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Environmental assessment of four Basque University campuses using the NEST tool

Iñigo Leon[1,*], Xabat Oregi[2], Cristina Marieta[1]

[1] EIG (UPV-EHU), Plaza Europa 1, 20018 Donostia-San Sebastián, Spain,

[*] Corresponding author: inigo.leon@ehu.eus

[2] Tecnalia Research & Innovation, Energy and Environment Division, Azpeitia, Spain

HIGHLIGHTS

- The Neighbourhood Evaluation for Sustainable Territories (NEST) tool calculates the environmental impact of districts with life-cycle approach
- Application of the NEST tool for the environmental assessment of four Basque University campuses (Spain)
- Environmental assessment of the baseline and several refurbishment scenarios.
- Analysis of the impact variation (%) for the four campuses studied in relation to the baseline

Abstract

Over the past few years, town planners and architects have been facing increasing demands regarding the performance of urban development projects in terms of environment, quality of life and socio-economic issues. For this reason, several tools capable of assessing their environmental impacts have been developed. NEST (Neighbourhood Evaluation for Sustainable Territories) is a particularly interesting one since it permits performing simultaneous environmental, economic and social analyses at a district scale, in addition to evaluating refurbishment scenarios, with a life cycle perspective. Nowadays, universities can be considered as "small cities" due to their large size, population, and the many complex activities that take place on the campuses; thus, they have a direct and indirect impact on the environment. In this article, the authors present the results obtained from the environmental evaluation of the four campuses of the University of the Basque Country (UPV-EHU), using NEST. First, the evaluation consisted of analysing baseline environmental impacts of the four campuses, and then, in order to reduce environmental impacts, the authors presented numerous refurbishment scenarios for the campuses, according to national and international declarations concerning sustainable development in higher education.

Keywords: Decision support tool; university campus development projects; life cycle assessment, university environmental impact.

1. Introduction

As the world knows by now, over the last few decades the global environment situation has become critical in some aspects. The depletion of natural resources, global warming or ozone layer depletion are all issues that are leading to increasing environmental awareness [1]. In 2016, an estimated 54.5% of the world´s population lived in urban settlements, and by 2030 urban areas are foreseen to house 60% of the global population, meaning that one out of every three people will live in cities [2]. This fact is explained by economic and social forces, as cities offer their citizens new opportunities for business, education, security, and community. However, as supporting these activities requires significant resources, there is an economic and environmental cost [3]. Thus, a recent assessment suggests that two thirds of the global primary energy consumption can be attributed to urban areas, which, in turn, leads to 71% of global direct energy-related greenhouse gas (GHG) emissions [4]. In the European community, more than 40% of the energy is consumed by buildings [5], [6]. However, it should also be mentioned that, according to recent studies, the built environment has the highest potential for increased energy efficiency [7]. In fact, the energy consumption needed for buildings in operation has already been reduced by the development of design methods, such as passive or zero energy buildings [8], [9].

After World War II, state societies composed of citizens were integrated into a world society comprised of empowered individuals. The redefinition of society in global and individual terms reduces nationally bounded models of nature and culture and extends the pool of university beneficiaries. This change has intensified “universalization” and the universities’ worldwide growth rate [10]. Thereby, universities can be regarded today as “small cities” due to their large size, population, and the many complex activities taking place on campuses, which also have direct and indirect impacts on the environment. These impacts caused by universities are related to energy and material consumption via teaching and research-related activities and operations, support services and in residential areas, and transport [11]. On the other hand, universities play a key role in society by preparing future graduates who will manage companies and other organizations, create new companies and become future leaders [12]. Therefore, universities have the mission to provide students with new competences to create a more sustainable society, and in light of the abovementioned environmental challenges, universities are facing a demand for projects with increased environmental performance [13]. Consequently, as they have already been done in other countries for educational buildings [14], [15], the authors of this work have conducted the environmental evaluation of the campuses of the UPV-EHU in the Basque Country (Spain).

According to the European Commission [16], [17] and international literature [18]-[21], the life cycle assessment (LCA) methodology is currently the best framework available to assess the potential environmental impacts of any activity. The International Organization for Standardization (ISO) adopted an environmental management standard in the 1990s as part of its 14000 standard series, with the 14040 series focusing on establishing methodologies for LCA [22]. Thus, in order to generate a comprehensive overview of the product´s total environmental effect, the ISO standard established that the LCA should be carried out in four distinct stages: (I) goal and scope definition, (II) Life Cycle Inventory (LCI), (III) Life Cycle Assessment (LCIA), and (IV) interpretation. The goal and scope definition establishes the definition of the goal and scope of the assessment, which is basically the description of the system to be studied: the functional unit, system boundaries, and quality criteria for inventory data. LCI analysis deals with the collecting and synthesising information on physical material and energy flows in various phases of the product/service life cycle. In the LCIA, the potential contribution of material and energy that flows to each predefined impact category is assessed. Finally, the results are interpreted. Typically, the LCA methodology contemplates the whole activity life cycle: cradle to grave analysis. However, for buildings, their prolonged use phase dominates all other life cycle stages, such as material manufacturing or end-of-life; thus, generally speaking, this phase is well-established, prevailing over all other life cycle stages [23]–[27]. For the building sector, standards such as 15978:2011 [28] define the criteria to assess the environmental behaviour of buildings with a life cycle approach. Based on this standard, new tools are currently being developed to assess the environmental impact of a district using the life cycle approach. This article highlights the Neighbourhood Evaluation for Sustainable Territories (NEST) tool [29], [30], which is one of the first tools to assess a new or refurbished district with a life cycle approach.

The authors of this study used NEST to carry out the environmental evaluation of 4 different university campuses. Further, although the concept of a building´s life cycle emissions has been widely recognized, it has not been frequently applied to sustainable refurbishment studies [31]. Therefore, in this study, first of all, the authors carried out the evaluation of the baseline impacts. Then, they proposed several energy efficiency improvement strategies with the objective of assessing the reduction of environmental impacts to achieve the 20-20-20 sustainability target launched by the European Union [32].

2- Assessment methodology: NEST

Depending on the aim of the district assessment, there are currently different simulation tools that enable different evaluations to be made. Among these tools, the user has the opportunity to choose between two assessment tool groups: qualitative and quantitative, whose main difference is the calculation methodology and the result interpretation system.

Qualitative tools are related to Multi Criteria Sustainability Evaluation systems, such as DGNB (German Sustainable Building Council), BREEAM (Building Research Establishment Environmental Assessment Method) or LEED (Leadership in Energy and Environment Design), which are of great significance at international levels, and play a key role in the whole development of sustainability [33]. Based on different calculation systems, these evaluation systems determine a score range for each assessed parameter and once that score has been attained, the end user obtains the final score or rating [34].

Quantitative tools are based on quantifying the impacts by applying harmonized assessment methodologies and avoiding subjective assessment systems. According to the system boundary applied, two general tool groups can be distinguished: tools with an operational approach, and tools with a life cycle approach. Operational approach tools (DPL, GPR, TRACE, Transep-DGO, DECA, CitySim, TERMIS) analyse different parameters of a district during its operational stage [34].

As already mentioned, according to the European Commission Communication on Resource Efficiency

Opportunities in the Building Sector, the life cycle methodology is currently the best framework available to assess the potential impacts of any activity, product or service without geographical, functional or time limits. Thus, several tools, which permit the evaluation of building performances with a life cycle perspective, have been developed: Athena, Bees, Ecoeffect, Eco-Quantum, Ecosoft, Elodie, Envest, Equer, Jomar, Legep or Sofias [34]. Among these tools there is NEST, one of the first tools that evaluates the environmental performance of the different elements (building, traffic, lighting, and so on) of a new or refurbished district with a life cycle approach.

NEST (Neighbourhood Evaluation for Sustainable Territories)

NEST was developed through a PhD thesis [35] that focused on the environmental assessment of eco-neighbourhoods. NEST is a PlugIn for Trimble SketchUp, which is one of the most used 3D modelers among urbanists and architects. The NEST analysis is performed directly on the 3D masterplan of the neighbourhood and performs the assessment of a set of indicators that was developed associating a scientific approach. NEST also presents a graphical and ergonomic interface, which is very useful to analyse and to confront theory with reality.

In terms of system boundaries, NEST takes into account four major neighbourhood components: buildings, land use (roads, parking, green spaces, etc.), infrastructure (public lighting), and mobility of neighbourhood users. Despite standardization efforts, there are very few studies that assess all the described life cycle stages defined by the 14040 ISO Standardization [22]. Most studies and tools focus on just some of the stages, i.e., the product phase and the operational energy use stage. Based on scientific studies, as well as on the conclusions obtained in the study carried out by Oregi [34], NEST focuses on assessing the environmental impact of the life cycle stages shown in Table 1.

The input data that NEST uses to perform the analysis can be entered [29] : Manually (MA), Manually by the NEST dropdown menu (MN), Automatic by NEST (A) or Imported from Integrated Environmental Solutions (IES) software (IES) [37].

To perform the analysis, NEST applies the calculation procedures shown in Figure 1. For the environmental and economic assessment of the building materials, refurbishment strategies, economic cost, embodied energy and associated GHG emissions, NEST relies on an internal database of former analyses that estimate embodied environmental and production cost impacts of different constructive systems, and refurbishment strategies. This database was designed by Nobatek and Tecnalia using national statistics, publicly available studies and internal data compiled from various studies [34], [35]. Some environmental information also comes from international databases, such as Ecoinvent for environmental aspects and Ecofys for economic aspects.

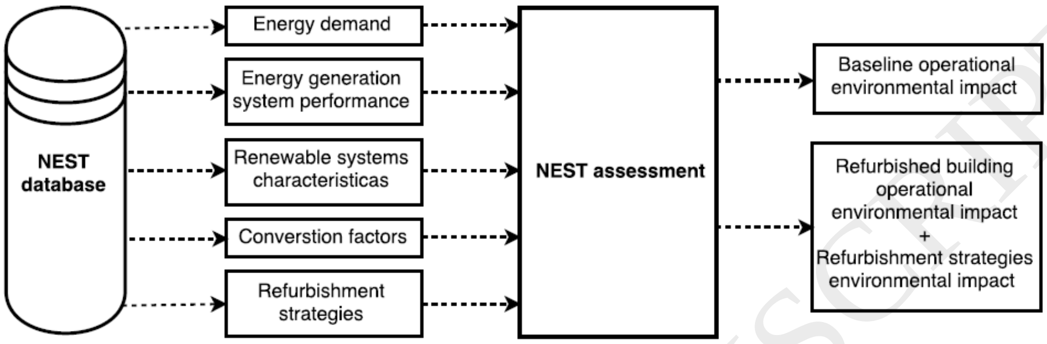


Figure 1 Diagram of the environmental assessment calculation processes of buildings in NEST.

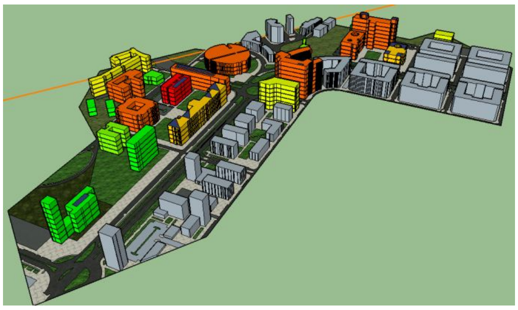
To estimate the energy demand of buildings (heating, cooling, lighting, domestic hot water and appliances) in automatic (A) mode, NEST requires the climate zone (g2), the usage category of the building (b2) and the energy label of the building (b6) as inputs. To convert the operational energy use values into economic and environmental impacts, conversion factors such as energy prices, PE factors or GWP factors are automatically adapted, depending on the location of each district (in France and Spain). If the user has the energy demand data, it is possible to manually insert this information and to import energy simulation tool results (IES, for instance).

To perform the analysis related to land use, NEST uses the type of surface (roads, parking, green spaces, etc.) and the area of the different surface types (m^2). The type of surface is defined manually during the modelling process of the district, using a typical "paint bucket" tool, but the area of each surface type is automatically recognized in SketchUp and is defined through the NEST interface. To conclude, NEST uses conversion factors to convert those amounts and types of land use into their respective environmental impacts. For public lighting, the user inputs (i) the number of public lighting points, (ii) the type of luminaries, and (iii) a possible regulation system. The number of luminaries makes it possible to quantify the environmental and economic impacts of the production (A1-A3) and replacement (B4) stages. Based on data from the NEST database, these three parameters make it possible to calculate the annual energy consumption of the lighting system, which is converted into operational energy use (B6) using conversion factors. The mobility or transport impact calculation is based on the manual (MN) definition of three inputs: distribution of the different social profiles (m1) of the neighbourhood users, in this case of the university campus (students and workers), mobility systems (m2) of each social profile (car, bicycle, bus, etc.), and the average distance (km) to the campus.

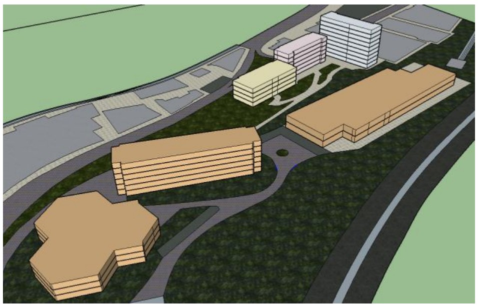
The NEST indicators have been considered broad enough to address key issues of sustainable urban planning and enable a comprehensive assessment of the project. Environmental indicators are divided into two groups: LCA-based indicators (Primary Energy consumption - PE; Global Warming Potential - GWP; biodiversity; and air quality, AQ), and flow indicators (water consumption and waste production). These indicators have already been described by Oregi et al. [38]. Due to the goal and scope of our assessment, the present study focuses on the PE and GWP environmental indicators. The PE consumption indicator (in MJ/(year·user)) is based on the CML 2002 method [39]. It accounts for PE use for production, transport and maintenance, replacement of construction materials, building and open space operations, end-of-life of construction materials, and daily mobility. And the GWP indicator ($kg_{eq}CO_2$/(year·user)) of impacts is based on the ILCD 2011 Midpoint [40] method. It accounts for GHG emissions associated with production, transport and maintenance of construction materials, construction works, building and open space operations, end-of-life of construction materials, and daily mobility.

3. The University Campus

The goal of the present research project was (i) to compare the environmental impacts of four main university campuses (see Figure 2) of the UPV-EHU, (ii) to compare the application of different energy refurbishment strategies according to national and international declarations concerning sustainable development in higher education, and (iii) to lay the foundations towards the Corporate Carbon Footprint for the UPV-EHU.



Campus of Donostia-San Sebastián



Campus of Eibar

Campus of Leioa

Campus of Vitoria-Gasteiz

Figure 2 Screenshots of the four university campus areas studied with this study framework.

The UPV-EHU is based in its three provinces: Gipuzkoa (1,997 km^2), Bizkaia (2,217 km^2), and Álava (3,030 km^2) that make up the Basque Autonomous Community (BAC) in the north of Spain (Figure 3). The major university campuses of Donostia-Ibaeta, Leioa and Gasteiz, which are the main subject of the study, are located in the three provincial capitals, Donostia-San Sebastián, Bilbao, and Vitoria-Gasteiz. In addition to these main campuses, the UPV-EHU has some faculties disseminated over the 3 provinces, some in quite isolated places. To complete the study, the Eibar campus was chosen, which is the only isolated location that is directly managed from a main campus, in this case, from Donostia.

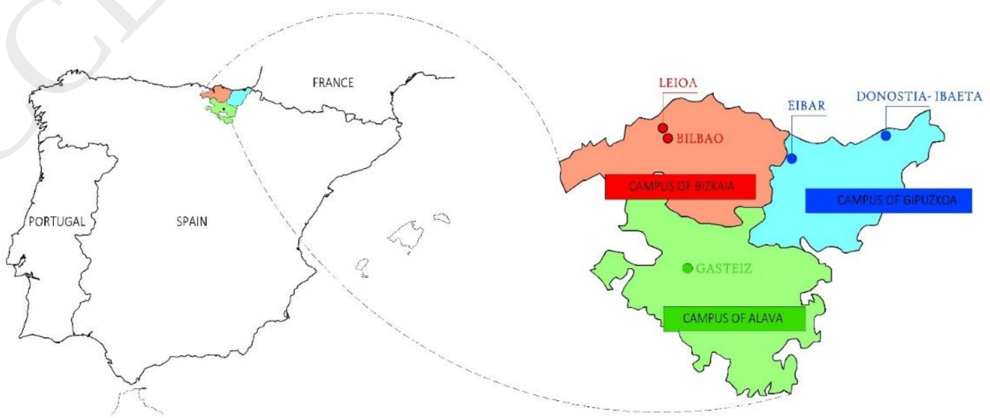


Figure 3 The three provinces of the Basque Autonomous Community BAC, the location of the studied campuses.

The 4 chosen campuses are especially interesting for comparison reasons, since they satisfy 4 different characteristic urban development typologies of higher education spaces. Two urban typologies (Gasteiz, Donostia-Ibaeta) and 2 sub-urbans (Eibar, Leioa) are compared. Each model studied has unique characteristics, so that a large number of university campus typologies implanted throughout the world can be reflected. Thus, Gasteiz is an urban campus model, developed in the existing urban plot. Its development has been based on recovering old buildings for university uses in historical urban areas of the city. The campus is the result of integrating various historical education centres of the city with the creation of new ones. It covers 15% of the students of the UPV-EHU. Donostia is a new creation urban campus model. It has been established on extensive grounds that belonged to the undeveloped periphery of San Sebastian in the 1970s. The San Sebastian General Urban Development Plan allocated an extension of suburban lands (which now occupies more than 170,000 m^2) where the various faculties are interspersed with extensive green areas. With the urban growth of the city of San Sebastian, these lands are now integrated into the city itself. It has a lot of public transport services as well as a bike lane network that connects the campus to the whole city. The different faculties and university colleges, which were scattered about the city before the creation of this campus, have been reinstalled and grouped into new buildings. Nowadays, it is starting to become saturated, so its capacity for extension is limited. Here, approximately 25% of the students of the whole UPV-EHU study. Leioa is a campus built in an isolated area, 15 km away from the centre of Bizkaia´s Provincial Capital, Bilbao. It can be considered as peri-urban, as it is understood to be far from the city, but it also performs tasks that are necessary for the urban population. Among its virtues are its great extension, allowing manifold university buildings to be grouped in a relatively compact space, as well as its high capacity for expansion. Its main weakness is that it is located on a hill, isolated from the urban centre, and there are few connections with sustainable transport modes. The Eibar campus is small in size. It can be considered as suburban, as it is understood to be developed in peripheral areas of the city. It has developed in the nearby periphery, but without the possibility of extension, or of being integrated into the urban plot, since Eibar sits in the valley of a river, surrounded by mountains. Based on this comparison of the 4 campuses studied, indicators can be extracted that help to detect which urban model of space development is more appropriate for higher education.

4. Scenarios and strategies

Baseline scenario

The baseline is defined as the current scenario (the current buildings, lighting, infrastructure and mobility characteristics of the four campuses). **Error! Reference source not found.** describes the most relevant inputs required for modelling the baseline scenario of each of the studied campuses.

One of the key elements when analysing the environmental behaviour of a university campus is the energy behaviour of its buildings. Due to the difficulty of monitoring and obtaining real energy consumption values, based on the energy rating, use and climatic zone of each of them, NEST permits defining the heating, cooling, domestic hot water, appliances and lighting energy demand value of each building. In the case of the Donostia-San Sebastian campus, 38.9% of the buildings have D energy rating, 22.2% C, 27.8% B and 11.1% A. On the Eibar campus, 83.3% of the buildings have D energy rating and 16.7% C. On the Vitoria-Gasteiz campus, 10.5% of the buildings have E energy rating, 63.2% D, 10.5% C, 10.5% B and 5.3% A. Finally, on the Leioa campus, 72% of the buildings have E energy rating, 20% D and 8% C. We must clarify that, due to the minimum requirements related to the thermal performance of the envelope, the technological performance of the energy installations or the use of renewable systems defined by the 2006 construction regulation, in buildings built prior to that year, the energy rating will be equal to or worse than D. However, during the last decade, numerous buildings on these campuses have been energetically refurbished or re-built, notably improving their energy rating. Finally, the energy rating of buildings constructed after 2013 is B or A, due to the increase in application of the regulation requirements.

Regarding energy sources, natural gas is the main source. However, some Eibar buildings have electric systems for the DHW system. In the case of Vitoria-Gasteiz, in conjunction with natural gas, in some buildings they use biomass boilers for heating. The natural gas system proposed by this study consists of a centralized natural gas installation with a nominal performance of 0.87 for all buildings. With respect to the biomass boiler, this study applies a nominal efficiency of 0.92.

Related to renewable technologies, such as solar thermal (ST) and photovoltaic (PV) panels, NEST considers some assumptions. For the solar thermal panels, NEST allows selecting between flat plate and evacuated tube solar collectors. For this study, the flat collector panel is considered, whose efficiency factor is 0.69. For photovoltaic panels, NEST allows selecting between monocrystalline and polycrystalline panels. For this study, the mono crystalline panel is considered, whose peak power coefficient is 0.15 with an efficiency factor of 0.8.

Through the correct definition of "conversion factor" values, the energy consumption, for heating space or water, for cooling or for lighting, is transformed into environmental impact. For the natural gas source, the related impacts were deduced from the Ecoinvent database [41], applying the “Heat production, natural gas, at boiler modulating” process (Europe without Switzerland), which has an energy performance of 95.9%. The conversion factor from natural gas applied by NEST to PE use will be 4.4 (MJ/kWh), and to GWP 0.2 (kg CO_2-eq/kWh). However, in the case of the electricity mix, the calculation is more complicated; as each Member State has a different electricity mix scheme. Therefore, the environmental loads assigned to electricity supply have been adapted, respectively, to the Spanish electricity mix for 2016, taking into account the data from “Red Eléctrica Española” [42]. After defining the scenario of the Spanish electricity mix, the environmental impact of each of the different electricity generation processes is calculated. 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). After applying each of the different energy processes and considering the amount of energy from each process that is applied to generate 1 kWh of electricity, the conversion factor from electricity (Spain 2016) applied during this case study to PE use will be 6.3 (MJ/kWh), and to GWP 0.3 (kg CO_2-eq/kWh). Finally, for the biomass source, the related impacts were deduced from the Ecoinvent database, applying the “heat production, wood pellet, at furnace 25kW” process (Rest-of-the-World), which has an energy performance of 85%. The conversion factor for biomass that this study applies is going to be 2.8 MJ/kWh (PE) and 0.01 kg CO_2-eq/kWh (GWP).

Finally, based on Ecoinvent v3.0, NEST defines the environmental impact of the different mobility systems. The conversion factor from car, bus, tram, train, bicycle and walking to PE use will be 42.05, 1.84, 1.36, 1.16, 0.00 and 0.00 (MJ/(user·km)), respectively; and to GWP 0.29, 0.10, 0.09, 0.08, 0.00 and 0.00 (MJ/(user·km)), respectively.

Refurbishment scenarios

Three scenarios are presented: 2020, 2030 and 2050, which propose the development of Campus Refurbishment strategies to achieve more sustainable campuses adapted to local policies in this field, based on European guidelines [16], [17], [43]. In the context of this research, the Basque Government has been developing different strategies aimed at fulfilling the EU objectives. The studies and guidelines established in the documents will be considered: Energy Strategy of the Basque Country 2020 [44]; Energy Strategy of the Basque Country 2030 [45]; and the Basque Country Climate Change Strategy 2050: Klima 2050 [46]. To achieve this vision in 2050, the Basque Government is aligned with EU commitments [47], which, in its energy policy for 2050, sets out three timeline milestones with specific objectives in each of them (Table 3). After analysing different scenarios, based on socioeconomic and energy hypotheses, the main objective defined by the Basque Country's 2050 Climate Change strategy is: Reducing GHG emissions in the Basque Country by at least 40% by 2030, and by at least 80% by 2050, and to achieve a renewable energy consumption of 40% over final consumption by 2050.

In order to reduce the environmental impact of university campuses, different energy refurbishment strategies for each aforementioned period have been evaluated during this study (Table 4). The first refurbishment strategy is based on applying different passive refurbishment strategies, improving the thermal properties of the façade and windows.

The second strategy focuses on changing the current energy generation systems used to heat or cool the buildings. Another strategy assesses a scenario which allows adding heat pumps with geothermal support to generate hot or cold air for the buildings. Furthermore, this study assesses the possibility of increasing the amount of solar thermal and photovoltaic panel surface area, which is directly related to the thermal energy and electricity consumption of the buildings. Finally, the last strategy improves the technical characteristics of the public lighting system. The insertion of these strategies into NEST is described by Oregi et al. (2016) [29].

5. Results and discussion

The functional equivalent used to compare the different university campuses is the whole campus. It was analysed over its reference service life (100 years) period and meeting the conditions of the design requirements. The results are expressed per year and per user (students and workers of the campus).

Baseline assessment

Table 5 shows the results of the baseline scenario obtained after inserting the input data into the tool. The highest primary energy consumption is related to the Leioa campus (25033 MJ/(year·user)), which is 113%, 133% and 131% higher than the campuses of Donostia-San Sebastián, Eibar and Vitoria-Gasteiz, respectively. In the Donostia campus, building materials, building operation, public lighting and transport account for 1.5%, 77.7%, 0.1% and 20.8%, respectively, of primary energy consumption. Due to the significant number of buildings without insulation (and therefore with associated high energy consumption and poor energy rating), the operation stage remains as the main contributor. On the other hand, due to the campus location, the impact related to mobility reflects only 20% of the overall impact. Regarding the Eibar campus, its environmental behaviour is similar to the Donostia campus. However, due its location and mobility infrastructure, transport accounts for 41.7% of the primary energy consumption of the campus. Due to the similarity between the infrastructures, building characteristics and mobility system of the campuses of Donostia-San Sebastián and Vitoria-Gasteiz, their environmental behaviour is similar. Finally, regarding the Leioa campus, it is interesting to note the really high contribution of private transport (52.61% of the campus) due to the fact that the campus is located 15 km away from the main urban area and it is difficult to access by train, tram or bicycle. The impact related to the operational use of the buildings is the second main primary energy consumption element (10757MJ/(year·user)) of Leioa, which reflects 43% of the whole campus primary energy consumption.

Regarding GWP results, the highest GWP is related to the Leioa campus (1324 $kg_{eq}CO_2$/(year·user)), which is 134%, 186% and 145% higher than the campuses of Donostia-San Sebastián, Eibar and Vitoria-Gasteiz, respectively. The values of the different impact percentages and their interpretation is similar to the primary energy consumption indicator. In the campuses of Donostia, Eibar and Vitoria-Gasteiz the impact related to the operational stage of the building reflects the highest impact with 78.6%, 61.5% and 68.1%, respectively. In the Leioa campus, the highest impact is related to mobility (743 $kg_{eq}CO_2$/(year·user)), which accounts for 56.1% of the overall GWP impact of the Leioa campus.

Refurbishment assessment

The NEST database related to environmental impact, associated with the production phase of each product and system, has been calculated using process data from Ecoinvent [41] and GaBi [48] databases as well as Environmental Product Declarations (EPD) issued by manufacturers. Regarding the transport distance of each product or system, NEST is based on 300 km [49]. It is assumed that 3% of all products or materials used in a refurbishment project will be discarded and become waste during the construction stage, and their treatment for end-of-life (transport and disposal) is therefore considered. In addition, in accordance with ISO 15686-8:2008 [50], construction materials and systems usually do not have the same Estimated Service Life as the building or district Reference Service Life, and may require one or multiple replacements. Therefore, NEST defines different service life values: district (100 years), buildings (50 years) and products (30 years). Finally, the environmental impacts generated during the transport of the refurbishment strategies to the waste treatment facility and their management are evaluated by NEST. This study has considered the same hypotheses for this stage as for waste management in the construction stage, acknowledging the uncertainty of waste management at the end-of-life of a building –in 50 years' time- [38].

In this study there will be no scenarios of mobility improvement, due to the fact that the decisions in the field of transport and mobility cannot be carried out by the Steering Committees of the University. These scenarios for more sustainable mobility are linked to higher-level scenarios where decisions are made at a political level. These are strategic decisions that affect territorial areas that exceed the BAC. Therefore, during this work, new mobility scenarios would be outside the scope of the study.

Table 6 shows the results of the baseline and the scenarios, 2020, 2030 and 2050, with the refurbishment strategies proposed in **Error! Reference source not found.**4 for the four campuses, DSS, EI, GV and LE.

First of all, it should be noted that the refurbishment strategies have virtually no impact on PE and GWP for public lighting and mobility. Regarding mobility, the sustainability strategies are developed by government entities outside the university, and regarding public lighting, the university is barely involved in its management.

As seen in table 6, the four campuses show a similar trend. Thus, the highest PE saving and the greatest reduction in GWP with the refurbishment strategies take place at the operational energy use stage of the buildings. The increase in PE and GWP in A1-5, B2, B4, C1-4 stages is worth noting. This fact is attributed to the proposed construction solutions, which involve the use of new elements (materials, installations, etc.) that initially demand energy expenditure. However, this slight increase is offset by a significant decrease in B6 and B7.

In order to give a general overview, in Figure 4 the percentage of impact reduction with respect to the baseline is depicted for the four campuses in the three scenarios.

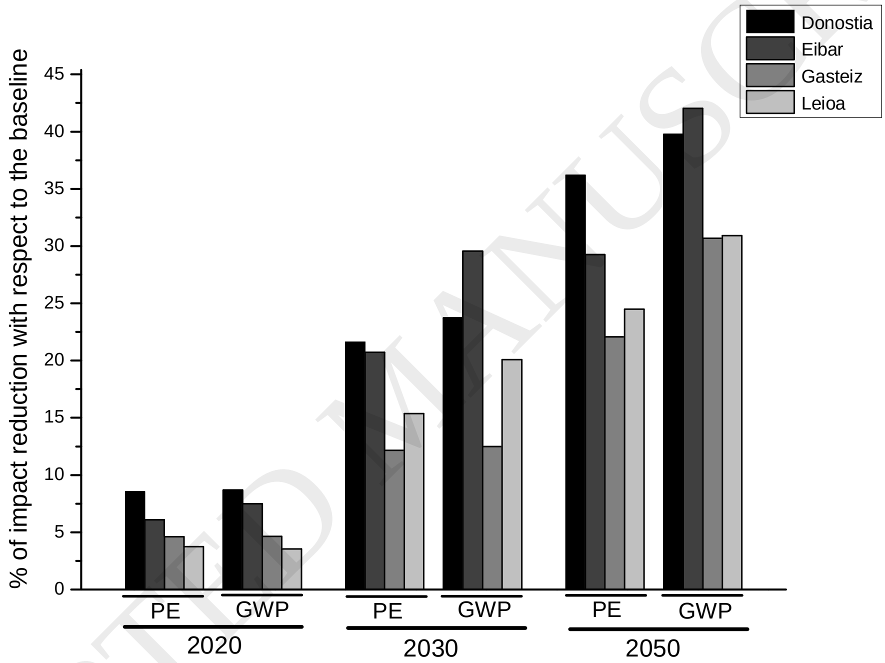


Figure 4 Impact variation (%) for four campuses studied in relation to the baseline.

It can be seen that the four campuses evolve in the same way, with reductions in terms of PE demand and GWP. Regarding PE, in 2020, the highest reduction occurs for Donostia, followed by Eibar and Gasteiz, and the lowest one is for Leioa. In 2030, the highest reduction is still for Donostia, but now a similar reduction is observed for Eibar. It now appears that the lowest reduction occurs for Gasteiz instead of Leioa. Finally, in 2050, the highest reduction is also for Donostia, followed by Eibar and Leioa, the lowest reduction being obtained for Gasteiz. Regarding GWP, a similar trend is found.

As mentioned above, the refurbishment strategies have virtually no impact on PE and GWP for public lighting and mobility. However, as seen in Table 5, the impact on mobility has a considerable effect on the total results for Leioa and Eibar. Therefore, in order to carry out a more precise analysis of the impact reduction due to the refurbishment strategies, the percentage of impact reduction without mobility is depicted in Figure 5.

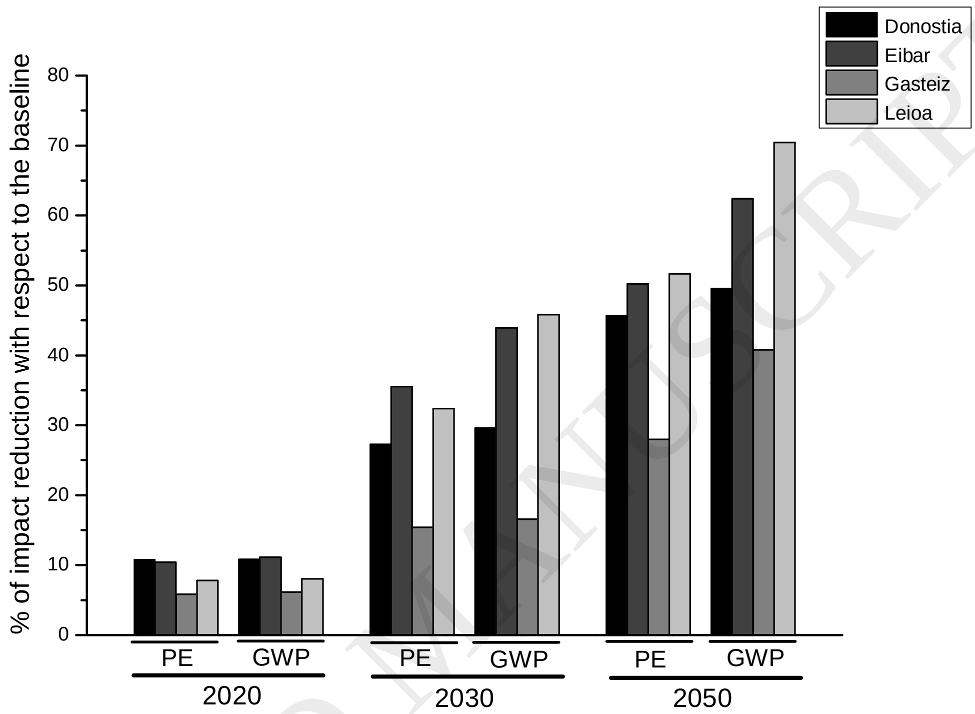


Figure 5 Impact variation (%) for the four campuses studied in relation to the baseline, without mobility.

As observed, the scenarios have changed. As before, PE and GWP have a similar trend, so both will be analysed jointly. In 2020, the reduction for Donostia and Eibar is similar and is the highest, followed by Leioa, the lowest being obtained for Gasteiz. In 2030, the highest reductions are for Eibar and Leioa, followed by Donostia, and the lowest for Gasteiz. In 2050, a similar trend is observed. The important reduction for Leioa is worth mentioning, especially with regards to GWP.

If mobility is not considered, and only the % reduction values are analysed, Leioa appears to be as sustainable as Eibar. These results could be attributed to the fact that Leioa has a large extension which allows concentrating buildings in a relatively compact space. Therefore, due to the fact that it is easy to centralize resources, especially in active strategies, the rehabilitation strategies are more successful in the long term. However, Leioa is an isolated peri-urban campus located on a hill 15 km away from Bilbao, with an impact on mobility of 13.168 MJ/(year*user) and 743 $kg_{eq}CO_2$ /(year*user), which is impossible to overcome with any rehabilitation strategy. Further, due to its geographical location, it is impossible to consider a strategy in terms of exclusive mobility by bicycle. It is also difficult to reduce the impact of other transport modes. The urban decisions taken, regarding location and typology, sometimes have a greater influence than any other approach to reform that may arise.

If the absolute values of PE and GWP consumption for 2020, 2030, and 2050 are analysed, it could be said that Eibar is the most sustainable campus, followed by Donostia. Gasteiz and Leioa have a similar behaviour.

When the impact of mobility was not taken into account, Gasteiz would be the least sustainable campus. Its type of urban campus, developed in the existing urban plot and based on recovering old buildings for university use, makes it difficult to share resources, and therefore, rehabilitation strategies have less impact in the long term.

Although Eibar is apparently the most sustainable campus, in terms of urban planning, it is similar to Donostia. However, its topographical and geographical characteristics do not allow its expansion, and thus it maintains reduced dimensions. Being compact is a benefit and makes it very sustainable, but it is not very effective for the development of university uses that require an expansion over the years.

Considering the university activity, it could be said that Donostia has the most appropriate typology, since it is a campus built on peripheral flat lands, which have been absorbed by the urban plot. Thus, the impact of mobility is low and can be reduced more easily in the future. It is less compact than Leioa and Eibar, but sufficient for rehabilitation strategies to have a high impact, as can be seen from our results. Although the impact of mobility is slightly greater than Gasteiz, the urban typology of Donostia is much more sustainable than implementing isolated buildings in the existing urban plot.

The impact reduction related to the refurbishment strategies: passive refurbishment, renewable strategies, passive house, and active strategies were analysed; Table 7 shows the results obtained.

As already mentioned, the refurbishment strategies have no impact on PE and GWP for public lighting and mobility, and they have a negative impact in A1-5, B2, B4, C1-4 stages, which is offset by a remarkable reduction in B6 and B7.

In 2020, the strategies with greater impact for the four campuses are the passive ones. However, in 2050 the highest reduction of PE takes place when the active strategies (electric boiler, natural gas, condensation, and biomass) are used. Worthy of note is Leioa, where, in 2050 the reduction of EP is estimated to be 30 times greater than in 2020. This is attributed to the fact that the refurbishment strategies chosen took into account that, over the last few years, several refurbishment works have been carried out and that no more would be done in the near future. Thus, the active strategies will be developed more easily coinciding with the ageing of the system installations.

With regard to the GWP, it can be said that the most interesting strategies are also the active ones, which, after implementation, could significantly minimize the Carbon Footprint of the campuses.

5. Conclusions

If we consider universities as "small cities", they have both a direct and an indirect impact on the environment. At the design stage, there is often a lack of budget, data, and experience to address these environmental problems that generally require cost and intensive data simulations. Previous research highlights the interest of the NEST tool, which allows rapid evaluation of different refurbishment strategies in different areas of the cities. However, this tool had not been previously used for analysing “university cities”.

Results have shown some differences between the four campuses and have helped the UPV-EHU to understand some critical issues. On the one hand, the evaluation carried out at baseline has helped to identify the critical environmental impacts and, therefore, to define the key action areas. On the other hand, comparing different scenarios helps to put the relative effects of some environmentally-respectful design choices into perspective, and to show the different impacts that they have on each type of university campus.

The results of the research mainly highlight 2 aspects:

- In the long term, rehabilitation strategies are more effective in compact suburban university campuses, while in the urban campuses, they are more limited.
- Regarding the impact of PE and total GWP, even applying these refurbishment strategies, the mobility especially penalizes the suburban campuses. This shows that urban decisions impact in excess.

Tools like NEST can place university designers on the right track to achieve an optimized design of university campuses, in terms of their location, typology, and distribution of buildings. These results can also encourage universities to conduct mobility studies of their students and workers, in order to raise awareness among the governing authorities to establish improvement policies.

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Table

Table 1 Building life cycle stages defined by EN 15978 [36] and the stages assessed by NEST.

	Product phase (A1-3)	Transport (A4)	On site processes (A5)	Maintenance (B2)	Replacement (B4)	Operational energy use (B6)	Operational water use (B7)	End-of-life phase (C1-4)
Buildings	X	X	X	X	X	X	X	X
Land use	X	X	X	X	X	X	X	X
Infrastructure	X				X	X	X	
Mobility	X	X	N/A	N/A	N/A	X		X

Table 2 Summary of aspects of the different UPV-EHU campuses.

	Donostia - San Sebastian	**Eibar**	**Vitoria - Gasteiz**	**Leioa**
General data				
Location	Donostia-San Sebastián	Eibar	Vitoria - Gasteiz	Bilbao
Climate zone	D1	D1	D1	C1
Service life of the district (years)	100	100	100	100
District users	12248	2792	9191	14773
Total surface of the district (m^2)	190243	28887	143855	395352
Residential surface (m^2)	0	4424	10636	0
Green surface (m^2)	8401	2576	8509	250468
Open space surface (m^2)	4166	3527	40363	46356
Other activities (m^2)	7404	2949	22129	82204
Parking surface (m^2)	1365	4574	1250	44959
University building surface (m^2)	36177	2813	94061	185641
Building characteristics				
Energy labelling – rating	A-B-C-D	C-D	A-B-C-D-E	C-D-E
Heating and DHW system	Natural gas	Natural gas and Electricity	Natural gas and biomass	Natural gas
Cooling	Electricity	Electricity	Electricity	Electricity
Renewable generation	1481 m^2 PV	77 m^2 ST	2787m^2 PV	2608 m^2 PV
Architectural protection grade	None	None	None	None
Population				
Active (administration workers, teachers and others)	7%	5%	9%	14%
Students	93%	95%	91%	86%
Mobility scenario				
Private car	4%	9%	9%	15%
Bus	31%	5%	39%	85%
Train	25%	37%	5%	0%
Bicycle	17%	2%	12%	0%
Walking	23%	47%	35%	0%
Public lighting				
Type-number	Fluorescence	High pressure sodium vapour		
Control system	Electronic ballast			

Table 3 Timeline objectives defined by the EU commitments.

	Reduction of GHG emissions	Energy from renewable sources	Improvement of the energy efficiency
2020	20%	20%	20%
2030	40%	27%	27-30%
2050	80-95%	-	-

Table 4 Refurbishment strategies proposed for Donostia-San Sebastian (DSS) - "Eibar" (EI) – "Vitoria-Gasteiz" (VG) – "Leioa" (LE) university campus. The strategies are defined by the percentage of its application.

Refurbishment strategy (Rs)		Baseline	2020	2030	2050
Passive refurbishment (Pr)	Façade (DSS)	None	30%	60%	90%
	Façade (EI)	None	20%	60%	100%
	Façade (VG)	None	10%	30%	40%
	Façade (LE)	None	20%	60%	100%
	Windows (DSS)	None	15%	25%	50%
	Windows (EI)	None	10%	20%	40%
	Windows (VG)	None	20%	40%	60%
	Windows (LE)	None	15%	30%	50%
Active strategies (As)	Electric boiler (EI)	83%	67%	17%	0%
	Natural gas (DSS)	100%	90%	65%	30%
	Natural gas (EI)	17%	17%	17%	17%
	Natural gas (VG)	64%	59%	44%	10%
	Natural gas (LE)	100%	90%	40%	0%
	Condensation (DSS)	None	10%	20%	40%
	Condensation (EI)	None	17%	50%	50%
	Condensation (VG)	None	5%	20%	40%
	Condensation (LE)	None	10%	20%	30%
	Biomass (DSS)	None	0%	5%	10%
	Biomass (EI)	None	0%	17%	33%
	Biomass (VG)	36%	36%	36%	50%
	Biomass (LE)	None	0%	30%	50%
Heat Pump with geothermal support	DSS	None	0%	10%	20%
	EI	None	0%	0%	0%
	VG	None	0%	0%	0%
	LE	None	0%	10%	20%
Renewable strategies (Rs)	Solar thermal (DSS)	0 m^2	100 m^2	300 m^2	750 m^2
	Solar thermal (EI)	77 m^2	100 m^2	120 m^2	200 m^2
	Solar thermal (VG)	0 m^2	0 m^2	50 m^2	175 m^2
	Solar thermal (LE)	0 m^2	0 m^2	300 m^2	1000 m^2
	Photovoltaic (DSS)	1481 m^2	1600 m^2	2500 m^2	4500 m^2
	Photovoltaic (EI)	0 m^2	50 m^2	150 m^2	300 m^2
	Photovoltaic (VG)	2787 m^2	3000 m^2	3500 m^2	5000 m^2
	Photovoltaic (LE)	2608 m^2	2800 m^2	4000 m^2	8000 m^2
Public lighting	DSS	High pressure sodium vapour (HPSV)		HPSV 70%, LED 30%	HPSV 25%, LED 75%
	EI			HPSV 100%	HPSV 70%, LED 30%
	VG			HPSV 75%, LED 25%	HPSV 40%, LED 60%
	LE			HPSV 60%, LED 40%	HPSV 30%, LED 70%

Table 5 Baseline results for Donostia-San Sebastian (DSS) - “Eibar” (EI) – “Vitoria-Gasteiz” (VG) – “Leioa” (LE) university campuses (per user and year). For life-cycle stage abbreviations: A1-3 (production), A4 (transport), A5 (on site processes), B2 (maintenance), B4 (replacement), B6 (operational energy use), B7 (operational water use) and C1-4 (end-of-life phase).

Impact indicator	**Sector**	**Life cycle stage** [25]	**DSS**	**EI**	**VG**	**LE**
PE (MJ/(year·user))	Buildings	A1-5, B2, B4, C1-4	171	504	753	1046
	Buildings	B6, B7	9132	5731	7752	10757
	Public lighting	A1-3, B4, B6	8	26	22	62
	Mobility	A1-4, B6, C1-4	2442	4470	2282	13168
	TOTAL		11753	10731	10809	25033
GWP ($kg_{eq}CO_2$/(year·user))	Buildings	A1-5, B2, B4, C1-4	9	26	38	53
	Buildings	B6, B7	445	285	368	525
	Public lighting	A1-3, B4, B6	1	1	1	3
	Mobility	A1-4, B6, C1-4	112	151	134	743
	TOTAL		566	463	541	1324

*Land use associated impacts are not considered here. During this exercise, no land use changes have been considered as part of the proposed energy refurbishment strategies.

Table 6 Global impacts of the baseline and the proposed scenarios, 2020, 2030, and 2050, for Donostia-San Sebastian (DSS) - "Eibar" (EI) – "Vitoria-Gasteiz" (VG) – "Leioa" (LE). For life cycle stage abbreviations: A1-3 (production), A4 (transport), A5 (on site processes), B2 (maintenance), B4 (replacement), B6 (operational energy use), B7 (operational water use) and C1-4 (end-of-life phase).

DSS

Impact indicator	Sector	Life cycle stage	Baseline	2020	2030	2050
PE (MJ/(year·user))	Buildings	A1-5, B2, B4, C1-4	171,0	231,0	311,2	392,6
	Buildings	B6, B7	9132,0	8065,3	6447,9	4658,3
	Public lighting	A1-3, B4, B6	8,0	8,0	7,2	4,8
	Mobility	A1-4, B6, C1-4	2442,0	2442,0	2442,0	2442,0
	TOTAL		11753,0	10746,3	9208,3	7497,6
GWP ($kg_{eq}CO_2$/(year·user))	Buildings	A1-5, B2, B4, C1-4	9,0	11,7	15,4	19,2
	Buildings	B6, B7	445,0	393,1	304,1	209,6
	Public lighting	A1-3, B4, B6	1,0	1,0	0,9	0,7
	Mobility	A1-4, B6, C1-4	112,0	112,0	112,0	112,0
	TOTAL		567,0	517,8	432,4	341,6

EI

Impact indicator	Sector	Life cycle stage	Baseline	2020	2030	2050
PE (MJ/(year·user))	Buildings	A1-5, B2, B4, C1-4	504,0	527,4	579,3	633,6
	Buildings	B6, B7	5731,0	5053,8	3430,8	2467,8
	Public lighting	A1-3, B4, B6	26,0	26,0	26,0	20,8
	Mobility	A1-4, B6, C1-4	4470,0	4470,0	4470,0	4470,0
	TOTAL		10731,0	10077,3	8506,2	7592,2
GWP ($kg_{eq}CO_2$/(year·user))	Buildings	A1-5, B2, B4, C1-4	26,0	26,9	28,8	30,9
	Buildings	B6, B7	285,0	249,3	145,3	85,7
	Public lighting	A1-3, B4, B6	1,0	1,0	1,0	0,8
	Mobility	A1-4, B6, C1-4	151,0	151,0	151,0	151,0
	TOTAL		463,0	428,3	326,1	268,4

VG

Impact indicator	Sector	Life cycle stage	Baseline	2020	2030	2050
PE (MJ/(year·user))	Buildings	A1-5, B2, B4, C1-4	753,0	787,3	849,4	899,9
	Buildings	B6, B7	7752,0	7219,7	6344,1	5221,3
	Public lighting	A1-3, B4, B6	22,0	22,0	20,2	18,7
	Mobility	A1-4, B6, C1-4	2282,0	2282,0	2282,0	2282,0
	TOTAL		10809,0	10311,0	9495,7	8421,9
GWP ($kg_{eq}CO_2$/(year·user))	Buildings	A1-5, B2, B4, C1-4	38,0	39,3	41,8	44,0
	Buildings	B6, B7	368,0	341,5	296,8	196,2
	Public lighting	A1-3, B4, B6	1,0	1,0	0,9	0,9
	Mobility	A1-4, B6, C1-4	134,0	134,0	134,0	134,0
	TOTAL		541,0	515,9	473,5	375,0

LE

Impact indicator	Sector	Life cycle stage	Baseline	2020	2030	2050
PE (MJ/(year·user))	Buildings	A1-5, B2, B4, C1-4	1046,0	1089,3	1179,8	1305,0
	Buildings	B6, B7	10757,0	9777,5	6790,0	4382,5

	Public lighting	A1-3, B4, B6	62,0	62,0	50,8	46,5
	Mobility	A1-4, B6, C1-4	13168,0	13168,0	13168,0	13168,0
	TOTAL		25033,0	24096,8	21188,6	18902,0
GWP ($kg_{eq}CO_2$/(year·user))	Buildings	A1-5, B2, B4, C1-4	53,0	54,1	56,7	60,8
	Buildings	B6, B7	525,0	477,2	255,7	108,7
	Public lighting	A1-3, B4, B6	3,0	3,0	2,5	2,3
	Mobility	A1-4, B6, C1-4	743,0	743,0	743,0	743,0
	TOTAL		1324,0	1277,3	1057,9	914,8

Table 7 Impact reduction related to refurbishment strategies at the proposed scenarios, 2020, 2030, and 2050, for Donostia-San Sebastian (DSS) - "Eibar" (EI) – "Vitoria-Gasteiz" (VG) – "Leioa" (LE).

			DSS			EI			VG			LE		
LC[1]	**Rs**	**Imp.***	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**
B1[2]	Pr	EP	-58,2	-128,1	-186,3	-21,0	-67,9	-113,5	-31,3	-86,2	-114,9	-41,6	-120,5	-208,2
		GWP	-2,6	-5,8	-8,4	-0,7	-2,4	-3,9	-1,2	-3,2	-4,3	-1,0	-3,0	-5,2
	Rs	EP	-1,7	-12,1	-35,2	-2,5	-7,5	-16,0	-3,0	-10,3	-32,0	-1,7	-13,3	-50,8
		GWP	-0,1	-0,6	-1,8	-0,2	-0,5	-0,9	-0,2	-0,5	-1,7	-0,1	-0,7	-2,6
B2[3]	PH (6)	EP	897,2	1719,1	2767,0	375,4	1031,6	1782,3	445,7	1081,4	1527,1	793,3	2113,8	3522,9
		GWP	43,7	83,8	134,8	18,7	51,3	88,6	21,2	51,3	72,5	38,7	103,2	171,9
	As	EP	169,1	1265,8	2938,9	318,7	2019,8	3105,9	81,3	335,7	1240,7	199,2	2820,4	6126,8
		GWP	8,2	78,4	190,5	18,3	166,8	335,8	5,2	21,5	167,2	9,7	331,7	1024,8
	Rs	EP	19,8	62,6	157,1	19,7	43,9	93,0	10,8	49,7	144,7	5,0	57,8	226,5
		GWP	0,9	3,0	7,6	0,9	2,1	4,4	0,5	2,4	7,0	0,2	2,8	10,9
Pl[4]	Pl	EP	0,0	0,8	3,2	0,0	0,0	5,2	0,0	1,8	3,3	0,0	11,2	15,5
		GWP	0,0	0,1	0,3	0,0	0,0	0,2	0,0	0,1	0,2	0,0	0,5	0,8
M[5]	M	EP	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
		GWP	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) LC: Life Cycle stage
(2) B1: Buildings (A1-5, B2, B4, C1-4)
(3) B2: Buildings (B6, B7)
(4) Pl: Public lighting
(5) M: Mobility
(6) PH: Passive House

*EP (**MJ/(year·user)**); GWP (**($kg_{eq}CO_2$/(year·user))**