0%	44.4%	-72.3%	-20.0%	20.0%	-20.0%	20.0%
4ah	0.0%	-44.2%	0.0%	-50.0%	11.6%	-37.1%	-20.0%	20.0%	-20.0%	20.0%
5bl	0.0%	-50.0%	0.0%	-50.0%	0.0%	-69.3%	-20.0%	20.0%	-20.0%	20.0%
5bh	0.0%	-50.0%	0.0%	-50.0%	0.0%	-74.9%	-20.0%	20.0%	-20.0%	20.0%
5el	0.0%	-50.0%	0.0%	-50.0%	0.0%	-69.3%	-20.0%	20.0%	-20.0%	20.0%
5eh	0.0%	-50.0%	0.0%	-50.0%	0.0%	0.0%	-20.0%	20.0%	-20.0%	20.0%
6b	0.0%	0.0%	0.0%	-50.0%	100.0%	-74.0%	0.0%	0.0%	-20.0%	20.0%
6e	0.0%	0.0%	0.0%	-50.0%	100.0%	-74.0%	0.0%	0.0%	-20.0%	20.0%
6a	0.0%	0.0%	0.0%	-50.0%	100.0%	-74.0%	0.0%	0.0%	-20.0%	20.0%
7e	0.0%	0.0%	0.0%	-50.1%	100.1%	-74.7%	0.0%	0.0%	-19.9%	20.0%
7a	0.0%	0.0%	0.0%	-50.1%	100.1%	-74.7%	0.0%	0.0%	-19.9%	20.0%
8	0.0%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-20.0%	20.2%	-10.0%	10.2%
1b-1e	0.0%	-49.5%	1.0%	-49.5%	61.5%	-74.5%	-33.5%	18.5%	-19.5%	15.5%
1e-1a	0.0%	-50.0%	0.0%	-50.0%	39.8%	-78.5%	0.0%	0.0%	-29.6%	25.0%
2bl-2el	0.0%	-50.0%	0.0%	-50.0%	0.0%	-74.2%	-20.0%	20.0%	-20.0%	20.0%
2el-2al	0.0%	-49.9%	-0.1%	-49.9%	-0.1%	-74.5%	-19.9%	20.1%	-19.9%	20.1%
2bh-2eh	0.0%	-50.0%	0.0%	-50.0%	0.0%	53.8%	-20.0%	20.0%	-20.0%	20.0%
2eh-2ah	0.0%	-50.1%	0.1%	-50.1%	0.1%	-67.3%	-19.9%	19.8%	-19.9%	19.8%
3bl-3el	0.0%	-50.0%	0.0%	-50.0%	0.0%	-69.2%	-20.0%	20.0%	-20.0%	20.0%
3el-3al	0.0%	-50.0%	0.0%	-50.0%	0.0%	-69.2%	-20.0%	20.0%	-20.0%	20.0%
3bh-3eh	0.0%	-50.0%	0.0%	-50.0%	0.0%	-83.7%	-20.0%	20.0%	-20.0%	20.0%
3eh-3ah	0.0%	-50.0%	0.0%	-50.0%	0.0%	0.0%	-20.0%	20.0%	-20.0%	20.0%
4bl-4el	0.0%	-50.0%	0.0%	-50.0%	0.0%	-69.2%	-20.0%	20.0%	-20.0%	20.0%
4el-4al	0.0%	-50.0%	0.0%	-50.0%	0.0%	-69.2%	-20.0%	20.0%	-20.0%	20.0%
4bh-4eh	0.0%	-50.0%	0.0%	-50.0%	0.0%	-86.9%	-20.0%	20.0%	-20.0%	20.0%
4eh-4ah	0.0%	-50.0%	0.0%	-50.0%	0.0%	0.0%	-20.0%	20.0%	-20.0%	20.0%
5bl-5el	0.0%	-50.0%	0.0%	-50.0%	0.0%	-69.3%	-20.0%	20.0%	-20.0%	20.0%
5bh-5eh	0.0%	-50.0%	0.0%	-50.0%	0.0%	-87.2%	-20.0%	20.0%	-20.0%	20.0%
6b-6e	0.0%	0.0%	0.0%	-50.0%	100.0%	-74.0%	0.0%	0.0%	-20.0%	20.0%
6e-6a	0.0%	0.0%	0.0%	-50.0%	100.0%	-74.0%	0.0%	0.0%	-20.0%	20.0%
7e-7a	0.0%	0.0%	0.0%	-50.1%	100.1%	-74.7%	0.0%	0.0%	-19.9%	20.0%

Internal Rate of Return value – IRR (%)

	Current	RSLb_25	RSLb_100	ESL_half	ESL_double	OE-20%	OE_+20%	EPI_0	EPI_double	DR_0%	DR_3%
1b	0.4%	-0.6%	-4.6%	-4.6%	4.0%	-0.3%	1.1%	-2.6%	3.4%	0.4%	0.4%
1e	2.3%	3.5%	-3.3%	-3.3%	6.8%	1.5%	3.1%	-0.7%	5.3%	2.4%	2.3%
1a	1.6%	1.9%	-3.8%	-3.8%	5.7%	0.8%	2.3%	-1.4%	4.6%	1.6%	1.6%
2bl	0.7%	-6.1%	-1.1%	-1.1%	0.7%	-0.1%	1.4%	-2.8%	3.9%	0.5%	0.5%
2bh	0.9%	-5.7%	-0.9%	-0.9%	0.9%	0.1%	1.6%	-2.6%	4.1%	1.0%	0.7%
2el	2.0%	-4.0%	0.0%	0.0%	2.0%	1.1%	2.7%	-1.4%	5.1%	2.1%	1.8%
2eh	2.2%	-3.6%	0.2%	0.2%	2.2%	1.3%	2.9%	-1.2%	5.3%	2.3%	2.0%
2al	1.7%	-4.4%	-0.3%	-0.3%	1.7%	0.8%	2.4%	-1.6%	4.7%	1.8%	1.6%
2ah	2.0%	-3.9%	0.0%	0.0%	2.0%	1.1%	2.8%	-1.3%	5.1%	2.1%	1.9%
3bl	-0.7%	-2.9%	-3.7%	-3.7%	2.7%	-1.5%	0.0%	-4.5%	2.5%	-0.5%	-1.0%
3bh	-0.4%	-2.3%	-3.4%	-3.4%	3.0%	-1.2%	0.3%	-4.3%	2.8%	-0.3%	-0.7%
3el	0.3%	-0.8%	-2.9%	-2.9%	4.0%	-0.6%	0.9%	-3.3%	3.4%	0.4%	0.0%
3eh	0.5%	-0.3%	-2.7%	-2.7%	4.3%	-0.3%	1.2%	-3.0%	3.6%	0.6%	0.3%
3al	-0.5%	-2.3%	-3.5%	-3.5%	3.0%	-1.2%	0.2%	-3.9%	2.6%	-0.4%	-0.6%
3ah	-0.2%	-1.7%	-3.2%	-3.2%	3.4%	-0.9%	0.5%	-3.6%	2.9%	-0.1%	-0.3%
4bl	2.6%	1.0%	-0.3%	-0.3%	2.6%	1.7%	3.4%	-0.6%	5.7%	2.6%	2.5%
4bh	3.0%	1.8%	0.0%	0.0%	3.0%	2.1%	3.8%	-0.2%	5.8%	3.1%	2.9%
4el	4.4%	4.6%	1.1%	1.1%	4.4%	3.4%	5.3%	1.2%	6.1%	4.4%	4.4%
4eh	5.0%	5.7%	1.5%	1.5%	5.0%	3.9%	6.0%	1.8%	7.5%	5.0%	4.9%
4al	3.7%	3.6%	0.5%	0.5%	3.7%	2.8%	4.6%	0.6%	8.1%	3.7%	3.7%
4ah	4.6%	5.1%	1.1%	1.1%	4.6%	3.5%	5.5%	1.4%	7.7%	4.6%	4.5%
5bl	5.9%	2.3%	3.3%	3.3%	5.9%	4.8%	7.0%	2.8%	9.0%	5.9%	5.9%
5bh	11.3%	9.6%	8.5%	8.5%	11.3%	9.5%	13.1%	8.1%	14.6%	11.3%	11.3%
5el	8.8%	6.3%	5.4%	5.4%	8.8%	7.3%	10.2%	5.7%	12.0%	8.8%	8.8%
5eh	15.8%	14.9%	11.3%	11.3%	15.8%	13.2%	18.4%	12.4%	19.2%	15.8%	15.8%
6b	9.7%	18.5%	1.1%	1.1%	19.1%	9.7%	9.7%	6.3%	13.0%	9.8%	9.6%
6e	8.7%	17.6%	0.6%	0.6%	18.3%	8.7%	8.7%	4.3%	12.5%	9.1%	8.3%
6a	8.7%	17.6%	0.6%	0.6%	18.3%	8.7%	8.7%	4.3%	12.5%	9.1%	8.3%
7e	5.4%	10.0%	-1.2%	-1.2%	11.7%	5.4%	5.4%	1.4%	8.9%	5.7%	5.1%
7a	5.4%	10.0%	-1.2%	-1.2%	11.7%	5.4%	5.4%	1.4%	8.9%	5.7%	506.0%
8	15.6%	35.2%	3.1%	11.0%	18.0%	12.9%	18.3%	12.0%	19.1%	15.7%	15.5%
1b-1e	16.2%	36.4%	3.3%	3.3%	36.5%	13.4%	18.8%	12.7%	19.5%	16.1%	16.1%
1e-1a	-0.2%	-1.8%	-5.1%	-5.1%	3.3%	-0.9%	0.4%	-3.1%	2.7%	-0.2%	-0.2%
2bl-2el	20.2%	26.2%	14.9%	14.9%	26.3%	21.7%	31.1%	18.7%	30.1%	26.4%	26.4%
2el-2al	0.4%	-6.4%	-1.6%	-1.6%	0.4%	-0.3%	1.1%	-2.5%	3.4%	0.4%	0.4%
2bh-2eh	23.2%	22.9%	13.0%	13.0%	23.2%	19.1%	27.2%	19.6%	26.8%	23.2%	23.2%
2eh-2ah	1.1%	-5.3%	-1.0%	-1.0%	1.1%	0.4%	1.8%	-1.8%	4.1%	1.1%	1.1%
3bl-3el	5.6%	11.1%	1.2%	1.2%	12.5%	4.5%	6.6%	2.5%	8.7%	5.6%	5.6%
3el-3al	-2.8%	-6.9%	-5.5%	-5.5%	0.1%	-3.4%	-2.3%	-5.6%	0.0%	-2.8%	-2.8%
3bh-3eh	5.7%	11.6%	1.2%	1.2%	13.0%	4.6%	6.7%	2.6%	8.8%	5.7%	5.7%
3eh-3ah	-2.4%	-6.1%	-5.2%	-5.2%	0.6%	-3.0%	-1.9%	-5.3%	0.4%	-2.4%	-2.4%
4bl-4el	13.7%	23.6%	7.0%	7.0%	13.7%	11.5%	15.9%	10.4%	17.0%	13.7%	13.7%
4el-4al	1.7%	0.5%	-1.3%	-1.3%	1.7%	0.9%	2.4%	-1.3%	4.7%	1.7%	1.7%
4bh-4eh	17.2%	31.3%	8.3%	8.3%	17.2%	14.3%	20.0%	13.8%	20.6%	17.2%	17.2%
4eh-4ah	3.1%	3.0%	-0.2%	-0.2%	3.1%	2.2%	3.9%	0.1%	6.1%	3.1%	3.1%
5bl-5el	30.2%	30.1%	17.2%	17.2%	30.2%	24.8%	35.7%	26.4%	34.0%	30.2%	30.2%
5bh-5eh	40.8%	40.8%	22.0%	22.0%	40.9%	33.3%	48.4%	36.8%	45.0%	40.8%	40.8%
6b-6e	6.2%	14.1%	-0.7%	-0.7%	15.4%	6.2%	6.2%	3.2%	11.2%	7.3%	3.7%
6e-6a	8.7%	17.6%	0.6%	0.6%	18.3%	8.7%	8.7%	4.3%	12.5%	9.1%	8.3%
7e-7a	5.4%	10.0%	-1.2%	-1.2%	11.7%	5.4%	5.4%	1.4%	8.9%	5.7%	5.1%

Variation of the IRR value with respect to the original scenario, (%)

	Current	RSLb_25	RSLb_100	ESL_half	ESL_double	OE-20%	OE_+20%	EPI_0	EPI_double	DR_0%	DR_3%
1b	0.0%	-250%	-1205%	-1205%	859.5%	-179%	150.0%	-721.4%	704.8%	4.8%	-9.5%
1e	0.0%	48.9%	-239.6%	-239.6%	190.1%	-36.5%	31.8%	-130.5%	129.2%	0.9%	-0.9%
1a	0.0%	19.8%	-332.0%	-332.0%	252.5%	-49.4%	43.2%	-185.2%	184.0%	0.6%	-1.2%
2bl	0.0%	-941%	-253.0%	-253.0%	0.0%	-116%	97.2%	-493.1%	434.7%	-31%	-30.6%
2bh	0.0%	-722%	-197.9%	-197.9%	0.0%	-92.4%	77.2%	-387.0%	341.3%	13.0%	-23.9%
2el	0.0%	-302%	-101.1%	-101.1%	0.0%	-44.9%	38.8%	-172.4%	159.2%	5.1%	-7.7%
2eh	0.0%	-267%	-92.0%	-92.0%	0.0%	-41.5%	35.5%	-156.2%	143.8%	4.1%	-6.9%
2al	0.0%	-358%	-117.8%	-117.8%	0.0%	-50.6%	42.9%	-195.3%	178.2%	4.7%	-7.6%
2ah	0.0%	-295%	-100.9%	-100.9%	0.0%	-44.0%	37.5%	-166.5%	155.0%	4.0%	-6.5%
3bl	0.0%	317.4%	430.1%	430.1%	-491.3%	114.5%	-95.7%	555.1%	-459.4%	-25%	44.9%
3bh	0.0%	441.5%	700.1%	700.1%	-807.0%	186.0%	-158.%	893.0%	-739.5%	-42%	72.1%
3el	0.0%	-437%	-1249%	-1249%	1480.0%	-324%	272.0%	-1412%	1248.0%	48.0%	-84.0%
3eh	0.0%	-154%	-623.0%	-623%	745.1%	-160%	135.3%	-692.2%	613.7%	23.5%	-41.2%
3al	0.0%	392.0%	639.3%	639.3%	-738.3%	159.6%	-136%	723.4%	-653.2%	-23%	36.2%
3ah	0.0%	935.4%	1919.7%	1919.7%	-2237%	481.3%	-406%	2137.5%	-1918%	-62%	112.5%
4bl	0.0%	-60.6%	-111.6%	-111.6%	0.0%	-34.5%	30.2%	-124.4%	119.4%	2.3%	-3.1%
4bh	0.0%	-40.8%	-98.9%	-98.9%	0.0%	-30.9%	26.9%	-107.3%	92.7%	1.7%	-3.0%
4el	0.0%	3.9%	-74.9%	-74.9%	0.0%	-23.4%	20.7%	-72.0%	38.6%	0.7%	-1.1%
4eh	0.0%	13.4%	-69.7%	-69.7%	0.0%	-21.6%	19.2%	-63.9%	50.3%	0.6%	-1.2%
4al	0.0%	-3.1%	-86.7%	-86.7%	0.0%	-25.8%	22.8%	-84.1%	117.7%	0.5%	-1.1%
4ah	0.0%	11.8%	-75.4%	-75.4%	0.0%	-22.6%	20.4%	-69.2%	68.1%	0.7%	-0.9%
5bl	0.0%	-61.8%	-44.1%	-44.1%	0.0%	-19.3%	17.6%	-52.0%	52.2%	0.0%	0.0%
5bh	0.0%	-15.2%	-25.3%	-25.3%	0.0%	-16.4%	15.8%	-28.6%	28.6%	0.0%	0.0%
5el	0.0%	-28.1%	-38.4%	-38.4%	0.0%	-16.8%	15.9%	-35.9%	36.0%	0.0%	0.0%
5eh	0.0%	-5.6%	-28.7%	-28.7%	-0.1%	-16.6%	16.4%	-21.3%	21.3%	0.0%	0.0%
6b	0.0%	90.5%	-88.4%	-88.4%	96.9%	0.0%	0.0%	-34.9%	33.9%	0.5%	-0.8%
6e	0.0%	102.1%	-93.0%	-93.0%	109.6%	0.0%	0.0%	-50.5%	42.6%	3.7%	-5.4%
6a	0.0%	102.1%	-93.0%	-93.0%	109.6%	0.0%	0.0%	-50.5%	42.6%	3.7%	-5.4%
7e	0.0%	84.6%	-122.0%	-122.0%	116.2%	0.0%	0.0%	-74.9%	63.8%	4.2%	-6.6%
7a	0.0%	84.6%	-122.0%	-122.0%	116.2%	0.0%	0.0%	-74.9%	63.8%	4.2%	928.8%
8	0.0%	125.7%	-79.9%	-29.5%	15.4%	-17.4%	17.1%	-22.9%	22.4%	0.4%	-0.6%
1b-1e	0.0%	124.8%	-79.4%	-79.4%	125.0%	-17.1%	15.9%	-21.4%	20.4%	-0.5%	-0.5%
1e-1a	0.0%	912.7%	2738.9%	2738.9%	-190%	388.9%	-333%	1616.7%	-161%	0.0%	0.0%
2bl-2el	0.0%	30.1%	-26.1%	-26.1%	30.5%	7.7%	54.1%	-7.2%	49.2%	31.0%	31.0%
2el-2al	0.0%	-155%	-460.8%	-460.8%	0.0%	-165%	140.9%	-66%	66%	0.0%	0.0%
2bh-2eh	0.0%	-1.3%	-43.7%	-43.7%	0.0%	-17.4%	17.4%	-15.5%	15.5%	0.0%	0.0%
2eh-2ah	0.0%	-575%	-187.7%	-187.7%	0.0%	-68.5%	59.5%	-264.9%	265.8%	0.0%	0.0%
3bl-3el	0.0%	98.2%	-78.4%	-78.4%	123.9%	-20.0%	17.7%	-55.2%	54.8%	-0.2%	-0.2%
3el-3al	0.0%	146.3%	96.8%	96.8%	-105.0%	21.4%	-18.2%	101.1%	-101.4%	0.0%	0.0%
3bh-3eh	0.0%	102.9%	-78.9%	-78.9%	126.8%	-19.6%	17.9%	-53.9%	53.9%	0.0%	0.0%
3eh-3ah	0.0%	154.8%	116.5%	116.5%	-125.4%	26.7%	-20.8%	119.2%	-117.5%	0.8%	0.8%
4bl-4el	0.0%	72.2%	-49.3%	-49.3%	0.0%	-16.4%	16.1%	-24.1%	24.1%	0.0%	0.0%
4el-4al	0.0%	-71.4%	-175.2%	-175.2%	0.0%	-46.8%	40.9%	-173.1%	173.7%	0.0%	0.0%
4bh-4eh	0.0%	82.1%	-51.8%	-51.8%	0.0%	-16.8%	16.6%	-19.9%	19.9%	0.0%	0.0%
4eh-4ah	0.0%	-3.1%	-106.7%	-106.7%	0.0%	-28.9%	25.3%	-97.4%	97.4%	0.0%	0.0%
5bl-5el	0.0%	-0.3%	-43.1%	-43.1%	0.0%	-18.0%	18.0%	-12.6%	12.6%	0.0%	0.0%
5bh-5eh	0.0%	0.1%	-46.2%	-46.2%	0.1%	-18.4%	18.7%	-9.9%	10.2%	0.0%	0.0%
6b-6e	0.0%	128.6%	-111.6%	-111.6%	149.5%	0.0%	0.0%	-48.2%	80.6%	18.6%	-39.5%
6e-6a	0.0%	102.8%	-93.0%	-93.0%	110.3%	0.3%	0.3%	-50.6%	43.1%	4.0%	-5.1%
7e-7a	0.0%	85.3%	-122.1%	-122.1%	117.0%	0.4%	0.4%	-74.8%	64.4%	4.6%	-6.3%

Life Cycle Payback value - LC_PB (years)

	Current	RSLb_25	RSLb_100	ESL_half	ESL_double	OE-20%	OE_+20%	EPI_0	EPI_double	DR_0%	DR_3%
1b	46.0	25.5	>100	>100	25.5	51.3	41.3	>100	32.1	45.6	46.1
1e	33.5	17.4	>100	>100	17.1	38.4	29.6	58.9	25.0	33.3	33.6
1a	37.5	19.9	>100	>100	19.9	43.0	33.5	71.1	27.4	37.4	37.7
2bl	43.7	43.5	58.2	58.2	43.7	50.8	38.9	>100	30.5	42.8	45.2
2bh	42.3	42.3	56.5	56.5	42.3	48.5	37.7	>100	29.8	41.4	43.7
2el	35.4	35.4	49.1	49.1	35.5	41.2	31.5	74.5	25.9	35.2	36.4
2eh	34.2	34.5	47.3	47.3	34.5	39.8	30.6	70.0	25.8	34.0	34.5
2al	37.2	37.1	51.7	51.7	37.1	42.9	33.0	79.1	27.1	36.8	38.1
2ah	35.5	35.5	49.0	49.0	35.5	41.0	31.3	71.9	25.9	35.0	36.0
3bl	54.5	31.9	>100	>100	31.9	51.5	50.1	>100	36.5	53.1	57.5
3bh	52.3	30.1	>100	>100	30.2	59.3	47.1	>100	35.1	51.0	55.2
3el	47.0	26.1	75.7	75.7	26.0	53.4	42.1	>100	32.5	46.2	48.8
3eh	45.0	24.5	>100	>100	24.7	51.5	40.2	>100	31.3	44.2	46.2
3al	52.8	30.2	>100	>100	30.2	59.0	47.7	>100	36.1	51.2	52.4
3ah	50.2	28.8	>100	>100	28.3	57.0	45.3	>100	34.3	49.5	51.8
4bl	32.1	21.9	51.2	51.2	32.1	37.3	28.3	58.0	24.0	31.9	32.5
4bh	30.1	20.1	48.6	48.6	30.1	34.9	26.3	52.0	22.4	29.9	30.5
4el	24.1	15.5	40.9	40.9	24.1	28.3	21.1	36.5	19.0	24.0	24.3
4eh	22.1	14.1	38.3	38.3	22.1	26.1	19.2	32.3	17.5	22.0	22.2
4al	26.8	17.0	45.2	45.2	26.8	31.3	23.5	42.3	20.3	26.7	26.9
4ah	23.6	14.9	40.8	40.8	23.6	27.6	20.4	35.1	18.5	23.5	23.8
5bl	19.2	19.2	28.5	28.5	19.2	22.6	16.7	25.2	15.7	19.2	19.2
5bh	10.2	10.1	13.9	13.9	10.2	12.3	8.7	12.1	9.0	10.2	10.2
5el	13.4	13.1	20.7	20.7	13.4	15.9	11.4	16.5	11.3	13.4	13.4
5eh	7.1	7.0	10.2	10.2	7.1	8.3	6.0	8.0	6.3	7.1	7.1
6b	12.1	5.8	40.9	40.9	5.8	12.1	12.1	14.9	10.3	12.0	12.2
6e	13.7	6.0	44.5	44.5	6.2	13.3	13.7	19.1	11.3	13.6	13.9
6a	11.3	6.1	44.5	44.5	6.2	13.3	13.7	19.1	11.3	13.6	13.9
7e	21.2	10.0	59.0	59.0	10.0	21.1	21.1	34.8	16.3	20.5	21.8
7a	21.1	10.0	59.0	59.0	10.0	21.1	21.1	34.8	16.3	20.5	21.8
8	38.0	3.0	29.4	29.4	3.0	52.1	24.2	48.7	21.7	39.7	35.8
1b-1e	7.0	3.0	28.3	28.3	3.0	8.5	5.9	7.7	6.2	6.9	7.2
1e-1a	50.7	28.9	>100	>100	28.5	56.5	45.7	>100	35.0	50.7	50.7
2bl-2el	4.5	4.0	7.5	7.5	4.1	5.0	3.5	5.8	3.8	4.5	4.5
2el-2al	45.3	45.7	63.0	63.0	45.3	51.4	41.2	>100	32.4	45.3	45.3
2bh-2eh	4.8	4.6	8.6	8.6	4.1	5.8	4.0	5.3	4.3	4.8	4.8
2eh-2ah	40.8	40.9	57.3	57.3	40.8	46.3	36.7	84.0	29.5	40.8	40.8
3bl-3el	20.2	9.0	40.2	40.2	9.2	23.8	17.5	28.0	16.3	20.2	20.2
3el-3al	75.5	48.1	>100	>100	47.9	100.0	70.1	>100	48.8	75.5	75.5
3bh-3eh	19.9	9.1	40.2	40.2	8.7	23.4	17.2	27.3	16.0	19.9	19.9
3eh-3ah	71.5	44.2	>100	>100	44.5	78.3	56.1	>100	46.7	71.5	71.5
4bl-4el	8.2	4.5	16.8	16.8	8.2	10.1	7.0	9.5	7.4	8.2	8.2
4el-4al	37.0	23.1	60.2	60.2	57.0	42.2	33.0	68.1	27.1	37.0	37.0
4bh-4eh	6.5	3.5	14.1	14.1	6.5	8.0	5.5	7.2	6.0	6.5	6.5
4eh-4ah	29.5	18.0	50.3	50.3	29.6	34.2	26.2	48.1	22.5	29.5	29.5
5bl-5el	3.5	3.5	6.5	6.5	3.6	4.3	3.0	3.6	3.2	3.5	3.5
5bh-5eh	2.5	2.5	5.0	5.0	2.6	3.2	2.2	2.8	2.4	2.5	2.5
6b-6e	20.5	8.0	54.2	54.2	8.0	20.5	20.6	25.6	14.1	18.0	26.8
6e-6a	13.5	6.0	44.5	44.5	6.1	13.5	13.5	19.0	11.2	13.4	13.7
7e-7a	21.0	10.0	58.9	58.9	10.0	21.0	21.0	34.2	16.3	20.5	21.7

Variation of the LC-PB value with respect to the original scenario, (%)

	Current	RSLb_25	RSLb_100	ESL_half	ESL_double	OE-20%	OE_+20%	EPI_0	EPI_double	DR_0%	DR_3%
1b	0.0%	-44%	160.9%	160.9%	-44.6%	11.5%	-10.2%	160.9%	-30.2%	-0.9%	0.2%
1e	0.0%	-48%	258.2%	258.2%	-49.0%	14.6%	-11.6%	75.8%	-25.4%	-0.6%	0.3%
1a	0.0%	-47%	220.0%	220.0%	-46.9%	14.7%	-10.7%	89.6%	-26.9%	-0.3%	0.5%
2bl	0.0%	-0.5%	33.2%	33.2%	0.0%	16.2%	-11.0%	174.6%	-30.2%	-2.1%	3.4%
2bh	0.0%	0.0%	33.6%	33.6%	0.0%	14.7%	-10.9%	183.7%	-29.6%	-2.1%	3.3%
2el	0.0%	0.0%	38.7%	38.7%	0.3%	16.4%	-11.0%	110.5%	-26.8%	-0.6%	2.8%
2eh	0.0%	0.9%	38.3%	38.3%	0.9%	16.4%	-10.5%	104.7%	-24.6%	-0.6%	0.9%
2al	0.0%	-0.3%	39.0%	39.0%	-0.3%	15.3%	-11.3%	112.6%	-27.2%	-1.1%	2.4%
2ah	0.0%	0.0%	38.0%	38.0%	0.0%	15.5%	-11.8%	102.5%	-27.0%	-1.4%	1.4%
3bl	0.0%	-41%	120.2%	120.2%	-41.5%	-5.5%	-8.1%	120.2%	-33.0%	-2.6%	5.5%
3bh	0.0%	-42%	129.4%	129.4%	-42.3%	13.4%	-9.9%	129.4%	-32.9%	-2.5%	5.5%
3el	0.0%	-44%	61.1%	61.1%	-44.7%	13.6%	-10.4%	155.3%	-30.9%	-1.7%	3.8%
3eh	0.0%	-45%	166.7%	166.7%	-45.1%	14.4%	-10.7%	166.7%	-30.4%	-1.8%	2.7%
3al	0.0%	-43%	127.3%	127.3%	-42.8%	11.7%	-9.7%	127.3%	-31.6%	-3.0%	-0.8%
3ah	0.0%	-42%	139.0%	139.0%	-43.6%	13.5%	-9.8%	139.0%	-31.7%	-1.4%	3.2%
4bl	0.0%	-32%	59.5%	59.5%	0.0%	16.2%	-11.8%	80.7%	-25.2%	-0.6%	1.2%
4bh	0.0%	-33%	61.5%	61.5%	0.0%	15.9%	-12.6%	72.8%	-25.6%	-0.7%	1.3%
4el	0.0%	-36%	69.7%	69.7%	0.0%	17.4%	-12.4%	51.5%	-21.2%	-0.4%	0.8%
4eh	0.0%	-36%	73.3%	73.3%	0.0%	18.1%	-13.1%	46.2%	-20.8%	-0.5%	0.5%
4al	0.0%	-36%	68.7%	68.7%	0.0%	16.8%	-12.3%	57.8%	-24.3%	-0.4%	0.4%
4ah	0.0%	-37%	72.9%	72.9%	0.0%	16.9%	-13.6%	48.7%	-21.6%	-0.4%	0.8%
5bl	0.0%	0.0%	48.4%	48.4%	0.0%	17.7%	-13.0%	31.3%	-18.2%	0.0%	0.0%
5bh	0.0%	-1.0%	36.3%	36.3%	0.0%	20.6%	-14.7%	18.6%	-11.8%	0.0%	0.0%
5el	0.0%	-2.2%	54.5%	54.5%	0.0%	18.7%	-14.9%	23.1%	-15.7%	0.0%	0.0%
5eh	0.0%	-1.4%	43.7%	43.7%	0.0%	16.9%	-15.5%	12.7%	-11.3%	0.0%	0.0%
6b	0.0%	-52%	238.0%	238.0%	-52.1%	0.0%	0.0%	23.1%	-14.9%	-0.8%	0.8%
6e	0.0%	-56%	224.8%	224.8%	-54.7%	-2.9%	0.0%	39.4%	-17.5%	-0.7%	1.5%
6a	0.0%	-46%	293.8%	293.8%	-45.1%	17.7%	21.2%	69.0%	0.0%	20.4%	23.0%
7e	0.0%	-53%	178.3%	178.3%	-52.8%	-0.5%	-0.5%	64.2%	-23.1%	-3.3%	2.8%
7a	0.0%	-52%	179.6%	179.6%	-52.6%	0.0%	0.0%	64.9%	-22.7%	-2.8%	3.3%
8	0.0%	-92%	-22.6%	-22.6%	-92.1%	12%	-22%	47.8%	-37%	-3.2%	2.8%
1b-1e	0.0%	-57%	304.3%	304.3%	-57.1%	21.4%	-15.7%	10.0%	-11.4%	-1.4%	2.9%
1e-1a	0.0%	-43%	136.7%	136.7%	-43.8%	11.4%	-9.9%	136.7%	-31.0%	0.0%	0.0%
2bl-2el	0.0%	-11%	66.7%	66.7%	-8.9%	11.1%	-22.2%	28.9%	-15.6%	0.0%	0.0%
2el-2al	0.0%	0.9%	39.1%	39.1%	0.0%	13.5%	-9.1%	164.9%	-28.5%	0.0%	0.0%
2bh-2eh	0.0%	-4.2%	79.2%	79.2%	-14.6%	20.8%	-16.7%	10.4%	-10.4%	0.0%	0.0%
2eh-2ah	0.0%	0.2%	40.4%	40.4%	0.0%	13.5%	-10.0%	105.9%	-27.7%	0.0%	0.0%
3bl-3el	0.0%	-55%	99.0%	99.0%	-54.5%	17.8%	-13.4%	38.6%	-19.3%	0.0%	0.0%
3el-3al	0.0%	-36%	58.9%	58.9%	-36.6%	32.5%	-7.2%	58.9%	-35.4%	0.0%	0.0%
3bh-3eh	0.0%	-54%	102.0%	102.0%	-56.3%	17.6%	-13.6%	37.2%	-19.6%	0.0%	0.0%
3eh-3ah	0.0%	-38%	67.8%	67.8%	-37.8%	9.5%	-21.5%	67.8%	-34.7%	0.0%	0.0%
4bl-4el	0.0%	-45%	104.9%	104.9%	0.0%	23.2%	-14.6%	15.9%	-9.8%	0.0%	0.0%
4el-4al	0.0%	-37%	62.7%	62.7%	54.1%	14.1%	-10.8%	84.1%	-26.8%	0.0%	0.0%
4bh-4eh	0.0%	-46%	116.9%	116.9%	0.0%	23.1%	-15.4%	10.8%	-7.7%	0.0%	0.0%
4eh-4ah	0.0%	-39%	70.5%	70.5%	0.3%	15.9%	-11.2%	63.1%	-23.7%	0.0%	0.0%
5bl-5el	0.0%	0.0%	85.7%	85.7%	2.9%	22.9%	-14.3%	2.9%	-8.6%	0.0%	0.0%
5bh-5eh	0.0%	0.0%	100.0%	100.0%	4.0%	28.0%	-12.0%	12.0%	-4.0%	0.0%	0.0%
6b-6e	0.0%	-61%	164.4%	164.4%	-61.0%	0.0%	0.5%	24.9%	-31.2%	-12.2%	30.7%
6e-6a	0.0%	-55%	229.6%	229.6%	-54.8%	0.0%	0.0%	40.7%	-17.0%	-0.7%	1.5%
7e-7a	0.0%	-52%	180.5%	180.5%	-52.4%	0.0%	0.0%	62.9%	-22.4%	-2.4%	3.3%

7.6. Chapter 6. Section 6.2.2. Review of software and evaluation systems for integration of sustainability in urban planning projects

Depending on the purpose of the urban assessment, currently there are different ICT tools that enable realizing different kind of evaluations. Among these tools mainly the user has the possibility to select between two evaluation tool groups: qualitative and quantitative, which mainly they differ in the calculation methodology and the system of interpretation of results.

Qualitative ICT tools usually are associated with Multi Criteria Voluntary Sustainability Evaluation systems (MCVSE). From 1990, with the aim of boosting the term "Green building" or sustainable building, different work teams began to define various MCVSE systems allowing to the end user to evaluate the overall performance (environmental, energy and social) of their building. In addition, due to the need of differentiate over other buildings, the use of MCVSE systems increases such as a new benchmarking system. Therefore, increasing number of MCVSE systems are adapting their scope, extending their evaluation scope from buildings to district. The general structure and working philosophy of all turns out to be similar. Using different calculation systems, each MCVSE determines a score range for each evaluated parameter and once obtained that score, by the sum of points or by a weighting system, the end user gets the final score or rating. By applying this kind of evaluation systems, the user has the possibility to assess different aspects of the district and obtain a final certification or rating.

	Environmental quality	**Economic quality**	**Socio functional quality**	**Technical quality**	**Process quality**	**Transport & movement**	**Land use and ecology**	**Pattern and design**	**Regional priority**	**Diversity**	**Environmental quality**
DGNB (http://www.dgnb.de)	X	X	X	X	X						X
BREEAM Communities (http://www.breeam.org)	X		X		X	X	X				X
LEED for Neighbourhood Development (http://www.usgbc.org/leed)	X				X		X	X			X
HQE2R (http://www.behqe.com/)	X		X					X		X	X
Ecocity (Gaffron et al., 2005)	X	X	X		X	X		X			X
SITES (http://www.sustainablesites.org/)	X		X		X			X			X
LCC - Living Community Challenge (http://living-future.org/lcc)	X	X	X								X

On the other hand, qualitative systems are based on quantifying and showing the impacts of one or more aspects of a city, applying harmonized calculation methodologies and avoiding weightings and subjective assessment systems. In the event that these kinds of tools show any final scores, this score is accompanied by the calculation result or impact value, reducing the rating system strength and facilitating the necessary information to reach new improvement decisions. According to the evaluated aspects or the system boundary applied, we can distinguish two general groups: Neighbourhood Sustainability Assessment (NSA) tools and tools with Life Cycle approach. NSA tools assess the different sustainability aspects of a district during its operational stage. That is, when the whole district or the assessed aspect is operational. Among these tools, we can mention:

- The tool DPL (Dutch acronym for Duurzaamheid Prestatie voor een Locatie, ‘Sustainability-Profile for Districts’) assesses in a clear and transparent way the spatial plan for a district on sustainability, based on the information from the urban plan. It so helps urban designers to creatively improve the sustainable performance of a district"(*Kortman et al., 2001*). Compared to other tools for assessing urban sustainability, DPL represents a relative simple and flexible approach. The idea is to use a limited number of indicators based on already collected data (environmental, social and economic), which are often accessible in the municipal registers. If data are not available, the model allows alternative methods for a 'best estimate' on the indicator.

- GPR software assesses and rates the environmental impact, energy performance and design quality of buildings and urban developments. Essential in the GPR methodology, is the dual approach of environmental impact on the one hand and district quality on the other. The key performance indicators are: Energy, Environment (assessing the environmental impact), Health, User quality, and Long term value (assessing the building quality), which are divided into several sub-indicators (*GPR*). This gives the opportunity to pin-point topics to be improved, while still keeping an overview of the overall environmental impact.

- TRACE (Tool for Rapid Assessment of City Energy) tool (*TRACE*) is a decision-support tool designed to help cities quickly identify under-performing sectors, evaluate improvement and cost-saving potential, and prioritize sectors and actions for energy efficiency (EE) intervention. It covers six municipal sectors: passenger transport, municipal buildings, water and waste water, public lighting, solid waste, and power and heat.

- The Transep-DGO tool (*Krikke, 2011*) is an Excel sheet that describes and calculates six teen energy concepts for districts. These energy concepts are classified into five main energy concepts: (Waste heat) district healing with biomass or geothermal, solar Thermal, solar Electric, conventional Healing and hydrogen Storage. Transep-DGO tries to stimulate the transition towards energy-neutral districts in 2050, by developing a back casting tool which supports municipal decision makers in the early design stages of district development.

- The software District Energy Concept Advisor supports actors in the field of urban planning during the first stages of planning energy-efficient district concepts (*DECA*). The very heart of the software is a tool for the energy assessment of districts, which uses archetypes and other pre-set configurations to allow for a simple and quick data input mapping all the buildings in the district. Thus it takes the user just a few steps to identify the energy saving potential of various strategies in the areas of building construction, technical building systems, and centralized supply systems.

- The software CitySim (*Robinson et al., 2009*) is aiming to provide a decision support for urban energy planners and stakeholders to minimize the net use of non-renewable energy sources as well as the associated emissions of greenhouse gases.

- TERMIS is a Real Time Hydraulic and Thermal Modelling and Simulation System (*TERMIS*). Among its characteristics should be highlighted: the real time component, which significantly improve the operational stage and identify-solve problems.

- Ecotect (*Autodesk Ecotect*) is a tool which, among other applications, assesses aspects of luminance and shading of the whole city. In addition, this tool allows evaluating climate conditions or energy performance of buildings.

	Energy Buildings	**Energy Transportation**	**Energy Water**	**Energy Public lighting**	**Solid waste**	**Safety**	**Health**	**Quality of work and home**	**Social cohesion**	**Economic vitality**	**Future value**	**Usage value**	**Urban mobility**
DPL	X					X	X	X	X	X	X		
GPR	X		X			X	X				X	X	
TRACE	X	X	X	X	X								
Transep-DGO tool	X												
DECA	X												
CITYSIM	X												
Termis	X									X			
SUMO													X
Trans Modeler													X
Ecotect	X												

Based on the standardization and LCA-LCC tool adaptation realized at building level, in recent years, the life cycle methodology is adapting to new evaluation levels, developing new tools that assess different sustainable aspects of the district with lifecycle approach. Among these tools, this article highlights the following two tools. The first tool is Neighbourhood Evaluation for Sustainable Territories - NEST (*Yepez et al., 2013*), which is one of the first tools which evaluate a design of a new district with Life Cycle Approach (LCA). The analysis evaluates 4 environmental aspects (infrastructures, buildings, transport and land use) and also evaluate the economic and social aspects. The second tool is UrbiLCA (*Zambrana et al., 2014*), which allows analyzing the energy and environmental impact of a district. In addition, the urban density, geographic location, power distribution, the use of renewable energy, waste collection systems and sustainable mobility are considered by this tool.

However, until now there is not any standardization which facilitates the assessment of this new evaluation level, making difficult the harmonization of the evaluation and the comparison between different results obtained by different tools.

Aspects evaluated by each Life Cycle approach tool

	Life Cycle stages								**Evaluated aspects**		
	Product phase (A1-3)	**Transport (A4)**	**On site processes (A5)**	**Maintenance (B2)**	**Replacement (B4)**	**Operational energy use (B6)**	**Operational water use (B6)**	**End of life phase (C1-4)**	**Environmental**	**Economic**	**Social**
NEST	X					X	X		X	X	X
URBILCA	X		X			X	X	X	X		

7.7. Chapter 6. Section 6.2.2. Refurbishment strategies at district level

District heating/cooling

District heating/cooling is a system for distributing heat/cool generated in a centralized location for residential and commercial requirements such as space heating/cooling and water heating. This system is one of the most interesting strategies to improve (refurbishment project) the energy performance of a district or a city. This generation and distribution system is mainly composed by 3 elements:

- **Thermal generation plant.** Centralised heat and / or cold production in a large installation that generates thermal energy required to meet the demand of all users. Thermal energy can be generated by turbine engines, biomass thermal plant, cogeneration system, waste heat recovery system and / or solar plants. The most important is that the energy is generated at a single point, optimizing performance of the entire system

- **Distribution pipe network.** The distribution pipe network enables the supply of fluids (hot and/or cold) and is formed by isolated pipes to minimize heat losses. Usually the pipes are distributed in underground drains that follow the layout of streets in urban areas.

- **Substations.**The heat transfer between the distribution network and consumers (buildings or homes) is done through a substation. It consists on a heat exchanger, the elements that regulate and control the correct operation and the measuring elements to bill the energy.

Advantages
It saves useful space in buildings because it’s not necessary to have energy production systems. Enables the use of renewable energy, waste, local and more efficient technologies such as cogeneration. Cost savings for users. Installations are more energy efficient because of the centralized management and maintenance. It reduces environmental impact and primary energy.
Disadvantages: Efficiency depends on critical parameters.
Temperature of the network: if the water temperature is lower the net energy efficiency of the system is higher. District density: increasing the density of the built area, the implementation of district heating systems is more favourable. District size: a minimum number of users connected to the network must be guaranteed. High Investment cost to be discounted in a long period. Heat demand: for very low heat demands (new buildings), district heating is not viable.

Waste Heat Recovery

A waste heat recovery unit (WHRU) is an energy recovery heat exchanger that recovers heat from hot streams with potential high energy content, such as hot flue gases from a diesel generator or steam from cooling towers or even waste water from different cooling processes such as in steel cooling.

Recovering industrial waste heat can be achieved via numerous methods. The heat can either be “reused” within the same process or transferred to another process. Ways of reusing heat locally include using combustion exhaust gases to preheat combustion air or feed water in industrial boilers. By preheating the feed water before it enters the boiler, the amount of energy required to heat the water to its final temperature is reduced. Alternately, the heat can be transferred to another process; for example, a heat exchanger could be used to transfer heat from combustion exhaust gases to hot air needed for a drying oven. In this manner, the recovered heat can replace fossil energy that would have otherwise been used in the oven. Such methods for recovering waste heat can help facilities significantly reduce their fossil fuel consumption, as well as reduce associated operating costs and pollutant emissions.

Advantages
The recovery process will add to the efficiency of the process and thus decrease the costs of fuel and energy consumption needed for that process.
Reduction in Pollution. Thermal and air pollution will dramatically decrease from the plant since most of the energy is recycled.
Reduction in the equipment sizes. As Fuel consumption reduces so the control and security equipment for handling the fuel decreases.
Reduction in auxiliary energy consumption. Reduction in equipment sizes means another reduction in the energy fed to those systems like pumps, filters, fans... etc.
Disadvantages: Efficiency depends on critical parameters.
Capital cost. The capital cost to implement a waste heat recovery system may outweigh the benefit gained in heat recovered.
Quality of heat: Often waste heat is of low quality (temperature). It can be difficult to efficiently utilize the quantity of low quality heat contained in a waste heat medium.

Seasonal Thermal Energy Storage (STES)

The thermal energy can be collected whenever it is available and be used whenever needed, such as in the opposing season. For example, heat from solar collectors or waste heat can be gathered in hot months for space heating use when needed, including during winter months. Or the natural cold of winter air can be stored for summertime air conditioning (*Paksoy & Stiles, 2009*). STES can be designed in such a way to support a single household or in a grid to supply blocks or neighbourhoods.

There are several types of STES technology, covering a range of applications from single small buildings to community district heating networks (generally, efficiency increases and the specific construction cost decreases with bigger size). Since seasonal thermal energy storage requires large inexpensive storage volumes, due to the large storage timescales, the most promising technologies were found in the ground. Such systems are called Underground Thermal Energy Storage (UTES) systems. Among the UTES systems developed since 1970s, the ongoing engineering research focused mainly on four types of storages: Aquifer Thermal Energy Storage (ATES), Borehole Thermal Energy Storage (BTES), Water Thermal Energy Storage (WTES) and Gravel-water Thermal Energy Storage (GTES).

Characteristics of the different STES technologies. Source: Own elaboration with data from (*Schmidt et al., 2003)* and *(Novo et al., 2010)*

	ATES	BTES	WTES	GTES
Storage medium	Sand/water-gravel	Soil/rock	Water	Gravel-water
Heat capacity (kWh/m^3)	30-40	15-30	60-80	30-50
Storage volume for 1 m^3 water equivalent (m^3)	2-3	3-5	1	2-3
Geological requirements	-Natural aquifer layer. high hydraulic conductivity. -Confining layers on top and below. -No or low natural ground water flow. -Suitable water chemistry at high temperatures	-Drillable ground. -High heat capacity. -High thermal conductivity. -Low hydraulic conductivity. -Natural ground water flow less than 1 m/a -30/200 m deep	-Stable ground conditions. -Preferably no ground water. -5/15 m deep.	- Stable ground conditions. -Preferably no ground water. -5/15 m deep.

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