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Multi-criteria methodology for the prioritisation of alternative energy transition scenarios of cities

Eneko Arrizabalaga Uriarte

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Under supervision of:

Prof. Luis del Portillo Valdés
PhD. Patxi Hernandez Iñarra

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If I have seen further,

it is by standing on the shoulders of giants

Abstract

Due to the high social and economic costs generated by the environmental context, the EU is committed to reduce drastically the aggregated greenhouse gas (GHG) emissions of its members by 2050. Exploring plausible pathways for the decarbonisation of the energy system of countries is becoming increasingly urgent to achieve GHG emissions reduction targets.

Energy is a key resource that is used in all economic sectors and the decisions made in the next few years will have important and long lasting implications in other aspects beyond climate change. Aspects such as economic growth, competitiveness of industrial subsectors, security of supply and social wellbeing will be conditioned by the direction of the energy transition.

Building and energy sectors have the greatest potential for cutting emissions. In the last few decades, cities have been attracting large population inflows from rural areas and nowadays they produce more than the 70% of the world's GHG emissions. Their role in environmental emission reduction and their potential for economic growth, employment and social wellbeing creation is widely acknowledged. Nevertheless, energy planning of cities is becoming increasingly complex due to rapid urbanisation and the necessity of transforming the urban environment to a fossil fuel-free future. There is a necessity to respond to the increasing use of resource and energy while ensuring the social wellbeing of their citizens. Moreover, many energy efficiency measures and new infrastructures and technologies for low carbon energy generation need to be integrated within the city boundaries.

The aim of this thesis is to develop a general framework for long-term city energy planning and a methodology capable of comparing different energy transition scenarios that will shape the path towards a low carbon future for cities. The methodology is developed in detail for the building sector energy planning, including energy generation, distribution and building operation energy use.

The core of the methodology relies on a multi-criteria (environmental, economic, social) and multi-scale (intervention, city, region) ex-ante impact assessment of energy transition scenarios. In the methodology the energy modelling and the life cycle impact assessment methodologies are combined with input-output based regional macroeconomic methodologies through supply chain analysis. In order to respond to the scale and the objectives of the study, the life cycle assessment framework has been adapted. In addition, the procedures for establishing links between methodologies of different scales have been defined. In order to perform a detailed analysis of the interventions and scenarios, the thesis also identifies the need for a more detailed hourly energy demand analysis of the city.

The developed methodology is applied to the case study of Donostia-San Sebastián, illustrating its practical use and demonstrating the importance of simultaneously considering various

potentially conflicting criteria for the prioritisation of scenarios. The results also demonstrate the relevance of other life cycle phases respect to the operational phase as well as the relevance of the indirect and induced socioeconomic impacts of energy transition scenarios for the strategic decision making.

In a wider perspective, the results obtained demonstrate the applicability of the developed methodology for providing useful criteria to support municipalities during the decision making processes linked to cities' energy planning.

Laburpena

Ingurumenaren testuinguruak sorturiko kostu sozial eta ekonomiko larriak direla eta, Europar Batasunak bere estatu kideen berotegi-efektuko gasen isurketa erabat murrizteko konpromezua hartu du 2050 urterako. Finkatutako berotegi-efektuko gasen isurketa murrizketetara irizteko, energia sistemaren deskarbonizazioa lortzeko bide sinesgarriak aurkitzea premiazkoa bihurtzen ari da.

Energia jarduera ekonomiko guztietan erabiltzen den baliabide kritikoa da eta hurrengo urteetan hartuko diren erabakiek aldaketa klimatikotik haratago doazen arloetan ere epe luzeko ondorio garrantzitsuak eragingo dituzte. Energia trantsizioak harturiko norabideak ekonomiaren garapena, industriaren hainbat azpisektoreen lehiakortasuna, horniduraren segurtasuna eta gizartearen ongizatea baldintzatuko ditu besteak beste.

Eraikinen eta energia sektoreak emisioen murrizketa lortzeko aukera handienak dituzten sektoreak dira. Azken hamarkadetan hiriek inguruko herri txikietatik biztanleriaren kantitate handia erakarri izan dute, gaur egun munduko berotegi-efektuko gasen isurketen %70-aren arduradunak izatera heldu arte. Beraien rola isurketen murrizketan, eta beraien potentziala ekonomia bultzatzeko, enplegua sortzeko eta ongizate soziala bermatzeko garaian guztiz onartua dago gaur egun. Hala ere, urbanizazio azkarrak eta hiri ingurumena karbono baxuko etorkizunerantz eraldatzeko beharrizanak, hirien energia plangintza lan gero eta konplexuagoa bihurtzen dute. Hiritarren ongizate soziala bermatzen den aldi berean, baliabideen eta energiaren erabileraren hazkundeari erantzuteko beharrizana baitago. Gainera, hiriek beraien eremuen barnean energia eraginkortasuna bultzatuko duten zenbait neurri eta karbono baxuko energia sorkuntza deszentralizatua baimenduko duten azpiegitura eta teknologia berriak izango dituzte.

Tesi honen xedea, epe luzeko hirien energia plangintzarako esparru orokor bat eta gure hiriak karbono baxuko etorkizun batera gidatuko dituen energia trantsizio eszenario ezberdinak alderatzeko gai den metodologia bat garatzea da. Metodologia hau eraikinen sektorearen energia plangintzarako garatzen da xehetasunez, bai energia sorkuntza eta horniketa eta baita eraikinen erabileran emandako energia kontsumoa kontuan hartuz.

Metodologiaren bihotza trantsizio eszenarioen irizpide anitzeko (ingurumena, ekonomia, soziala) eta eskala anitzeko (proiektu, hiri, eskualde) eraginaren ebaluazioan datza. Garatutako metodologiak energia modelizazioa eta bizi zikloaren analisian oinarritutako metodologiak eskualde mailako eragin makro ekonomikoak aztertzeko erabiltzen den input-output metodologiarekin lotzen ditu hornidura katearen ebaluazioaren bitartez. Ikerketaren eskala eta helburuari erantzuteko, metodologiak bizi zikloaren analisiaren esparrua moldatzen du eta eskala desberdinetako metodologien arteko lotura ezartzeko prozedurak definitzen ditu. Gainera,

proiektuen eta eszenarioen xehetasunezko analisia egiteko garaian, tesian hiriaren energiaren beharrizanen orduz orduko analisia egiteko beharra identifikatzen da.

Garatutako metodologia Donostia hirian aplikatzen da bere erabilera praktikoa argituz eta eszenarioak lehenesteko garaian gatazkan egon daitezken zenbait irizpide aldi berean kontutan hartzearen garrantzia frogatuz. Lortutako emaitzek, erabilera-etaparekiko bizi zikloaren beste etapen garrantzia frogatzen dute. Baita erabaki estrategikoak hartzeko garaian, zeharkako eta induzitutako eragin sozioekonomikoak kontutan hartzearen garrantzia ere.

Ikuspegi orokorrago batetik, lortutako emaitzek garatutako metodologiaren aplikagarritasuna frogatzen dute. Hirien energia plangintzaren testuinguruan erabakiak hartzeko orduan lagungarri izan daitezkeen irizpideak emateko balio izango du hain zuzen ere.

Resumen

Debido al elevado coste económico y social generado por el contexto medioambiental, la UE se ha comprometido a reducir drásticamente las emisiones de gases de efecto invernadero (GEI) de los estados miembro para el año 2050. La búsqueda de vías plausibles para la descarbonización del sistema energético resulta cada vez más urgente para alcanzar los objetivos fijados para la reducción de emisiones de GEI.

La energía es un recurso clave utilizado en todos los sectores de actividad económica y las decisiones que se tomarán durante los próximos años tendrán implicaciones importantes y duraderas en varios aspectos más allá del Cambio Climático. Aspectos tales como el crecimiento económico, la competitividad de los diferentes subsectores industriales, la seguridad de suministro o el bienestar social se verán condicionados por la dirección tomada por la transición energética.

El sector edificios y el sector energético tienen el mayor potencial de reducción de emisiones. Durante las últimas décadas las ciudades han atraído una gran cantidad de población desde las zonas rurales y actualmente representan más del 70% de las emisiones de GEI del mundo. Su rol en la reducción de emisiones y su potencial como motor de la economía, creación de empleo y bienestar social es ampliamente reconocido. Sin embargo, la planificación energética de ciudades se está convirtiendo en un proceso cada vez más complejo debido a la rápida urbanización y a la necesidad de transformar el entorno urbano hacía un futuro bajo en carbono. Existe la necesidad de dar respuesta a un creciente uso de recursos y energía al mismo tiempo que se asegura el bienestar social de sus ciudadanos. Además, la ciudad deberá albergar dentro de sus límites numerosas medidas de eficiencia energética y nuevas infraestructuras y tecnologías que serán necesarias para la generación descentralizada de energía baja en carbono.

El objetivo de esta tesis es desarrollar un marco general para la planificación energética de ciudades y una metodología capaz de comparar diferentes escenarios de transición energética que guiarán la transformación de nuestras ciudades hacia un futuro bajo en carbono. La metodología se desarrolla en detalle para la planificación energética del sector edificios, incluyendo la generación y distribución de energía en la ciudad así como el uso de energía durante la operación de los edificios.

El núcleo de a metodología se basa en la evaluación de impacto multi-criterio (ambiental, económico y social) y multi-escala (intervención, ciudad y región) de los escenarios de transición. La metodología desarrollada combina el modelado energético y las metodologías de análisis de ciclo de vida con la metodología de evaluación de impacto macroeconómico input-output regional a través de la evaluación de la cadena de suministro. Con el propósito de responder a la escala y el objetivo del estudio, la metodología adapta el marco de evaluación del

análisis de ciclo de vida y define los procedimientos para establecer los vínculos entre las metodologías asociadas a las diferentes escalas. Además, en la tesis se identifica la necesidad de realizar un análisis horario de la demanda energética de la ciudad para asegurar una evaluación detallada de las intervenciones y de los escenarios.

La metodología desarrollada es aplicada a la ciudad de Donostia-San Sebastián, ilustrando su uso práctico y demostrando la relevancia de la consideración simultanea de varios criterios potencialmente conflictivos para la priorización de escenarios. Los resultados también demuestran la importancia del resto de las fases del ciclo de vida respecto de la fase de operación, así como la relevancia de los impactos socioeconómicos indirectos e inducidos de los escenarios de transición para la toma de decisiones estratégica.

Desde una perspectiva más amplia, los resultados obtenidos demuestran la aplicabilidad de la metodología desarrollada en el contexto de la planificación energética para proporcionar criterios útiles que apoyen a las municipalidades durante el proceso de toma de decisiones.

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Ezin ahaztu hurbilen ditudan ekipoko lankideak. Eskerrak bereziki Larari bere eskuzabaltasunagatik eta Xabateri tesiaren prozeduren inguruan emandako aholkuengatik. Ezin ahaztu Azpeitiko lankide guztiak ere, lanean hasi nintzanetik giro ezin hobea sortu izan duzue eta azken urtean asko bertaratu ez nazen arren, gogoan zaituet hitz hauek idazten ditudan bitartean.

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Azkenik, nire eskerrik zintzo eta berezienak nire familiari. Naiara, bidea zabaldu eta ibili daitekeela erakutsi didazu, beti ere eredu bikaina izan zara. Aitari eta amari, beti laguntzeko prest egon izanagatik eta momentu gogorrenetan ere kemenarekin aurrera egin daitekeela egunero frogatzeagatik. Eta Itzal, zure pazientzia, alaitasuna eta maitasuna ezinbestekoak izan dira. Tesi hau zuentzako da.

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List of abbreviations

AHP	Analytical Hierarchy Process
BAHED	Building Annual Heating Demand
BHHD	Building Heating Hourly Demand
BIOM	Biomass
Ca,I (int)	Net cash flow of the intervention in the year i
CAPEX	CAPital EXpenditures
CAPV	Comunidad Autónoma del País Vasco
CBB	Biomass central heating boilers
CDCBP	Cumulative Discounted Cost in Basic Prices
CDCBPD	Cumulative Discounted Cost in Basic Prices Domestic
CDCPP	Cumulative Discounted Cost in Purchase Prices
CGE	Computable General Equilibrium
CGWPRint	Cumulative Global Warming Potential Reduction of the intervention
CI,i(int)	Investment cost of the interventions in the year i
C-LCA	Consequential Life Cycle Assessment
CLREGTS	Cumulative Local Renewable Electricity Generation Increase of the transition scenario
CLEGTS	Cumulative Local Energy Generation Increase of the transition scenario
CLRHGTS	Cumulative Local Renewable Heat Generation Increase of the transition scenario
CNGB	Natural gas central heating boilers
CNPCint	Cumulative Net Present Cost of the intervention
CNPC-PPCTS	Cumulative Net Present Cost of Public Private Companies
CNPC-STS	Cumulative Net Present Cost-Social of the transition scenario
CNPVTS	Cumulative Net Present Value of the transition scenario
CNR-PER	Cumulative Non-Renewable Primary Energy Use Reduction
CSHPNG	Central Solar Heating Plants with Seasonal Storage and natural gas boilers
CSHPB	Central Solar Heating Plants with Seasonal Storage and biomass boilers
DHCHPB	District heating with combined heat and power, wood chips fired
DHCHPNG	District heating with combined heat and power, gas-fired
DHNGB	District heating with biomass and natural gas boilers
DHW	Domestic Hot Water
DPPint	Dynamic Payback Period of the intervention

EIO	Environmental Input-Output
ECY	Energy Consumption of the fuel y
ERY	Energy Replaced of the fuel y
ESCO	Energy Savings Company
ESSDcity	Electricity Self-Sufficiency Degree of the city
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographical Information Systems
GWPfy	Global Warming Potential conversion factor for the fuel y
HNf	Heating Normalized Factor
HP	Heat pumps
HSSDcity	Heat Self-Sufficiency Degree of the city
INGB	Natural gas individual heating boilers
IO	Input Output
K	The number of different type of fuels consumed
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCI	Life Cycle Inventory
LCIA	Life Cycle Inventory Assessment
LCOPE	Life Cycle Operational Primary Energy
m	Marginal Propensity of Consumption
MADM	Multi-Attribute Decision Making
MCDA	Multi-Criteria Decision Analysis
MODM	Multi-Objective Decision Making
NG	Natural Gas
NRPEfy	Non-Renewable primary Energy conversion factor for the fuel y
OPEX	OPerating Expense
PIFB	Passive interventions for buildings
QSHD	Individual heat demand for each consumer
QSHL	Heat load for space heating
QSHWL	Heat load for domestic hot water
r	Discount rate
Rd	Discount factor

RE	regional Employment
RGDP	Regional Gross Domestic Product
RU	Reference Unit
SAM	Social Accounting Matrixes
SLCA	Social Life Cycle Assessment
SPV	Solar photovoltaic system
ST	Solar thermal heating systems
STES	Seasonal Thermal Energy Storage
T	Transition period
Vf	Residual Value

CHAPTER 1

Introduction

1. Chapter 1: Introduction

1.1. Context and motivation

<u>Energy in the international context</u>

Use of fossil fuels has predominated the generation of energy used for satisfying the rapid growth in energy demand that has occurred in the world since 1970. The influence of this trajectory on the increase of global CO_2 concentration in the atmosphere has been notable, reaching global values of 400ppm in 2015 (Dlugokencky & Tans, 2016). Nowadays, it is accepted that unless additional actions are taken immediately, these values will exceed 450ppm this century, value that, according to the IPCC, would result in a global temperature rise of 2ºC above pre-industrial levels. This phenomenon would provoke an environmental context of terrible weather anomalies and associated unacceptable social and economic costs.

Recent global agreements on climate and sustainable development confirm that there is an emerging consensus on putting sustainable energy at the top of the global development agenda. The adoption of the first-ever universal and legally binding global climate deal at the Paris climate conference (COP21) in December 2015 represents a turning point where energy decarbonisation became the main focus of the efforts to reduce greenhouse-gas emissions. This recent decision will inevitably condition the global energy transition.

Evaluating the evolution and exploring the most likely energy futures have been the focus of several studies in recent years. According to one of the latest studies of the World Energy Council (WEC), the main factors that have shaped world energy until 2015 are related to new technologies and productivity, population and labour force growth, environmental priorities, and international governance and geopolitical relationships (see Figure 1).

Although there are many factors that cannot be predicted with security currently, alternative scenarios developed by experts in the field show that there are several drivers, such as lower employment growth, linked to a decline in population, a tendency towards the electrification of energy demands, the rise of non-fossil fuel-based energy technologies, the necessity for the diversification of transport fuels, increasing carbon prices, and a shift in economic and geopolitical power towards Asia, that will influence the future energy system.

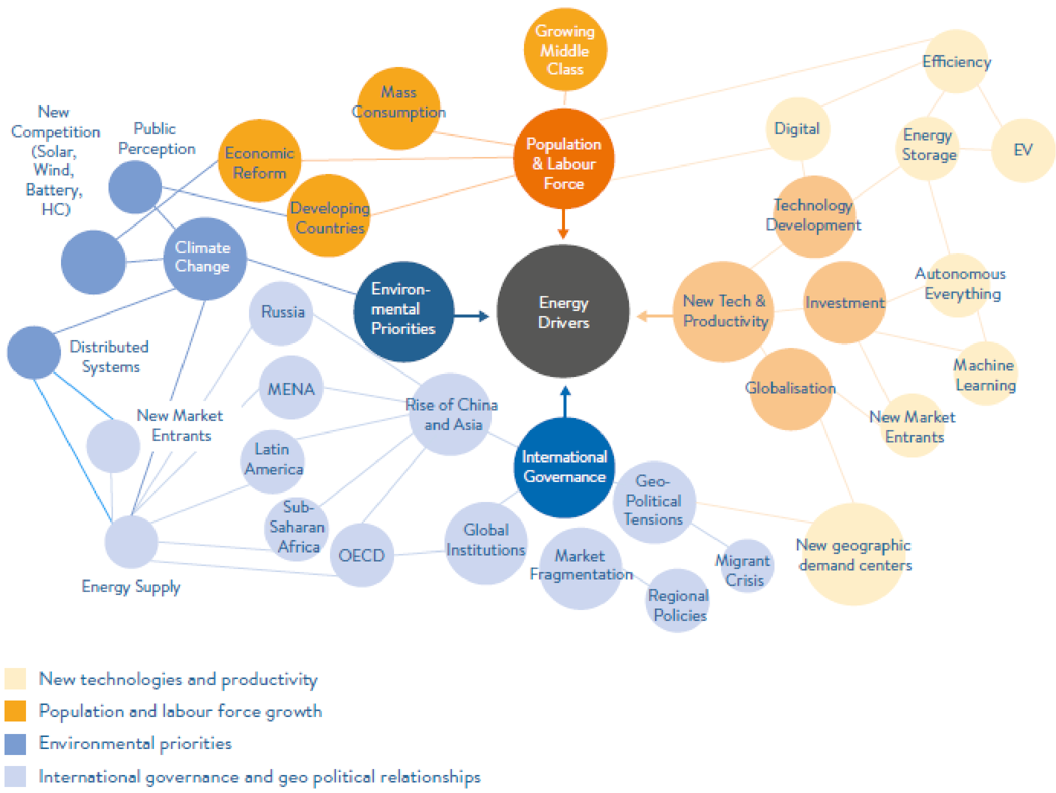

Figure 1. Factors that shaped world energy from 1970 to 2015 (World Energy Council, 2016).

The comparison presented by the WEC between the three future global energy scenarios developed to explore the main plausible pathways (titled Modern Jazz, Unfinished Symphony, and Hard Rock) reflects how the direction followed and the decisions made during this transition period will result on very diverse impacts on economic growth, the environment, and society.

EU's role

With a combination of financial support and regulation, the EU has been at the forefront of international efforts to avoid the worst scenarios of climate change. The EU is committed to reducing the aggregated GHG emission of developed countries by at least 80% by 2050 compared to 1990 levels. The roadmap proposed by the European Commission for moving to a competitive low-carbon economy in 2050 (EC, 2011a), shows that all sectors need to contribute to the low-carbon transition. More specifically, it is foreseen that emissions from transport could be reduced to more than 60% below 1990 levels by 2050, emissions from houses and office buildings could be reduced by around 90%, energy intensive industries could cut emissions by more than 80%, emission reduction in agriculture would also be necessary, and the sector with the biggest potential for cutting emissions, the power generation and distribution sector could almost totally eliminate CO_2 emissions by 2050, as shown in Figure 2.

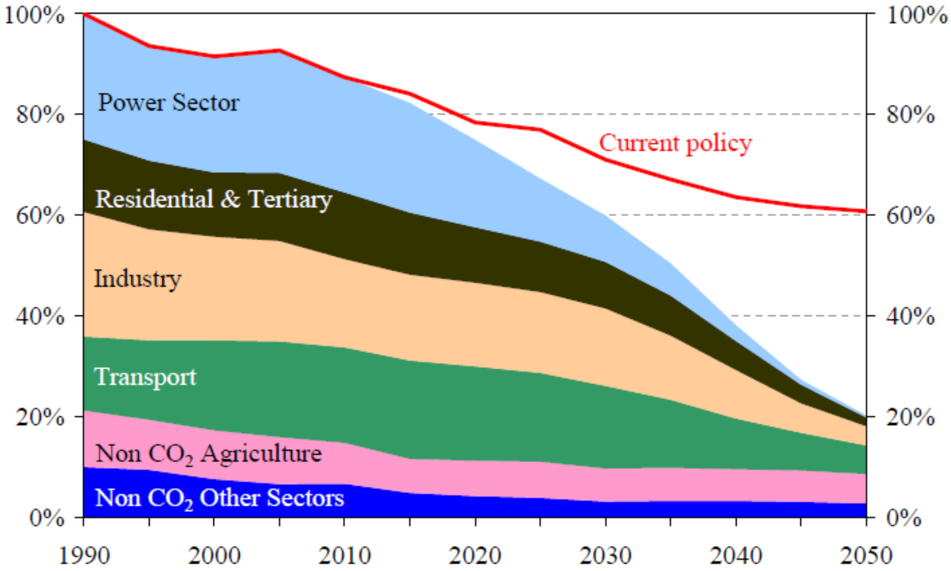

Figure 2. EU GHG emissions towards an 80% domestic reduction (1990=100%) (EC, 2011a).

The relevance of the energy sector is such that the goal of the decarbonisation of the EU is carefully evaluated in the Energy Roadmap 2050 (EC, 2011b). This roadmap shows that although the Energy 2020 goals and the Energy 2020 strategy were ambitious, they are insufficient for achieving the EU's 2050 decarbonisation objective. However, it emphasises that the decarbonisation of the energy system is feasible from a techno-economic point of view by making a significant investment in new low-carbon technologies, renewable energies, energy efficiency, and grid infrastructure.

The scenarios show that the long-term costs of inaction will be greater than the cost of the actions. In fact, the EU imports 53% of the energy it consumes, creating a big dependence on the external energy suppliers of several countries. Moreover, the associated costs of these imports are more than €1 billion a day, (European Energy Agency, 2014). Therefore, it is evident that changing the way of producing and using energy will have a major impact on the economy, society, and the environment.

Currently, the European energy system is engaged in a profound transformation process, where the complexity of the market is increasing due to the need for greater flexibility with the integration of bigger shares of renewable energies, better interactions between large-scale and decentralised generation, the inclusion of the consumer as an active player, and a progressive increase in energy efficiency.

The challenge and the opportunity linked to the energy transition

Ensuring energy security, competitiveness and sustainability has become essential for the socioeconomic development of our countries. Energy is a key resource that is used in all economic sectors and its instability can directly affect their competitiveness, which can result in negative social impacts. Besides, in many cases, the energy sector itself is one of the most relevant sectors with regard to economic activity and the employment created and maintained throughout the supply chain of each phase, from fuel extraction to energy transformation, distribution, and consumption.

Therefore, considering that direct and indirect environmental emissions related to energy have a clear influence on climate change, energy transition brings a unique opportunity for meeting climate goals while fuelling economic growth and enhancing human welfare (IRENA, 2016).

In this context, not all countries will have to contribute in the same way to emissions reduction. Each country will have to decide what can be done in a way that conforms to their possibilities and commitments, and the way in which the energy matrix will be changed by the energy generation and consumption patterns. Policy-makers will have to explore low carbon energy supply options, considering their impacts on aspects, such as the security of supply, the dependency on imported fossil fuels, and cost effectiveness.

The direction of the path followed during the transition will determine, among other aspects, the focus of important investments that will be carried in specific energy technologies and infrastructures. These investments will have long-term implications not only from the point of view of their effect on aggregated GDP growth, but also on the way that different economic sectors in general and different subsectors in particular will evolve towards a new structure.

The decisions made during this period and the new situation thus created will also affect critical aspects, such as the vulnerability or the response capacity of countries and regions to new potential economic crises. Moreover, these decisions will condition social development and the resulting situation regarding equity and social cohesion.

Role of cities, regions and local authorities

The text of the Paris agreement highlights the relevance of the role of cities and regions in addressing climate change. Years before, the EU had already illustrated this idea in documents such as the ‘Opinion of the Committee of the Regions — Towards an Integrated Urban Agenda for the EU’, where cities were identified as potential motors for economic growth, employment, and social wellbeing creation and emissions reduction. Other initiatives such as the ‘Joint programme on Smart Cities of the European Energy Research Alliance (EERA) within the Strategic Energy Technology Plan (SET-Plan)’ and the ‘Covenant of Mayors for Climate & Energy’, which is the world’s biggest urban climate and energy initiative, represent the need for urgent planning processes and actions at the city scale.

Cities became attractive in comparison with rural areas due to the great opportunity of socioeconomic growth that they represent. A large part of the world's population, in looking for better employment opportunities, infrastructures and services, have moved to cities, which nowadays represent more than the 70% of the world's GHG emissions. This migration tendency is expected to continue and some forecasts show that more than the 70% of the world population will be living in cities by 2050.

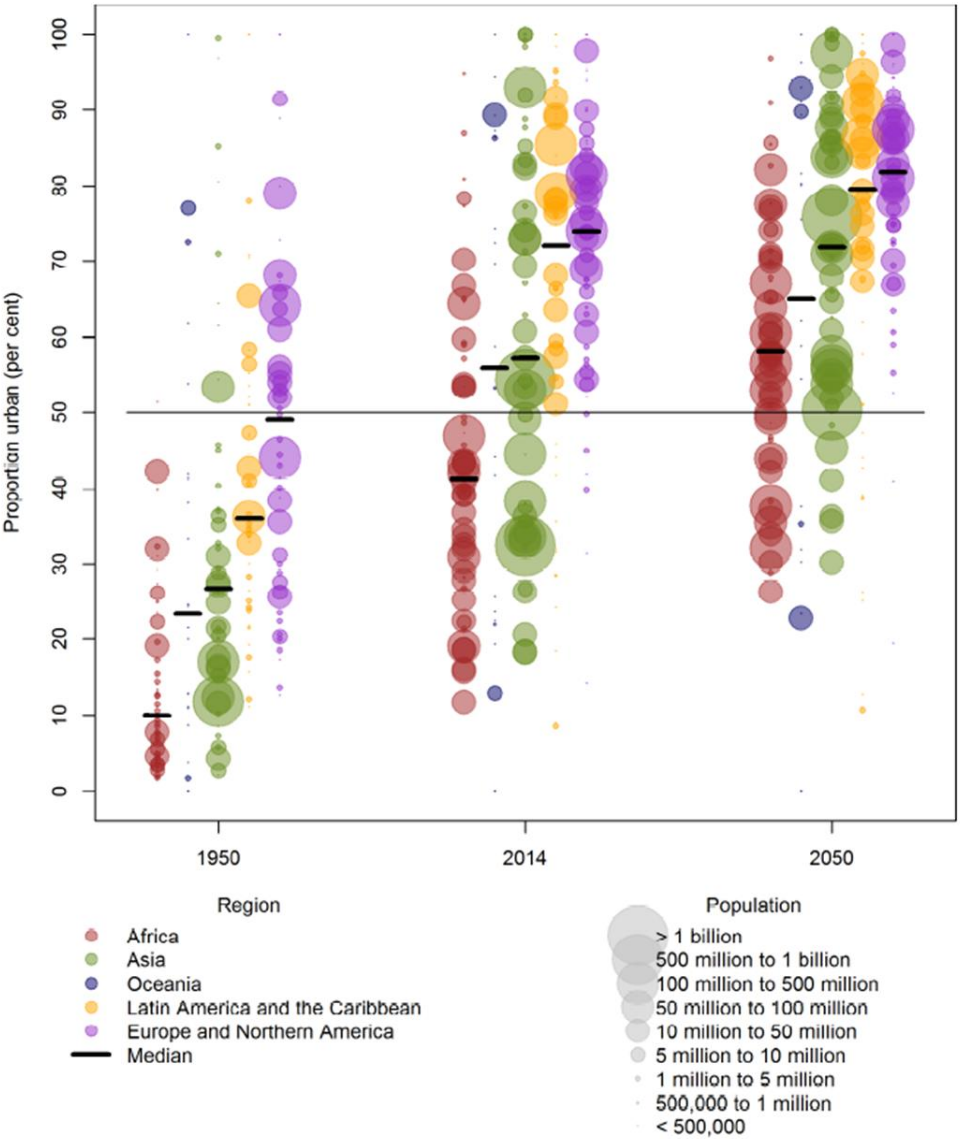

Figure 3. The urban percentage of all countries by geographic area and population size in 1950, 2014 and 2050 (United Nations. Department of Economic and Social Affairs/Population Division, 2014).

This mobilisation represents a big challenge for cities that have to face a significant increase in their resource, energy, and infrastructure needs, among others while ensuring, at the same time, the social wellbeing of their citizens and the achievement of the GHG emission reduction targets set by the European Commission. In fact, as pointed out by (Jian & Zhengang, 2015), urbanisation is not only the physical expansion of cities and the growth of populations living in them, but it is also a change in social production and life-style. In parallel with cities, the expectations of citizens are also growing and becoming increasingly immediate, and citizens expect the same kind of access and quality from city services.

Moreover, this fast urbanisation and over-concentration of populations have led, to several challenges for sustainable urban development and have made cities vulnerable in terms of achieving comfortable living standards for their citizens. Some of the problems related to rapid urbanisation are traffic congestion, pollution, and noise, greater vulnerability to natural disasters, lack of green space, lack of preservation of the heritage and the environment, inadequate infrastructure, and inadequate social inclusion (Broere, 2016).

The results are also inevitable in terms of the building stock of our cities. In Europe, buildings are responsible for around 40% of total GHG emissions (Saheb, 2016). This is a sector with a huge improvement potential through the implementation of cost-effective energy efficiency measures.

Therefore, as the world becomes more urbanised, maintaining cities sustainably is becoming a priority for policy-makers and new strategies will have to be adopted by municipalities to ensure sustainable growth in a context where the energy planning of cities is getting increasingly complex. This complexity largely has arisen from the necessity of integrating within city boundaries new infrastructures and energy technologies that are necessary for the decentralisation of energy generation. The transformation and strengthening of grids, combined with flexible energy generation, the optimum use of different storage options, building refurbishment and demand-side management, will become the main challenges in future years. In this regard, the transformation of the electricity grid and the incorporation of information and communications technologies into electricity transmission and distribution could be useful for minimising environmental impacts, enhancing markets, improving reliability and services, and reducing costs of the electricity sector (Kempener et al., 2013). In the same way, for the heating sector, district heating and cooling networks may facilitate the integration of renewable heat and improve the efficiency. Important linkages can be also created between the heating and power sectors through the use of technologies such as cogeneration, increasing, in this sense, the overall flexibility of the system.

In this context, prioritising the different available energy efficiency measures and technologies for building energy demand reduction and for renewable and efficient energy supply, as well as the design and optimisation of the city energy flows, is necessary. In the next few years, greater efforts will be required of city planners, for whom one of the main challenges will be to solve the existing disconnection between long-term environmental change and shorter-term planning horizons that are usually linked with a political vision.

The necessity of holistic approaches to city energy planning and impact assessment

In a context where the competition between cities is rapidly increasing on securing investment, business, and talent, while simultaneously reducing environmental emissions, city energy planning has become a critical and complex issue that can only be faced through a holistic approach and using innovative tools that help local authorities during the decision-making process. Although every city has its own particularities and needs to find its own path, as evaluated by (Mirakyan & De Guio, 2013), most long-term, model-based energy planning processes follow a common scheme. The main steps of this scheme are shown in Figure 4.

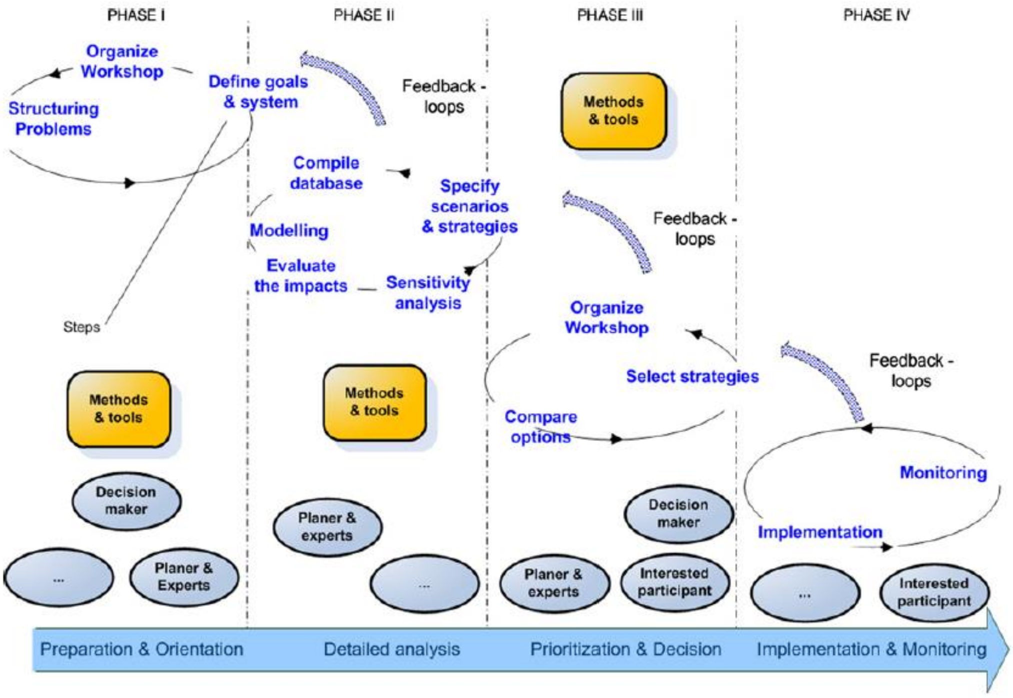

Figure 4. General procedure for integrated energy planning in cities and territories (Mirakyan & De Guio, 2013).

However, even if the main impediments to be considered are identified and agreed, as described in Chapter 2, there is a lack of specific frameworks that define in detail the procedure to be followed in order to define and prioritise the optimum energy transition scenarios for cities.

In focusing on energy generation, distribution, and consumption for the buildings of cities, in order to consider a holistic approach, city energy planners need to combine various complex methodologies and tools with different time steps, scales and approaches, for which clear linkages are still unavailable.

This situation makes it difficult for municipalities to develop a baseline analysis of the energy demand and supply of their cities as well as a definition and evaluation of the potential medium or long-term energy transition scenarios that will help to transform their cities.

1.2. Research hypothesis

Intelligent energy planning applied to energy transition scenarios can reduce the energy demand and environmental emissions of cities while reducing the dependence on imported fossil fuels, ensuring security of supply, optimising economic growth, and enhancing human welfare. Holistic approaches, specific frameworks, and innovative methods are necessary to help local authorities during this process.

The hypothesis that we wish to test in this thesis may be summarised as follows:

Energy modelling of buildings, energy technologies and systems, and life cycle impact assessment methodologies can be combined with other macroeconomic methods through a supply chain analysis technique in order to evaluate and prioritise different long-term energy transition scenarios for cities.

A multi-criteria and multi-scale ex-ante impact assessment of alternative energy transition scenarios of cities, provides useful criteria that can be used to assist municipalities during the decision-making process of energy planning.

1.3. Objectives of this work

The main objective of this thesis was to develop a general framework for long-term city energy planning and a methodology capable of comparing different energy transition scenarios that will shape the path towards a low carbon future for our cities.

Evaluating the impacts associated with the implementation of each scenario, this methodology aims to identify the optimum scenario that will guide the transformation of the energy generation, distribution and consumption of the building sector of cities.

Considering the main objective of this thesis, the specific objectives are listed as follows:

- To define a framework for a city energy transition scenario analysis that considers the entire process. The phases of city contextualisation, definition, evaluation, and the impact assessment of potential scenarios and the prioritisation of such scenarios will be included
- To develop an impact assessment methodology that evaluates the environmental, economic, and social dimensions and that takes into account not only the direct impacts, but also the indirect and induced impacts
- To develop a methodology that serves to evaluate the effects from different perspectives and for different scales. Considering the project or intervention analysis, the effects that will originate in the entire city due to the progressive implementation of interventions and the potential effects of the city transition scenario at the regional scale
- To adapt the existing methodologies that are included in the analysis to the specific purpose of the work and to formulate specific indicators for each phase of the methodology
- To define and establish the necessary linkages, between the methodologies that comprise the final methodology
- To discuss and demonstrate how such a methodology could be applied within the building and energy generation and distribution sectors of cities and the implications of this approach for city energy planning

1.4. Thesis structure

The thesis is divided into five chapters. The first chapter reviews the relevance of energy use to avoiding the worst scenarios of climate change in the international and European contexts and focuses on the identification of the main challenges and opportunities linked to the energy transition. It also provides a vision of the role of regions and cities in the decarbonisation of the energy system and identifies the necessity of applying holistic approaches to problem-solving in the context of city energy planning. Moreover, it introduces the research hypothesis and the objectives of the thesis and describes the content and the dissertation structure.

The findings of the literature review are discussed in Chapter 2. This chapter assesses the most relevant topics that need to be considered for the purpose of the thesis. The review covers the main activities of various fields, such as a sustainable energy transition scenario, city energy planning, and a sustainability assessment in the context of city energy planning where different city sustainability frameworks and impact assessment methodologies are assessed.

Chapter 3 presents the development of the methodology for the analysis and the prioritisation of alternative energy transition scenarios for cities. Section 3.1 introduces the main phases of the framework proposed by the methodology, while sections 3.2 to 3.7 describe the methodology developed. Within these sections, subsection 3.4.1 focuses on the definition of a methodology for the energy characterisation of the building stock of cities and section 3.6 focuses on the definition of the methodology for the multi-criteria analysis of energy transition scenarios of cities, representing the most relevant contributions of the methodological development.

The validation of the methodology is the subject of Chapter 4. This chapter describes the main outcomes of the application of the sustainability assessment framework of city energy transition scenarios defined in Chapter 3 to the case study of Donostia-San Sebastián. In this chapter, the different stages of the methodology developed are tested in a real case study and the main results are discussed.

Finally, Chapter 5 provides the conclusions and makes recommendations for the application of the methodology. This chapter also describes the possibilities of future work.

All the references provided throughout this thesis are included in the reference section after the appendices, which provide complementary information for the different chapters of the thesis.

1.5. Scientific impacts

Even though some results have been already published, the dissemination of the results is under process. The most relevant contributions of the research undertaken are subsequently listed.

International Journals

- **Arrizabalaga, E.**, Hernandez, P., Del Portillo-Valdés., L. (2017). Profiling city energy use for the evaluation of alternative energy technologies. A case study of the city of Donostia-San Sebastián. Energy and Buildings – *Submitted*

- Rabaneda, A., Zambrana-Vasquez, d., Aranda-Usón, A., Zabalza-Bribián, I., Jañez, A., Ilera-Sastresa, e., Hernandez, P., **Arrizabalaga, E.** (2015). Environmental assessment of domestic solar hot water systems: a case study in residential and hotel buildings. Journal of Cleaner Production 88 (2015), 29- 42

International conferences

- **Arrizabalaga, E.**, Hernandez, P., Del Portillo-Valdés., L. (2017). Long term energy transition scenario analysis for the city of Donostia. The 5th annual Sustainable Places International Conference (SP'17). Middlesbrough, UK.

- **Arrizabalaga, E.**, Hernandez, P., (2017). Multi-criteria impact assessment methodology for evaluating energy transitions: Prioritisation of scenarios for Donostia-San Sebastián. 8th international sustainability transitions conference, IST. Gothenburg, Sweden.

- Ortega, E., Criado, C., **Arrizabalaga, E.**, Vasallo, A., (2017). KPI-driven methodology for urban renovation at district level. Sustainable Strategic Urban Planning. The 5th annual Sustainable Places International Conference (SP'17). Middlesbrough, UK.

- Oregi, X., Mabe, L., Hernandez, P., **Arrizabalaga E.**, Miera, E., Saiz, S., (2017). Quantitative Impact Assessment of SEAP Measures Implementation on several Districts in the City of Donostia. World Sustainable Built Environment Conference, Hong Kong. ISBN 978-988-77943-0-1.

- Manjarres, D., Mabe, L., Oregi, X., Landa-Torres, I., **Arrizabalaga, E.**, (2017). A Multi-objective Harmony Search Algorithm for Optimal Energy and Environmental Refurbishment at District Level Scale. 3rd International Conference on the Harmony Search Algorithm. Bilbao, Spain.

- Criado, C., Pinto, H., Garcia, J., Vasallo, A., Martín, A., **Arrizabalaga, E.,** Hernandez, P., Mabe, L., (2016). CITyFiED Project methodology: an innovative, integrated and open methodology for near zero energy renovation of existing residential districts. CESB 16 - Central Europe towards Sustainable Building, Prague, Czech Republic.

- Oregi, X., Hernandez, P., Gazulla, C., **Arrizabalaga, E.**, (2013). Optimization of the refurbishment of the envelope throughout its Life Cycle. CESB 13 - Central Europe towards Sustainable Building, Prague, Czech Republic.

- **Arrizabalaga, E.**, Hernandez, P., Mabe, L., Oregi, X., Sanchez, B., (2012). Net energy analysis of geothermal energy installations. BSA. 1º International Conference on Building Sustainability Assessment, Porto, Portugal.

- Oregi, X., Hernandez, P., **Arrizabalaga E.**, Mabe, L., Sanchez, B., (2012). A new vision for improving the energy efficiency of residential buildings in existing urban areas. EESAP3 – 3th European Conference on energy efficiency and sustainability in architecture and planning. Donostia, Spain.

<u>National conferences</u>

- Ortega, E., Vasallo, A., Criado, C., **Arrizabalaga, E.**, (2017). Metodología del proyecto europeo Cityfied: metodología innovadora, integrada y abierta, para la renovación de distritos residenciales existentes. III Congreso Ciudades Inteligentes. Madrid, Spain.

- Hernandez, P. Mabe, L. Oregi, X. **Arrizabalaga, E.** (2016). Metodología, herramientas y ejemplos de evaluación de ciclo de vida en entornos urbanos. 1er Workshop esLCA: “Gestión del ciclo de vida en los sectores de la construcción y de la energía” Madrid, España.

- Mabe, l., Izaga, I., **Arrizabalaga, E**., Hernandez, P., Perez, G., (2013). “LCA for Offshore wind technology”, I Symposium of the Spanish Network of LCA: “LCA & bioenergy”, CIEMAT, Madrid.

- Hernandez, P. Maiztegi, A. Velte, D. **Arrizabalaga, E.** Mabe, L., (2013) “Life Cycle Approach to Sustainability Evaluation of Energy Technologies”, I Symposium of the Spanish Network of LCA: “LCA & bioenergy”, CIEMAT, Madrid.

CHAPTER 2

State of the sustainability assessment of energy transition scenarios for cities

2. Chapter 2: State of the sustainability assessment of energy transition scenarios for cities

2.1. Introduction

This chapter presents a critical review of the research undertaken in the field of sustainability assessment of cities' energy transition scenarios. It also discusses the different approaches considered for the prioritisation of interventions that can form these scenarios.

The research under review covers, in a first approach, studies focused on the definition of alternative transition scenarios at different scales. In this regard, the potential for energy savings, CO_2 emissions reduction, and the improvement of the socioeconomic development of each alternative future energy matrix proposed for the country, region, or city is assessed.

Once the general overview of the subject of study is carried out, the existing sustainability frameworks and indicators and the different methodologies for the city energy baseline assessment are characterised in the context of the energy planning for cities.

Finally, different sustainability assessment methods are evaluated with the aim of identifying the existing possibilities for the impact assessment with a multi-criteria and a multi-scale point of view.

2.2. Sustainable energy transition scenarios

Sustainable development became established as a new global paradigm after being introduced to the international policy debate by the World Conservation Strategy (IUCN, 1980). This complex and ambitious term has been defined in different ways, but the most widespread definition is the one established by the WCED (World Commission for Environment and Development (WCED), 1987): *'a development in which the needs of the present generation are fulfilled in such a way that future generations will be able to meet their needs to'*. It can be seen that this definition covers various scales and several criteria, responding to potentially conflicting targets and with different time-frames.

In this regard, energy policies seek to achieve diverse objectives that contribute to the sustainable future of our countries. In this context, energy scenarios are identified as tools that can help to evaluate alternative energy futures and reduce the inherent uncertainties of energy transition (Laugs & Moll, 2017). In most cases, these scenarios incorporate and evaluate approaches for the transformation of the energy matrix of the country evaluated, since this matrix is one of the basic elements to be taken into account in energy planning.

The principal aim of these scenarios is to help stakeholders put forward different policy options that address the 'energy trilemma' (WEC, 2013). The so-called energy trilemma proposes achieving a balance between environmental sustainability, energy security, and energy equity. This responds to the point that one scenario is not necessarily better than another if we take into account not only the necessary initial investment and the created economic growth, but also other aspects such as environmental and social benefits.

The environmental sustainability axis of the trilemma focuses on the reduction of CO_2 and other GHG emissions among other aspects, which is linked to the use of renewable and low-carbon energy sources. The second axis, energy security, encompasses aspects such as the concentration or the diversity of the energy generation and the import dependence. Finally, the third axis of the trilemma, the energy equity, is related to how accessible and affordable the energy supply is across the industry and across a population.

In the case of scenarios that aim to help cities address the 'energy trilemma', the lack of consensus on its definition and principles, and the methodological approaches used have been the subject of several studies over many years. Authors such as (Bradfield et al., 2005) and (Huss & Honton, 1987) have discussed the advantages and disadvantages of using qualitative approaches such as those followed by the intuitive logic methodology (which takes an explorative focus rather than looking at the normative purposes) and quantitative approaches, such as the probabilistic modified trends methodologies and the prospective ones.

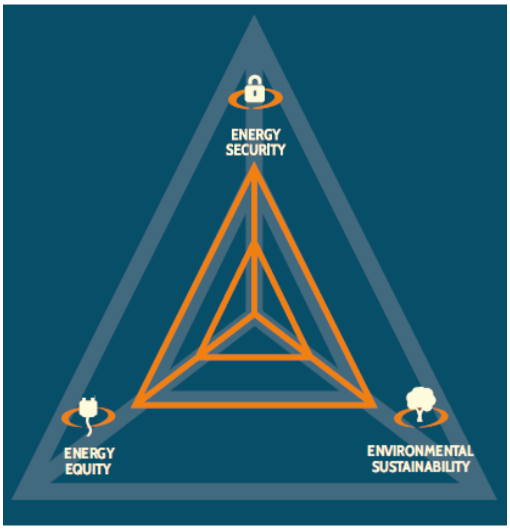

Figure 5. The energy trilemma (WEC, 2013).

From the extensive literature available in the field, various scenario typologies were discerned. One of the most outstanding classifications is that proposed by (Börjeson et al., 2006), who distinguished between the scenarios depending on their role. In this sense, scenario techniques can be divided into predictive, explorative, and normative scenarios. Predictive scenarios seek to respond to the question *'What will happen?'* and can be described as those scenarios which propose a continuation of the past. The explorative scenarios focus on obtaining a response to *'What can happen?'* and are described as those which explore different future possibilities but do not aim to predict them. Finally, normative scenarios respond to the question *'How can a specific target be reached?',* and try to define specific aims to create a certain future (Gormally et al., 2016).

Another classification is the one proposed by (Wang et al., 2015), which makes the distinction between forecasting scenarios and backcasting scenarios. While forecasting scenarios (considering the initial situation and with several assumptions) propose different future possibilities depending on the changes that can occur in the following years, backcasting scenarios (based on specific desirable future situations) propose roadmaps that can guide the transformation towards the desirable future situation. These last scenarios are, in general, normative ones.

In the specific field of energy planning and in energy policies analysis, the use of model-based energy scenarios is one of the most common practices for decision-making support (Grunwald, 2011). Despite being a widely accepted method, working with the context of uncertainty mainly focused on the prediction of the evolution of critical parameters is identified as one of the most relevant challenges (Weimer-Jehle et al., 2016). Working correctly with this uncertainty serves to comply with minimum standards of transparency, traceability, and intersubjectivity when describing the main variables of the scenarios, such as energy demand and supply development and the associated costs, or in the case of other variables, such as demography, technology innovation, and user behaviour.

The existing literature in the field of energy transition scenarios focuses mainly on the national, European, and global scales, where information such as the tendencies of macro-magnitudes needed for modelling are easier to achieve. Proof of this is the examples of the scenarios presented in the IEA's world energy outlook 2016 (IEA, 2016b), the Technology Data for Energy Plans (DEAc, 2017), and the projections included in the (IPCC, 2013). Hence, it can be said that academia, policy-makers, organisations and large private firms are the main actors dealing with the various scenarios.

However, as highlighted in the document ‘Opinion of the Committee of the Regions — Towards an Integrated Urban Agenda for the EU’, in recent years, the EU recognised the necessity of the commitment of cities to implementing energy and climate goals. This commitment is necessary to ensure that both the cities and the regions are able to achieve their full potential as motors of economic growth, employment, and social wellbeing in a sustainable way.

Therefore, the planning of coordinated energy transition scenarios of cities with regional and European strategies is increasingly becoming a requirement since urban areas will have a major impact on the future sustainable development of the European Union and its citizens.

2.3. City energy planning

In contrast to the studies at country or European scales, the integrated medium and long-term energy planning at city scale is not an extended practice nowadays. However, over the last few years, there has been an increase in the use and adaptation of models that were created for energy scenario assessments at the country or a larger scale at the local scale. The literature reveals some recent examples such as the case of Oslo (Lind & Espegren, 2017). Adapting the national energy, environmental, and economic Times model to the particularities of the city, this study evaluates the transition to a low carbon future for the city. Another study to be emphasised is the Nordic Energy Technology Perspectives (IEA, 2016a) where the strategy of the energy transition scenario is coordinated at various scales, ranging from a group of countries to the description of each specific country and finally detailed and adapted to the city scale with a top-down approach, also using the Times model. Another use of this model at the city scale is the study focused on Integrative Smart City Planning by (Gouveia et al., 2014), which evaluates the buildings and mobility sectors of the city of Évora. (C. Dong et al., 2016) adopt a large-scale Bayesian interval robust energy system optimisation (BIRESO) approach for improving energy system management in Qiqihar City. (Mathiesen et al., 2015) follow an energy system modelling and scenario generation approach using the EneryPlan model to evaluate the short-term goals for Copenhagen of becoming CO_2 neutral by 2025.

Therefore, there is an increasing tendency of adapting or using tools for large-scale application to cities, following a top-down approach. In this regard, the review carried out by (Connolly et al., 2010) offers a complete analysis of the various tools for evaluating the integration of renewable energy into various energy systems. This study evaluates tools such as HOMER, LEAP, ENPEP-BALANCE, EnergyPlan, H2RES, MESSAGE, and PRIMES among others, classifying them according to the application scale, the evaluated sectors, the scenario timeframe, and the time-step or the modelling approach. With regard to the latter characteristics, Connolly et al. make a distinction between top-down and bottom-up approaches, the simulation, scenario generation and the equilibrium approaches and the operation or investment optimisation approaches. This review shows that it is difficult to find a modelling tool that incorporates the capacities needed for evaluating all the aspects to be considered in the energy planning activities of cities. In some cases, this lack is linked to the limitations of the scale or the sectors included while in others, limitations of the time-steps are more relevant. Figure 6 shows the general structure to be considered in city energy planning, including the main inputs, characteristics, and outcomes.

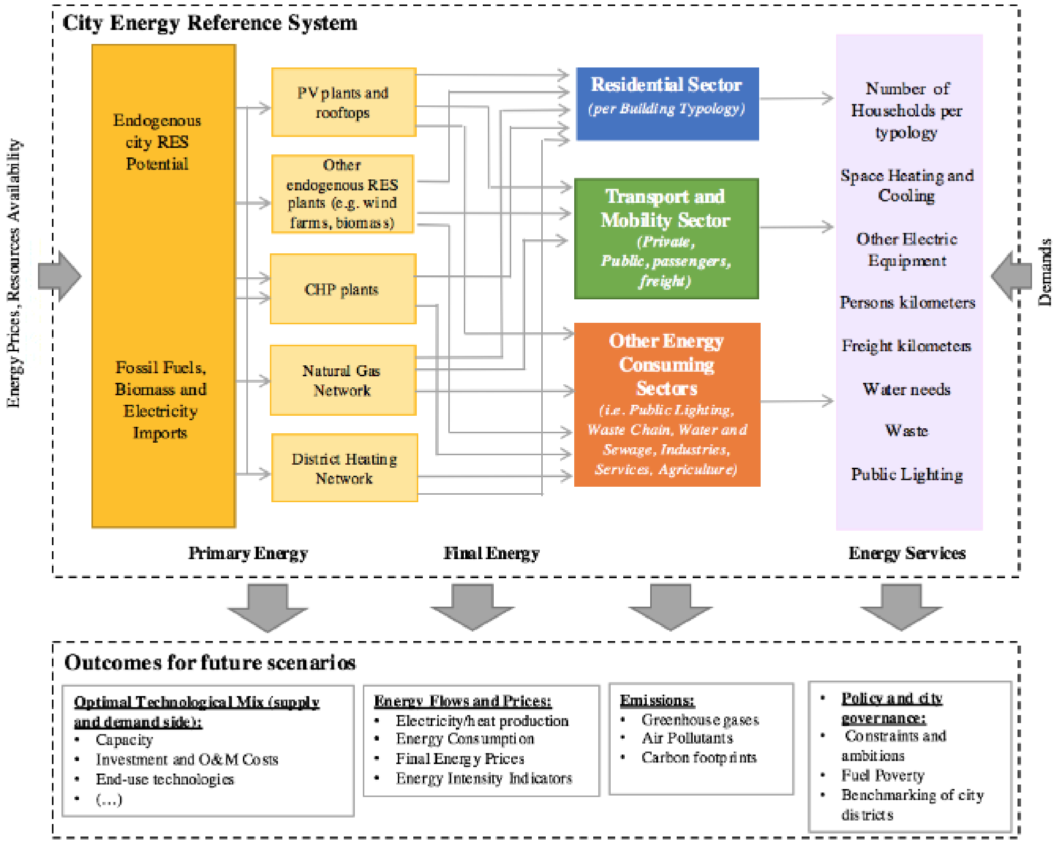

Figure 6. City energy planning structure and major outcomes (Gouveia et al., 2016).

The analysis and the review conducted by (Mirakyan & De Guio, 2013) evidences the potential and the necessity of an integrated energy planning for cities. The latter study presents a generic integrated energy planning procedure, where the integrated city energy planning is divided into four main phases, including, as one of the core phases, a detailed analysis of cities' energy systems. The four phases identified are: preparation and orientation, model design and detailed analysis, prioritisation, and decision and implementation and monitoring. This proposed structure captures the complexity of the various stages and the necessary wide perspective that should be adopted when approaching this type of analysis.

However, the real situation nowadays is that not many municipalities have the capacity to carry out this type of detailed analysis considering that very specialised tools and very time consuming analyses are associated with it.

Besides, there are no specific requirements for cities in defining their energy transition scenario using these types of techniques. In this regard, there are some knowledge-sharing programmes between cities, such as the Covenant of Mayors for Climate & Energy, Mayors Adapt, and the Smart Cities and Communities Initiative, among other initiatives, that cities can join voluntarily. Covenant of Mayors is the most common and widespread initiative. It was officially launched in

2008 by the European Commission, after the adoption of the 2020 EU Climate and Energy Package. It aims to endorse and support the efforts of local authorities in the implementation of sustainable energy policies, mainly in the fields of energy efficiency and use of renewable energy sources. This movement today has 6466 signatories, and 3843 have a Sustainable Energy Action Plan (SEAP) approved by Covenant of Mayors.

Another movement that is quickly spreading through European cities is one related to the Smart Cities and Communities Initiative. According to a policy study by the European Parliament, the main idea behind this concept is to better connect energy, mobility, and ICT infrastructures in order to generate greater and more sustainable economic development and a better quality of life for citizens. This tendency is linked more to the definition of a city plan, considering a wider perspective but not necessarily using modelling tools or a deep analysis. Nevertheless, the transformation of European cities into Smart Cities requires not only holistic approaches for city planning but also different evaluation and monitoring procedures to ensure that the implemented actions achieve the expected result. This is the reason why there are emerging initiatives, such as the Smart Cities Information System (SCIS). This initiative exchanges data, experience, and know-how between ongoing projects under the Concerto initiative and the Smart Cities and Communities programme within the Horizon 2020 framework, in order to collaborate on the creation of smart cities.

2.3.1. Energy in cities – baseline assessment

Modelling tools for an energy systems scenario analysis at the city scale have to allow assessment of the role of decentralised energy generation. As seen before, there are several tools that, although mainly focused on the regional or country scales, are being used also at city scales in recent years. These types of tools allow for a detailed annual energy supply and demand characterisation of cities. However, an energy balance on an annual basis makes it difficult to evaluate in detail some aspects, such as the integration of renewable intermittent generation, the influence of energy storage at different scales, and the potential synergies between the heating, electricity, and mobility sectors. This type of analysis is becoming essential, as highlighted by (Lund et al., 2016) that explains the relevance of connecting the *Smart Energy Systems* concept and the concept of *4th Generation District Heating*. The concept of Smart Energy Systems emphasises the relevance of discovering synergies between-sectors and calls for the active inclusion of the heating and cooling sectors in any analysis of energy systems. On the other hand, 4th Generation District Heating identifies the potential and the necessity of further development of district heating and cooling technologies in order to achieve better inclusion in the future sustainable energy systems of cities (Figure 7).

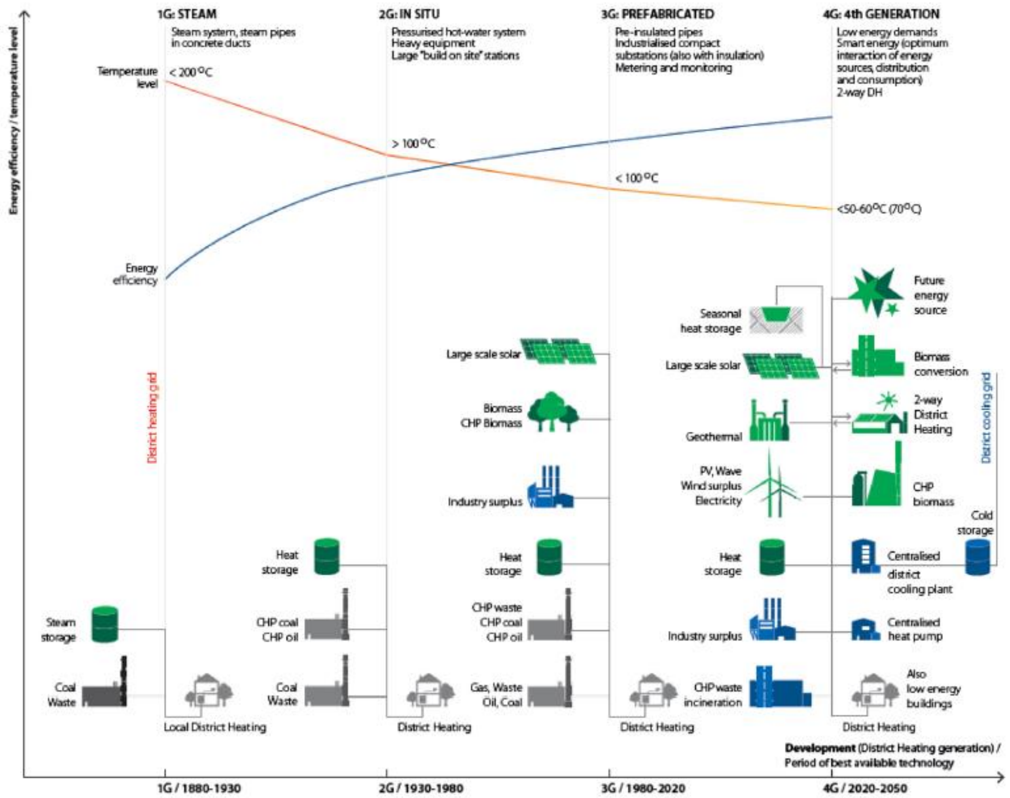

Figure 7. Illustration of the concept of 4th Generation District Heating (Lund et al., 2014).

Other reviews, such as those carried out by (Sinha & Chandel, 2014) and (Allegrini et al., 2015), offer very wide analyses of the existing various tools and approaches for simulating energy systems. Nonetheless, both studies conclude that many of these tools are focused on a district scale analysis or are limited to specific energy technologies or sectors, such as CitySim (Robinson et al., 2009), EnerGis (Girardin et al., 2010), SynCity (Keirstead et al., 2010), (Sinha & Chandel, 2014), RETScreen (Leng, 2000), HOMER, HYBRID 2, and the iHOGA tool.

Therefore, considering this inevitable tendency towards evaluating simultaneously energy aspects of different sectors of cities, it can be said that there is a lack of tools that allow evaluation simultaneously and on an hourly basis the energy demand and supply of the different sectors. Even in the case of tools which have these capabilities of incorporation of hourly energy demand curves, such as EnergyPlan, it is difficult to have the specific input profile of the city evaluated, and, instead, generic national profiles are frequently used. This evidences also the increasing necessity of profiling city energy use on an hourly basis.

Profiling city energy use for the evaluation of alternative energy technologies

Matching energy supply and demand at district and city levels is a key preliminary step of city energy planning. This step facilitates optimising the integration of decentralised low carbon energy technologies with intermittent resources in the energy matrix of cities. With regard to the building sector of the city, while at the building level, there are many methodologies, tools, and studies that allow a detailed hourly or sub-hourly analysis, at the city level, the temporal dimension of supply and demand is not so well documented. City energy planners usually need to combine various methodologies and tools with different time-steps, scales, and approaches, which makes it difficult to develop a baseline analysis of energy demand and supply.

Over the last 20 to 30 years, many different approaches and tools for building energy modelling at different scales have been developed. Several reviews, such as (Swan & Ugursal, 2009) and (Bourdic & Salat, 2012) describe different modelling approaches that can be used for evaluating the energy consumption and environmental impact of buildings at the district and city level. Bourdic and Salat propose a classification that distinguishes four main approaches: agent-based modelling, morphologic modelling, energy and environmental modelling, and economic modelling. While the first three follow a bottom-up approach, economic modelling is based on a top-down approach.

With regard to the tools that can be used for building energy modelling, the situation varies depending on the scale of the project. As mentioned by (Martos et al., 2016), the development of tools for evaluating and predicting the future energy consumption of cities will be one of the biggest challenges in the field. Despite the achievements that have been made in recent years, there are still difficulties in finding commercial tools to evaluate energy demand and use at the district and city level, particularly in the case of tools that can be applied to different cities, since the tool developments are in many cases linked to projects carried out only for one or several specific cities or for a particular country.

The situation is much better in terms of the availability and reliability of tools for analysis of single buildings or building groups. There are several tools, such as EnergyPlus and TRNSYS, that are broadly accepted and that allow for a very detailed and dynamic building energy simulation. Testing and validation procedures such as Building Energy Simulation Test (BESTEST) and ANSI/ASHRAE Standard 140, aim to increase confidence in these building energy simulations, and the accuracy and consistency of these tools have much improved over the years. These tools allow the hourly energy demand curve of a group of buildings to be obtained, but as discussed by (Andri´c et al., 2016), modelling an urban area with a high number of buildings using these tools can be very laborious and time-consuming.

To simulate a large number of buildings, other types of tools and approaches have been developed which are less focused on detail and accurate simulation results for individual buildings; instead, they integrate simplified calculations with a capacity to visualise large amounts of buildings in a georeferenced way. This is the case for SEMANCO, Nest (Neighbourhood Evaluation for Sustainable Territories) (Oregi et al., 2016), and CitySim tools (Robinson et al., 2009). These tools can incorporate additional functionalities and inputs from technologies, such as LIDAR (Light Detection and Ranging) and GIS (Geographical Information System) to support a quick and effective characterisation of urban areas. These tools, however, also have their limitations. For example, most of these tools for modelling urban areas do not provide results on an hourly basis. In the case of the Nest tool, an approximation of the energy demand of the building is done considering several characteristics, such as the use, the age, the climatic zone, and the thermal characteristics of their envelope, and the total annual energy demands for each building are estimated as a result. The GIS and LIDAR-based approaches also have some problems of resolution when the area of study is not city-wide, as explained by (Calderón et al., 2015), which reduces its applicability at a district level.

Another approach, based on using several reference buildings as representative of the different typology of buildings existing in cities, was adopted by (Howard et al., 2012) for characterizing the annual energy consumption of the buildings of New York. In this study, several reference buildings were defined according to their typology of use, from residential and, office use, to educational and, health use to commercial use.

Other types of studies have focused on evaluating the simultaneity effects of the energy demand, an aspect that is relevant when evaluating simultaneously a high number of buildings in the context of city energy planning. Considered properly, this aspect will allow the optimisation of the peak load design of the systems used for district or city energy supply, which will contribute to the optimisation of city energy fluxes. Studies such as those by (Winter et al., 2001) and (Tol & Svendsen, 2012) evaluated the effect of the simultaneity of the demand for optimising the dimensioning of the pipes of a district heating network connected to low energy demand buildings. (Ji et al., 2016) evaluated the effect of a combination of buildings with different use typologies that are connected to a common energy generation system for reducing the capacity of systems when the effect of simultaneity is considered.

Finally, another aspect that has interesting results, especially when dealing with data obtained following both the bottom-up and the top-down approaches. This aspect is known as the energy prediction gap and considering it is essential during the validation stage for matching the aggregated building energy demand obtained from the modelling with the city’s actual energy data. The influence of this gap has been also evaluated in the literature (Majcen et al., 2015) and is especially relevant for cases in which the behavioural characteristics and the human factor can influence results, as in the case of energy analyses of cities.

2.4. Sustainability assessment in the context of city energy planning

This sub-section assesses the main activities devoted to the sustainability evaluation of cities within the context of energy planning. Here, different approaches and methodologies for the sustainability assessment of interventions and transition scenarios of cities are evaluated. The review is divided into two main sections covering different purposes. The first one aims to evaluate the main activities related to the various frameworks and indicators for sustainability assessment of cities that have been developed in recent years. The second one, on the other hand, is more focused on evaluating different approaches to conducting multi-scale impact assessments of cities covering the three dimensions of sustainability.

2.4.1. Frameworks and indicators for the sustainability assessment of cities

The concept of the sustainable city or the low carbon city considers other aspects apart of GHG emissions. Issues such as other environmental aspects, social aspects, and aspects related to economic development covering the many dimensions of cities are also considered. Many cities are implementing various low-carbon practices in order to reduce environmental emissions. However, it is still unclear how this sustainability or low carbon level can be certified. In fact, the way in which a city evolves towards a low carbon future can change significantly the final state of the city arrived at.

In this context, many efforts have been made at developing indicators-based frameworks capable of evaluating cities' sustainability. These frameworks show interesting results in stablishing the initial situation of cities and in measuring their evolution in the following years. Nevertheless, standardisation of the field is necessary in order to allow a reliable comparison to be made between cities. With this aim, many frameworks have emerged in the last few years. However, the ISO 37120, 'Sustainable development of communities – Indicators for city services and quality of life', published in May 2014, is the first published international standard for a city sustainability assessment. The committee responsible for this document is the ISO/TC 268, Sustainable development in communities. This standard aims to establish a set of indicators to track and monitor progress on city performance considering 17 dimensions used for characterizing the city; economy, education, energy, environment, finance, fire and emergency response, governance, health, recreation, safety, shelter, solid waste, telecommunication and innovation, transportation, urban planning, wastewater, and water and sanitation. Recognising the different capabilities of cities worldwide, the proposed set of indicators for city performance is divided into 46 'core' indicators and 51 'supporting' indicators.

Another framework that needs to be mentioned is defined in the CITYKEYS initiative, which proposes an assessment method and specific indicators for evaluating the success of the Smart

City projects that are being implemented in Europe. This initiative proposes a two level evaluation framework. The first level corresponds to the project level where a set of indicators divided into five dimensions (people, planet, prosperity, governance, and propagation) is defined. These dimensions are classified at the same time into 23 sub-themes that include more than 100 indicators. The second scale is the smart city scale, which is also formed by the same dimensions, subthemes, and indicators as at the project scale but is applied to the entire city. The overall idea of this framework is to establish a direct link between the interventions implemented in smart city projects that usually cover the district scale with the effect that those interventions have on the entire city.

A similar perspective is the monitoring framework defined in the REPLICATE project, where there is a common monitoring framework for the interventions implemented in three European cities. The monitoring framework is defined with the objective of it acting as a baseline for the future development evaluation of cities. The monitoring framework is also defined at two main levels, the city level (composed of six dimensions) and the intervention level (with various indicators, depending on the type of intervention). However, in this case, the indicators have been defined in such a way that the relation between the two scales is ensured using different approaches, depending on the indicator dimension. Some indicators have a direct relation, others have a relation through indirect calculations, and other indicators related to the socioeconomic characteristics of the city have a relation through different simplified impact assessment methods.

It should be mentioned that the multi-level approach and the impact assessment approach adopted in the last two initiatives mentioned are not the most extensive procedures. Many other indicator frameworks have been evaluated in this study and these consider a broad variety of the existing International Frameworks, International European Standards, European Frameworks, Neighbourhood Certification Schemes, and the FP7 and H2020 projects.

Figure 8 shows the mapping of the evaluated 29 frameworks depending on their scope, distinguishing between the project/district and the city scales. A second classification is presented distinguishing also between the integrated approach (covering various dimensions) and the sectoral approach. The frameworks corresponding to the numbers represented in the figure are provided in Table 1.

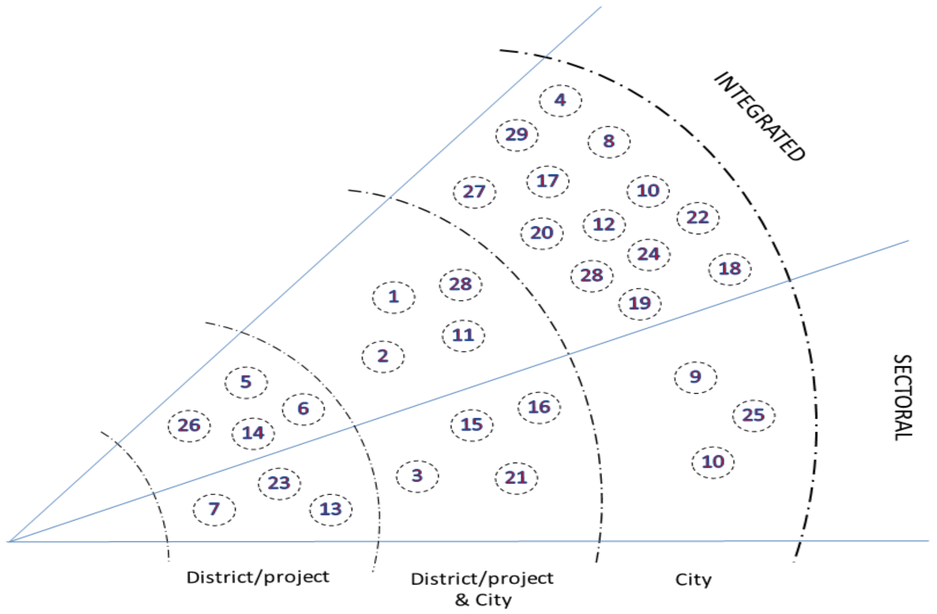

Figure 8. Mapping of sustainability frameworks**.**

A more detailed description of the framework evaluated is provided in Table 1. The indicators considered by each case have been classified according to the following five dimensions: social, energy, environment, economy, innovation, and governance.

The analysis shows that most of the frameworks are focused only on the city scale, where the integrated vision is mainly adopted, rather than the sectoral perspective. Frameworks focused on the project or district scale are also abundant, covering both the sectoral and the integrated perspectives.

Moreover, frameworks aimed at considering both the project and the city scales have emerged in recent years, linked in most cases to European-funded research projects. In evaluating the classification of indicators by their theme, most of the indicators aim to cover the energy perspective (694), followed by the social (440), the economic (325), and the environmental (319) dimensions. Governance and innovation dimensions remain the focus of only a few indicators.

As a general conclusion, that all these frameworks are focused on evaluating the sustainability of districts and cities rather than following an impact assessment perspective should be highlighted. Therefore, these frameworks are useful mainly for the initial stages of the sustainable energy planning of cities, where the city baseline situation needs to be assessed. This type of contextual information can also serve to identify the main needs of cities as well as set the specific objectives that will be pursued in the planning process.

Table 1. Review of the sustainability frameworks. Numbers of indicators considered classified by the defined six dimensions both for the city scale and the district/project scale.

	Social		Energy		Environment		Economy		Innovation		Governance
	city	**D/P**	**city**	**D/P**	**city**	**D/P**	**city**	**D/P**	**city**	**D/P**	**city**
1.REPLICATE	5	10	7	8	7	2	7	8	6	-	5
2.CITYKEYS	23	30	6	8	20	24	6	8	6	6	11
3. Triple Helix	14	10	2	-	2	1	16	1	4	1	6
4.Smart City Profiles	13	-	9	-	4	-	19	-	-	-	5
5. DGNB	-	33		13	-	26	-	26	-	2	-
6. BREEAM	22	-	11	-	-	-	17	-	-	-	13
7. LEED	-	35		10	-	25	-	13	-	3	-
8. CASBEE	9	-	6	-	4	-	4	-	-	-	3
9. DESIRE	3	-	10	-	21	-	1	-	-	-	1
10.City Protocol	80	-	53	-	35	-		-	-	-	28
11. CIVITAS	4	4	2	3	8	7	13	14	-	1	1
12. ClimateCon	8	-	12	-	21		16		-	-	7
13. URB-GRADE	-	-	-	17	-	3	-	7	-	-	-
14. ISO 37151.1	-	4	-	5	-	9	-	8	-	-	-
15. Concerto	-	-	7	12	1	2	14	24	-	-	1
16. Siemens Green City Index	1	3	10	2	13	3	3	1	-	-	3
17. RFSC	9	-	2	-	2	-	7	-	1	-	7
18. GCIF	31	-	5	-	24	-	30	-	6	-	18
19. Green Capital Award	33	-	2	-	12	-	21	-	-	-	4
20. SCP Rotterdam	42	-	10	-	20	-	27	-	-	-	-
21. IDEAS	0	-	13	-	-	-	-	-	-	-	-
22. ISO 37120	40	-	6	-	25	-	23	-	1	-	5
23. Smart City Wheel	9	3	1	1	5	-	6	1	5	3	3
24. European Smart Cities	28	3	-	-	7	-	19	16	-	-	13
25. PLEEC	6		21	-	3	-	19	-	-	-	-
26. Eurbanlab	3	7	93	10	4	7	0	4	3	17	-
27. URBES	37	-	1	-	7	-	11	-	2	-	12
28. READY	-	-	54	-	-	-	2	-	-	-	-
29. Transform	13	-	154	-	56	-	33	-	-	-	106

2.4.2. Impact assessment

The phase of impact assessment is very complex when referring to the context of city energy planning. Studies such as the one carried out by (Mirakyan & De Guio, 2013) identify the necessity of evaluating city energy planning in an integrated way, combined with territorial planning. This study proposes the combination of various impact assessment methodologies, such as the Life Cycle Assessment or the Systems Thinking with other integrated energy/economic/environmental analysis tools, such as MARKAL/TIMES, EnergyPlan, and LEAP, to cover the various scales of the impact assessment. Another study carried out by (Mattoni et al., 2015), also identifies how the approach adopted in this type of analysis often does not appear as holistic, complete, or integrated as it should. The latter study introduces a holistic approach to cities and territories combining the district scale, the city scale, and the regional scale in its approach. Using a wider perspective, (Pissourios, 2013) presented an interdisciplinary study for an indicators review in which the perspectives of quality-of-life, macroeconomics, environmental aspects, welfare and sustainability were evaluated with the aim of detecting potential similarities between different theoretical indicator frameworks.

It has become clear that multiple impacts at different scales need to be considered for ex-ante impact assessments of alternative energy scenarios for cities. However, not many studies can be found that offer such a wide perspective and ensure an optimum choice for society, the environment, and economic development.

Although some recent studies identify the necessity of quantitative assessment methods based on the notion of multiple impact pathways, these frameworks are still in their infancy (Ürge-Vorsatz et al., 2016). This study reveals that the most important challenge is still linked to the appropriate integration of the various impact assessment methodologies and approaches that need to be considered. Ürge-Vorsatz et al., also propose the adoption of different assessment approaches for this type of study. Approaches such as cost-benefit analyses and the life cycle assessments for valuing externalities, such as environmental externalities or the impact on health, among others, macroeconomic models, such as the Input-Output analysis, partial equilibrium and computable general equilibrium (CGE) models, econometric models for assessing the macroeconomic impacts, and multi-criteria analyses for combining different impact results are included in the analysis. (Igos et al., 2015) adopt a similar approach based on a combination of equilibrium models and hybrid life cycle-input–output analyses for the evaluation of ex-ante environmental impacts on energy policy scenarios.

It can be concluded that this type of analysis is mainly applied nowadays in studies to conduct climate and energy policy analyses on a large scale and not in city energy planning.

A review by (H. Dong et al., 2016) concentrates on the urban environment, focusing on eco-city evaluation methods, and it highlights the most relevant aspects for the integration of six methods that are applicable at different scales and that can be used for a holistic analysis of cities. The methods assessed are input–output analysis (IOA), life-cycle analysis (LCA), ecological footprint (EF), carbon footprint (CF), emergy analysis, and cost benefit analysis.

Finally, other types of studies focus on the methodological approach used for the impact assessment of specific energy technologies. (Wicke et al., 2009) evaluate the macroeconomic impacts in terms of GDP, trade balance, and employment for large-scale bioenergy production. This study reflects the relevance of considering the direct, indirect, and induced impacts during an assessment.

Another approach that should be highlighted is the one by (Dalton et al., 2016). This study offers a holistic approach considering both the narrow economic and the broader socioeconomic assessment of ocean renewable energy, incorporating methods from areas of the environment, the economy and social assessment. The study also links the private and public perspectives as well as the type of methodologies and purposes of the scale of the analysis from the component or project scale to the regional and the national scale. Here, the financial and economic performance of a technology (evaluated usually through parameters like the net present value or the interest rate of return) is distinguished from the macro-economic, social, and environmental assessments that generally refer to wider impacts, such as the impact of employment, GDP, and the environment. These latter impacts need to be assessed through other types of methodologies such as extended input output tables or general equilibrium models.

Considering the methodological approaches proposed in the studies mentioned and taking into account also the potential of each methodology for an integrated impact assessment in the field of city energy planning, a more detailed analysis of several methodologies is provided here.

Life cycle assessment

Life cycle assessment provides a well-established and comprehensive framework for comparing the full range of environmental impacts of products and services, taking into account upstream and downstream activities associated with all the stages of the products' life cycles. Life cycle assessment study dated from the late 1960s and early 1970s, and its principles, framework, requirements and guidelines are detailed in the ISO14040:2006 and ISO 14044:2006 standards.

Since then, LCA has been applied to evaluate the potential environmental impacts of diverse aspects, including buildings, energy technologies, and districts. Most of the available literature is based on attributional life cycle analysis, which is focused on investigating the environmental impacts associated with the average product or technology life cycle. Those static models do not consider any mechanism of revenue maximisation and price equilibrium under external constraints (Marvuglia et al., 2013). With the aim of resolving these aspects, studies based on the consequential life-cycle assessment (C-LCA) are becoming more widely used as a modelling technique. These describe the consequences of decisions (Zamagni et al., 2012). As described by Marvuglia et al., in the C-LCA the relationships between activities and processes are not only based on technical connections. Other socioeconomic mechanisms are considered via market information and in some cases via partial or computable general equilibrium economic models. It is currently accepted that the C-LCA has not yet achieved a fully methodological consensus and development.

Life Cycle Cost (LCC), on the other hand, is a technique which allows a comparative cost assessment of products and services, taking into account all the relevant initial capital costs and future operational and replacement costs, as well as all other costs and incomes through the life cycle during a specific period of time. The literature shows also that LCC studies are becoming common in the fields of buildings and energy technologies.

However, Social Life Cycle Assessment studies are still not so common nowadays. It could be said that the publication of the Society of Environmental Toxicology and Chemistry (SETAC) Workshop Report, 'A Conceptual Framework for Life Cycle Impact Assessment' (Fava et al., 1993), started the discussion on how to incorporate different social and socioeconomic aspects within the LCA framework. Since then, many discussions have focused on different aspects, such as the purpose, and the system boundaries of the methodology. Finally, in 2010, the Guidelines for Social Life Cycle Assessment of Products (Benoît et al., 2010) were published. In this publication, Social Life Cycle Assessment is described as 'the identification of key issues, assessing, and telling the story of social conditions in the production, use, and disposal of products'.

Since then, many methods and approaches have been proposed in this field. (Macombe et al., 2013), for example mention two families of methods, one addressing the impact on human health due to environmental issues such as the Eco-Indicator 99 (Goedkoop & Spriensma, 2001) and the other one, on the possible harm to workers' health due to the exposure to pollutants. In any case, as pointed out by Macombe et al., all of those approaches are highly innovative and experimental. Social Life Cycle Assessment is not considered within the scope of this study and is not evaluated in detail in this review.

Consideration of the life cycle perspective has been widely extended in some fields, such as in the case of the building sector. In this regard, standards written by CEN TC 350 provide a framework for the sustainability assessment of buildings using a life cycle approach. This sustainability assessment quantifies the impacts for the three pillars of sustainability: the environmental, social, and economic dimensions.

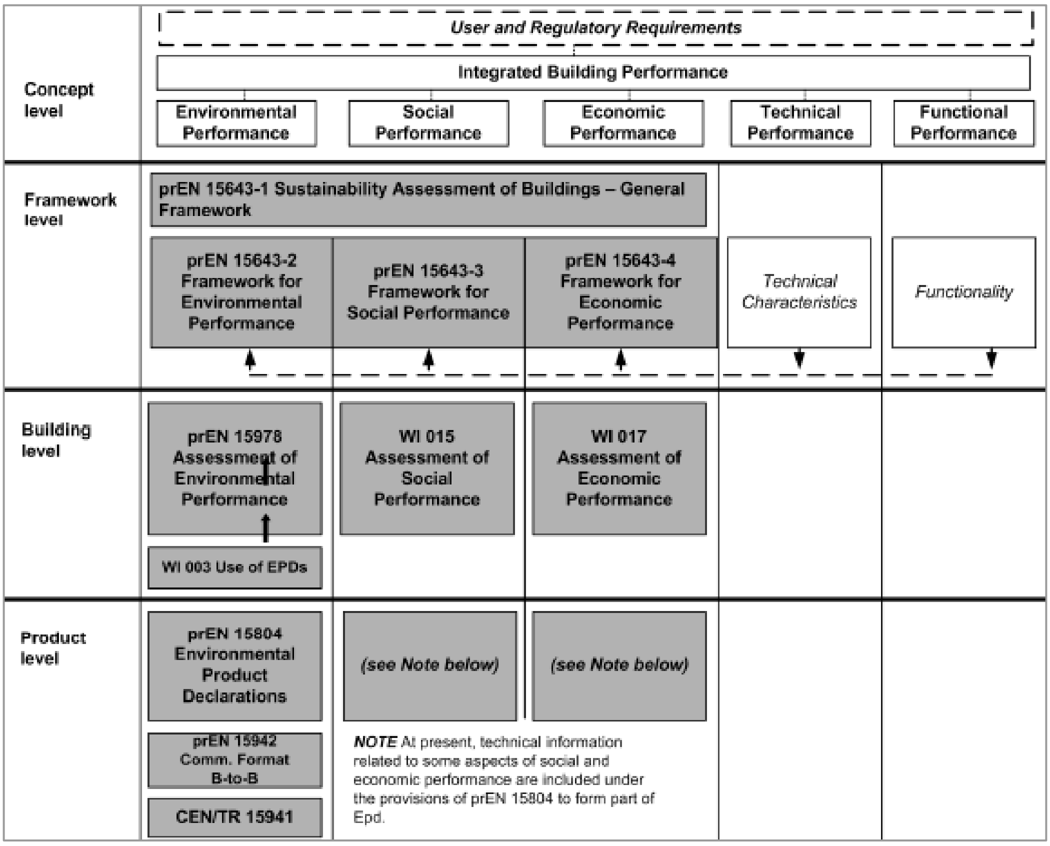

Figure 9. Work Programme of the CEN TC 350.

Although other fields related to city energy planning, such as energy technologies and the urban environment, have not been developed to this level of standardisation, reviews like the one by (Lotteau et al., 2015) reveal the efforts that have been made in the life cycle assessment of the built environment at the neighbourhood scale, which are mainly focused on the environmental dimension. This review evaluates 21 studies and reveals that the most evaluated impact categories are primary energy consumption and climate change, excluding other categories such as the depletion of abiotic resources (kgSb), the acidification potential (kgeqSO_2), the eutrophication potential (kgeqPO_4), the oxidation (summer smog) (kgeqC_2H_4) and the land use, among others. Studies by (Cabeza et al., 2014) and (Stephan et al., 2013) are also focused on the building sector and on multi-scale life cycle analysis of the urban environment respectively but have a greater focus on the energy axis. The latter study is based on the life cycle energy analysis framework developed by (Stephan et al., 2012) for the analysis of parameters like the Embodied Energy and the Life Cycle Primary Operational Energy (LCOPE) of neighbourhoods.

It needs to be mentioned also that although the study by (Roux et al., 2016) is mainly focused on the building scale, it evaluates life cycle impacts, integrating climate change and the evolution of the energy mix in the long term (to 2050).

In contrast, with the process-based modelling used in most of the studies described up to now, the input-output (IO) LCI and hybrid methods can also be found in the literature. This approach allows extending the boundaries of the systems in order to consider the environmental impact of other stages, such as financing of projects, which in the case of the process-based modelling are generally omitted.

However, many authors discuss about the lower accuracy obtained with this approach in the rest of the stages of the life cycle. Studies by (Chen et al., 2015) evaluate the carbon footprints of the two largest metropolitan areas of Australia, Melbourne and Sydney. This study uses a multi-scale, multi-region input/output model with nested regions at the city, state, nation, and world levels. This type of analysis, which is focused on IO-based hybrid assessment, is performed by extracting particular paths and data from IO matrixes for their use in process-based LCA modelling. Other studies, such as that by (Kjaer et al., 2015), show an example of the method for translating LCC into LCA based on the (EIO) LCA. This approach is based on the environmental input-output (EIO) LCA that uses IO tables to estimate the environmental impacts of processes, including global supply chain impacts. Many studies, for example the one by (Islam et al., 2016) debate the existing potential and the limitations of using IO-based data during the life cycle inventory definition phase of LCA studies. In any case, the studies mentioned are mainly focused on the impact assessment of districts of cities but are not specifically used for comparing cities' alternative future transition scenarios.

With regard to the use of an LCA application for an energy technology impact assessment, significant research has already been done to understand the impacts on the environment and the economy associated with various energy technologies and energy systems (Pehnt, 2006), (Afgan & Carvalho, 2008), (Evans et al., 2009), (Myhr et al., 2014), (Barron & McJeon, 2015), (Houshyar & Grundmann, 2017), (Beccali et al., 2016). Figure 10 shows a comparison of the lifecycle GHG emissions for most of the renewable and non-renewable electricity generation technologies.

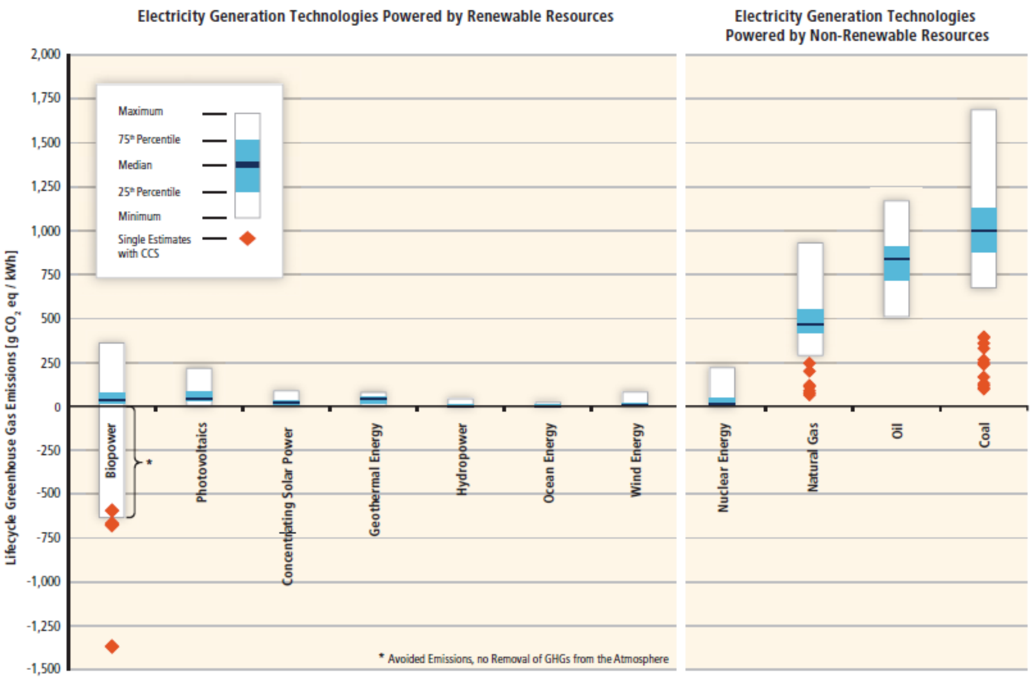

Figure 10. Comparison of the lifecycle GHG emissions of renewable and non-renewable electricity generation technologies (IPCC, 2013).

Another aspect that is becoming the subject of many studies focused on energy generation is the evaluation of the externalities. As defined in the document, ‘Study on external environmental effects related to the life cycle of products and services’ of the European Commission, ‘Externalities are the costs imposed on society and the environment that are not accounted by the producers and consumers, i.e. that are not included in market prices’. Studies have focused on evaluating the sustainability of future electricity generating technologies, such as the NEEDS project (Friedrich, 2007), combining the economic indicators with external costs in order to produce the total cost associated with each technology. Another relevant project in the field is the ExternE-Externalities of Energy project, which provides a framework for transforming impacts that are expressed in different units into monetary values.

In this regard, some efforts have been made also in defining appropriate ways to internalise these external costs (to define how someone will pay for the negative effects created). Studies such as those by (Georgakellos, 2010), (Zvingilaite, 2013), and (Zvingilaite, 2011) incorporate this perspective in the modelling of their energy systems but it can be said that we are still far from considering this perspective in the market.

It is also necessary to mention the important research carried out with regard to the definition of the impact indicators to be considered in the sustainability assessment of energy technologies. Many studies can be found in the literature. For example, as part of the China Energy

Technology Program (CETP), (Andre Haldi & Jacques, 2003) evaluated seven environmental indicators (GWP, resource consumption, waste total, health impact due to accidents, expected fatalities, and land use degradation, among others), the economic indicators of total investment cost and the fuel transport burden (% increase in fuel transportation by 2020), and the social indicators of direct employment and the technology qualitative indicator of maturity. (Hirschberg et al., 2004) in a study related to the energy system in Germany, evaluated indicators such as the regional impact (change in unprotected ecosystem areas), fuel price increase sensitivity, energy long-term sustainability, and the impacts on human health. Another study, by (Khan et al., 2004), in implementing life cycle sustainability indexing system (LInX), considered a different classification of indicators. Among the environmental and resource, economic, and technical indicators, this classification includes also the socio-political dimension, where qualitative indicators such as acceptance, social impacts, and the vulnerability indicators are included.

Some years later, (Begić & Afgan, 2007) evaluated four environmental indicators (CO_2 emissions, SO_2 emissions, NO_x emissions and resource use), three economic indicators (thermal efficiency, cost per kWh, and investment cost) and one social indicator (jobs in hours/kWh) in examining Bosnian energy scenarios. In the study, 'Renewable energy systems: A societal and technological platform' conducted by (Polatidis & Haralambopoulos, 2007), the authors included new economic indicators, such as the payback period and the net present value, and energy and resource indicators (the amount of imported oil avoided and the amount of electricity produced related to the energy security). In a study on the analysis of different renewable energy scenarios for Austria, (Kowalski et al., 2009) considered 35, indicators including qualitative indicators, such as regional economic development, the diversity of technology, and technological advantage, and quantitative indicators, such as import dependency, employment and the cumulative energy input.

Those are some of the many examples available in the literature. Reviews like the one carried out by (Stamford, 2012) or the one by the PLANETS European project for the sustainability assessment of energy generation systems and energy technology scenarios, include a wide variety of impact indicators used for each dimension of sustainability. Table 2 provides many of the indicators resulting from the latter two reviews.

Table 2. Techno-economic, environmental and social **i**mpact indicators for energy generation technologies. Adapted from the reviews presented by (Stamford, 2012) and the PLANETS European project.

Category	Indicator	Unit
Techno-economic	Capacity factor	Percentage (%)
	Availability factor	Percentage (%)
	Technical dispatchability	Summed rank
	Economic dispatchability	Dimensionless
	Lifetime of global fuel reserves at current extraction rates	Years
	Ratio of plant flexibility and operational lifetime	Years-1
	Time to plant start-up from start of construction	Years
	Total levelised cost	Pence/kWh
	Financial incentives and assistance (e.g. ROCs, taxpayer burdens)	Pence/kWh
	Net Present Value (NPV)	€
	Net Present Cost (NPC)	€
	Return on investment (payback period of initial cost)	years
	Security of supply	Score (1-5)
	Private costs (investment and operational)	€/kWh
Environmental	Recyclability of input materials	Percentage (%)
	Freshwater eco-toxicity potential	kg 1,4 DCB‡ eq./kWh
	Marine eco-toxicity potential	kg 1,4 DCB‡ eq./kWh
	Global warming potential (GHG emissions)	kg CO2 eq./kWh
	Ozone depletion potential (CFC and halogenated HC emissions)	kg CFC-11 eq./kWh
	Acidification potential (SO2, NOx, HCl and NH3 emissions)	kg SO2 eq./kWh
	Eutrophication potential (N, NOx, NH4+, PO43- etc.)	kg PO43- eq./kWh
	Photochemical smog creation potential (VOCs and NOx)	kg C2H4 eq./kWh
	Greenfield land use (proportion of new development on previously undeveloped land relative to total land occupied)	Percentage (%)
	Terrestrial eco-toxicity potential	kg 1,4 DCB‡ eq./kWh
	Human Health Impact	€/kWh
	Environmental external costs	€/kWh
	Consumption of fossil fuels	(MW/kWh)
Social	Direct employment	Person-years/GWh
	Total employment (direct + indirect)	Person-years/GWh
	Worker injuries	No. of injuries/TWh
	Human toxicity potential (excluding radiation)	kg 1,4 DCB‡ eq./kWh
	Human health impacts from radiation (workers and population)	DALY¥/GWh
	Fatalities due to large accidents	Nº of fatalities/GWh
	Proportion of staff hired from local community relative to total direct employment	Percentage (%)
	Spending on local suppliers relative to total annual spending	Percentage (%)
	Direct investment in local community as proportion of total annual profits	Percentage (%)
	Amount of imported fossil fuel potentially avoided	toe/kWh
	Diversity of fuel supply mix	Score (0-1)
	Fuel storage capabilities (energy density)	GJ/m3
	Use of non-enriched uranium in a reactor capable of online refueling; use of reprocessing; requirement for enriched uranium	Score (0-3)
	Use of abiotic resources (elements)	kg Sb eq./kWh
	Use of abiotic resources (fossil fuels)	MJ/kWh

*Note: ‡DCB – dichlorobenzene; ¥DALY – disability-adjusted life years

Macroeconomic effects

As is pointed out in the book, 'Assessing the Multiple Benefits of Clean Energy: A Resource for States', most approaches for assessing local economic and social impacts make the distinction between direct, indirect, and induced effects. The definition provided for each type of effect or impact is as follows:

'Direct effects are changes in sales, income, or jobs associated with the on-site or immediate effects created by an expenditure or change in final demand'

'Indirect effects are changes in sales, income, or jobs in upstream-linked sectors within the region. These effects result from the changing input needs in directly affected sectors'

'Induced effects are changes in sales, income, or jobs created by changes in household, business, or government spending patterns. These effects occur when the income generated from the direct and indirect effects is re-spent in the local economy'

Different approaches can be followed for this type of impact assessment. The main classification distinguishes between basic approaches and sophisticated approaches. Within the group of basic approaches, the rule-of-thumb estimates and the screening models like the Job and Economic Development Impact (JEDI) Model developed by the U.S. Department of Energy/National Renewable Energy Laboratory (DOE/NREL) for the evaluation of wind projects should be highlighted. These types of models require reduced inputs and they are very transparent. Nevertheless, they are considered in many cases to be overly simplified, are focused on a single technology, and need to be adapted to each particular location.

Other basic approaches for assessing the employment impacts of energy technologies (one of the main macroeconomic impact indicators addressed in this type of study), are the employment factor one and the supply chain one (IRENA, 2011). The employment factor approach applied to energy technologies uses estimated factors with the average number of jobs per unit of capacity installed. An example of this approach can be seen in the study by (Cameron & Van Der Zwaan, 2015). This first method can be considered in some cases not to be tailored enough to each specific case. The second approach, based on supply chain analysis, maps and estimates the material costs, the labour costs, and the profit margin for each of the components of the evaluated technology across its supply chain and allows for considering both the direct and the indirect employment impacts. Figure 11 shows the main segments to be considered through the value chain and the activities included in each of them for the case of wind technology.

A similar approach based on supply chain analysis is followed in the (Scottish Renewables (SR), 2012) study which aims to estimate the employment in renewable energy in Scotland for various RE technologies. (Hoggett, 2014) also adopted the supply chain approach for comparing different energy technologies that can guide energy transition towards a low carbon economy in a more secure way.

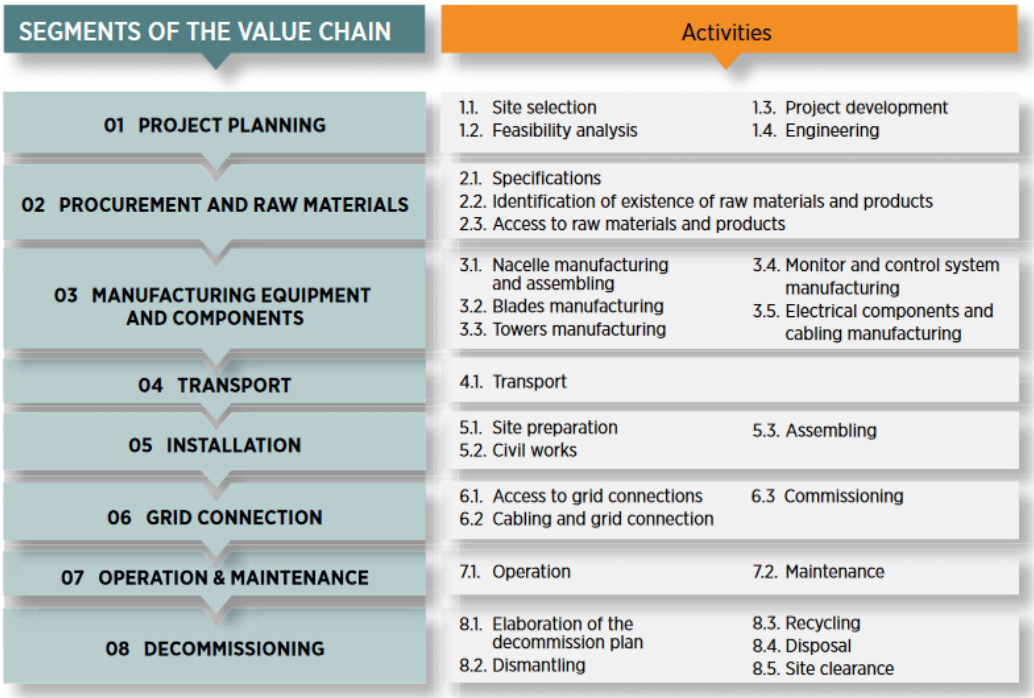

Figure 11. Segments of a wind energy project value chain (IRENA, 2016).

On a larger scale, (Liu et al., 2014) evaluated China's energy security based on supply chain theory and using a MARKAL-CGE-EIA model. (Allan et al., 2016) propose that the low carbon and renewable energy sector should be embedded in a set of input-output accounts to facilitate the planning and implementation of low carbon and renewable energy-based regional development and evaluates different cases, considering also the supply chain approach. The theory has also been applied to energy technologies. (Llera et al., 2013) evaluated the job creation associated with solar photovoltaic technology in Spain. A recently published study by (Ansari & Kant, 2016) reviews the main work in the field of the sustainable supply chain and offers an assessment of the main works carried in the last 15 years. As a general conclusion, it can be stated that although there are some related studies, currently there are difficulties in finding a supply chain analysis of energy technologies and interventions incorporated within the cities' energy transition scenarios.

In the category of sophisticated approaches, the input-output, the computable general equilibrium, the hybrid models, and the econometric model-based approaches can be distinguished (Ürge-Vorsatz et al., 2016), (Lawrence et al., 2016). These types of approaches are considered more robust, detailed, and proper for modelling a long-term perspective. Each of these approaches is very extensive, and covering the reviews on current developments and the main associated barriers in this study would be close to impossible. The most relevant differences between these approaches are well documented. See, for example, (Rose & Miernyk, 1989) and (Partridge & Rickman, 2010).

The input-output model, as developed by (Leontief, 1941) describes the interaction of sectors in a national or regional economy and explicitly reveals supply chain relationships. However, the basic I-O model has some limitations. It only shows a snapshot of the economy at a given point in time and does not take into account aspects such as the interactions and the re-spending of household income in the economy. Therefore, the so-called induced impacts cannot be evaluated (Wicke et al., 2009). The econometric approach, on the other hand, uses models composed of a set of related equations based on mathematical and statistical techniques that are used to analyse present and future economic conditions. In contrast, computable general equilibrium models are based on the principles of the microeconomic general equilibrium theory to trace the goods and services flows across the economy and solve levels of supply, demand and prices in such a way that equilibrium is achieved. This type of model is calibrated in many cases using Social Accounting Matrixes (SAM), which are extended IO tables. These models are considered adequate for evaluating the effects in the full economy due to specific policy scenarios that propose price changes, for example at the level of IO tables (Igos et al., 2015).

Finally, hybrid models combine various aspects of the previously mentioned approaches, such as IO tables and the econometric approach, in order to achieve a more flexible and robust framework that is able to respond to the specific purposes of the analysis. Therefore, the latter approach seeks to exploit the synergies and complementarities of different approaches that, in principle, are considered remote from each other. Contributions such as that of (Kratena & Streicher, 2009) reveal that there are possibilities of embedding several variables into the IO static models in order to develop a dynamic or full macroeconomic model. A study by (Kratena et al., 2013) describes the FIDELIO (Fully Interregional Dynamic Econometric Long-term Input-Output Model for the EU27) model developed for impact assessment at the European level. Following a similar philosophy, in another study, Kratena also developed a simplified model called MIOCIM (Kratena, 2015) which is adaptable to different countries and regions. This model allows a socioeconomic impact analysis in a broad sense of new investment projects, the establishment of new firms and industries, the impact of public or private consumption, and the impact of cultural events, among others.

Most of the studies in the literature using this type of model are focused at the European, national, or regional level, but not at the city level. Regarding the impact indicators evaluated in this type of studies, in a study focused on energy production, (Wicke et al., 2009) propose direct, indirect and induced impact indicators for employment, GDP, and imports. In a study by (Yushchenko & Patel, 2016), the macroeconomic analysis of an energy efficiency program was carried out by evaluating the net and gross impact on employment and the GDP. The review by (Ürge-Vorsatz et al., 2016) evaluates the most common methodologies used to assess multiple impacts in physical and monetary terms. The review reveals that the most commonly evaluated impact indicators in macroeconomic studies are the following: employment impacts, industrial productivity, macroeconomic impacts (including economic output, prices, and trade balance effects), disposable income, public budget impacts, poverty alleviation and energy prices.

2.4.3. Multi-criteria decision analysis

The prioritisation of strategies and scenarios for the transformation of cities needs to be based on the evaluation of a number of criteria that cannot be optimised simultaneously. Therefore, in the context of city energy planning it can be said that there is no a unique optimum scenario within the set of alternative options for achieving a specific goal for the city. Different methodologies are needed to support the decision-making once the evaluation studies have been carried out.

With this aim, Multi-criteria Decision Analysis (MCDA) offers a wide range of methodologies and tools to support decision-makers, allowing the combination of their own preferences with the data available (from modelling or not) to reach their own conclusions in a structured and consistent way. Figure 12 shows the basic flux between the analyst, the model, and the decision maker, which can also be applied to the energy planning process.

Figure 12. Basic flux between the analyst, the model and the decision maker (Romero, 1993).

In the last few decades, the number of MCDA methods has substantially increased and nowadays, there are hundreds of methods available (Hobbs & Horn, 1997). Many studies and different classifications of these methods can be found in the literature. In the review carried out by (Pohekar & Ramachandran, 2004), an assessment of more than 60 studies regarding the application of multi-criteria decision making to sustainable energy planning is presented. In this study, multi-criteria decision-making methods are divided into two main groups, multi-objective decision-making (MODM) and multi-attribute decision-making (MADM). MODM studies the decision problems in which the decision space is continuous and where alternatives are not predetermined. On the other hand, MADM concentrates on problems with discrete decision spaces where a set of decision alternatives has been predetermined (Triantaphyllou & Shu, 1998). In the latter classification, Triantaphyllou and Shu also identify the priority-based, outranking, distance-based and mixed methods that, at the same time, can also be classified as deterministic, stochastic, and fuzzy methods (Chen & Hwang, 1992). In their review, Pohekar and Ramacharadran focused on the following methods that can be applied to sustainable energy planning problems: the weighted sum method (WSM), the weighted product method (WPM), the analytical hierarchy process (AHP), the preference ranking organisation method for enrichment evaluation (PROMETHEE), the elimination and choice translating reality (ELECTRE), the technique for order of preference by similarity to the ideal solution (TOPSIS), compromise programming (CP), and multi-attribute utility theory (MAUT). A description of each method is also provided in the paper. The review concludes that in energy planning, the Analytical Hierarchy Process is the most popular technique, followed by the outranking techniques PROMETHEE and ELECTRE.

A few years later (Løken, 2007) published a study also focused on the use of multi-criteria decision analysis methods for energy planning problems. The study follows a different classification of methods, distinguishing between value measurement models, goal, aspiration and reference level models, and outranking models. In the first category, various criteria are given weights based on the relative importance of each criterion in order to define their contribution to the overall score. Within this category, methods like the AHP and the MAUT can be included. In the category of goal, aspiration, and reference level models, methods such as goal programming, STEM and TOPSIS can be included. These methods seek to determine the alternatives that in some sense are the closest achieving a determined goal or an aspiration level (Belton & Stewart, 2002). Finally, within the outranking models, a pair-wise comparison is applied to different alternatives to determine which alternative is preferred for each of the evaluated criterion. Here, methods like ELECTRE or PROMETHEE can be placed. In the same way, the study by (Diaz-Balteiro et al., 2016) offers an extensive review of 271 papers using MCDA methods for measuring systems sustainability. The study shows that the use of methodologies such as the AHP developed by Saaty (Saaty, 1980) and the Weighted Arithmetic Mean (WAM) are, in general, increasing in recent years. It needs to be mentioned also that the use of combined MCDA methods is becoming more common, with the aim of considering the strengths of both methods. In this field, the AHP method is one of the most commonly used ones for combining with other methods, such as PROMETHEE II, TOSIS and VIKOR. For example, (Rojas-Zerpa & Yusta, 2015) combines the AHP and the VIKOR methods for the prioritisation of alternatives for electric supply in rural and remote areas.

The case of (Terrados et al., 2009) is a good example from the various studies available of the integration of MCDA methods within broader energy planning studies. The MCDA is considered to be part of the phase focused on ranking different alternatives to be prioritised and included in phases such as the definition of the renewable energy plan at the regional scale. Also, in the context of regional energy planning, (Mourmouris & Potolias, 2013) used MCDA methods combined with geographical information systems (GIS), to select the most appropriate geographical locations for the installation of different renewable energy facilities. At the country scale, the study by (Ribeiro et al., 2013), shows how MCDA can also be applied to support the evaluation of different electricity production scenarios. A recent study focused at the city scale (Marinakis et al., 2016) identifies the potential and the need of using MCDA methods for facilitating the real implementation of Sustainable Energy Action Plan (SEAP) in the municipalities. Marinakis et al., identify MCDA methods to support local authorities during the decision-making process when identifying and prioritising the best actions to be implemented in cities to achieve their emission reduction targets.

It can be concluded that using multi-criteria analysis in the context of energy planning has attracted the attention of decision makers for a long time and that although there is not a specific method that can be prioritised, some of them seem to be more appropriate if we consider the development of the last few years.

CHAPTER 3

Methodology for the analysis and prioritisation of alternative energy transition scenarios of cities

3. Capítulo 3: Metodología de evaluación y priorización de escenarios de transición energética de ciudades

3.1. Fases principales del marco metodológico propuesto

En este capítulo se presenta el desarrollo metodológico llevado a cabo a lo largo de este trabajo de investigación, objetivo principal de esta tesis. En base a una evaluación ex-ante de impactos, la metodología que se presenta a continuación pretende sentar las bases para la evaluación y priorización de los potenciales escenarios que guíen el proceso de transición energética de ciudades hacia una economía baja en carbono. Para ello, se define el modo en el que diferentes metodologías que a priori pueden utilizarse para ámbitos distintos, pueden ser combinadas bajo la perspectiva de ciclo de vida para llegar a conformar un marco de evaluación de la sostenibilidad de escenarios de transición energética de ciudades. La metodología resultante, considera para la priorización tanto los impactos originados en la ciudad, como los efectos inducidos a escala regional.

Las fases principales de la metodología se resumen en la Figura 13 y se desarrollan más en detalle en la Figura 14. Este trabajo engloba las siete fases propuestas, pero cabe destacar que el principal desarrollo metodológico se ha llevado a cabo para las fases centrales de la metodología, para las cuales se ha identificado mayor necesidad.

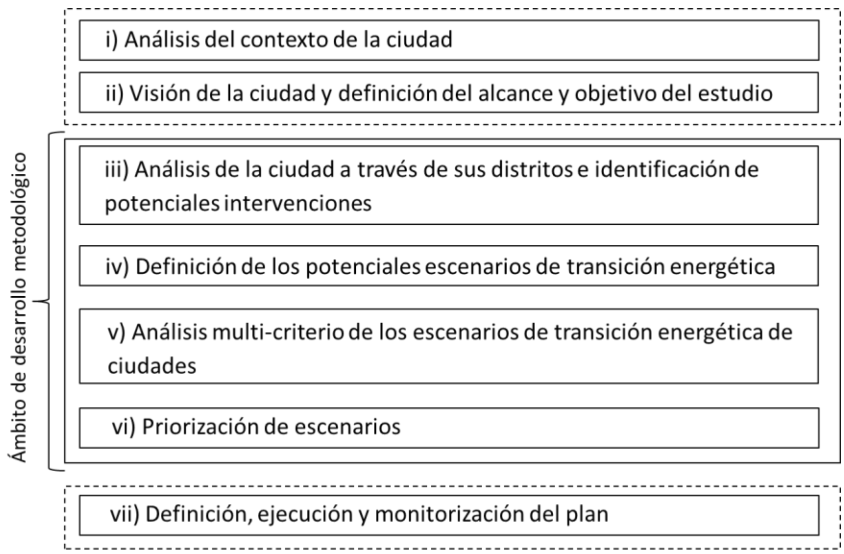

Figura 13. Fases principales del marco metodológico propuesto.

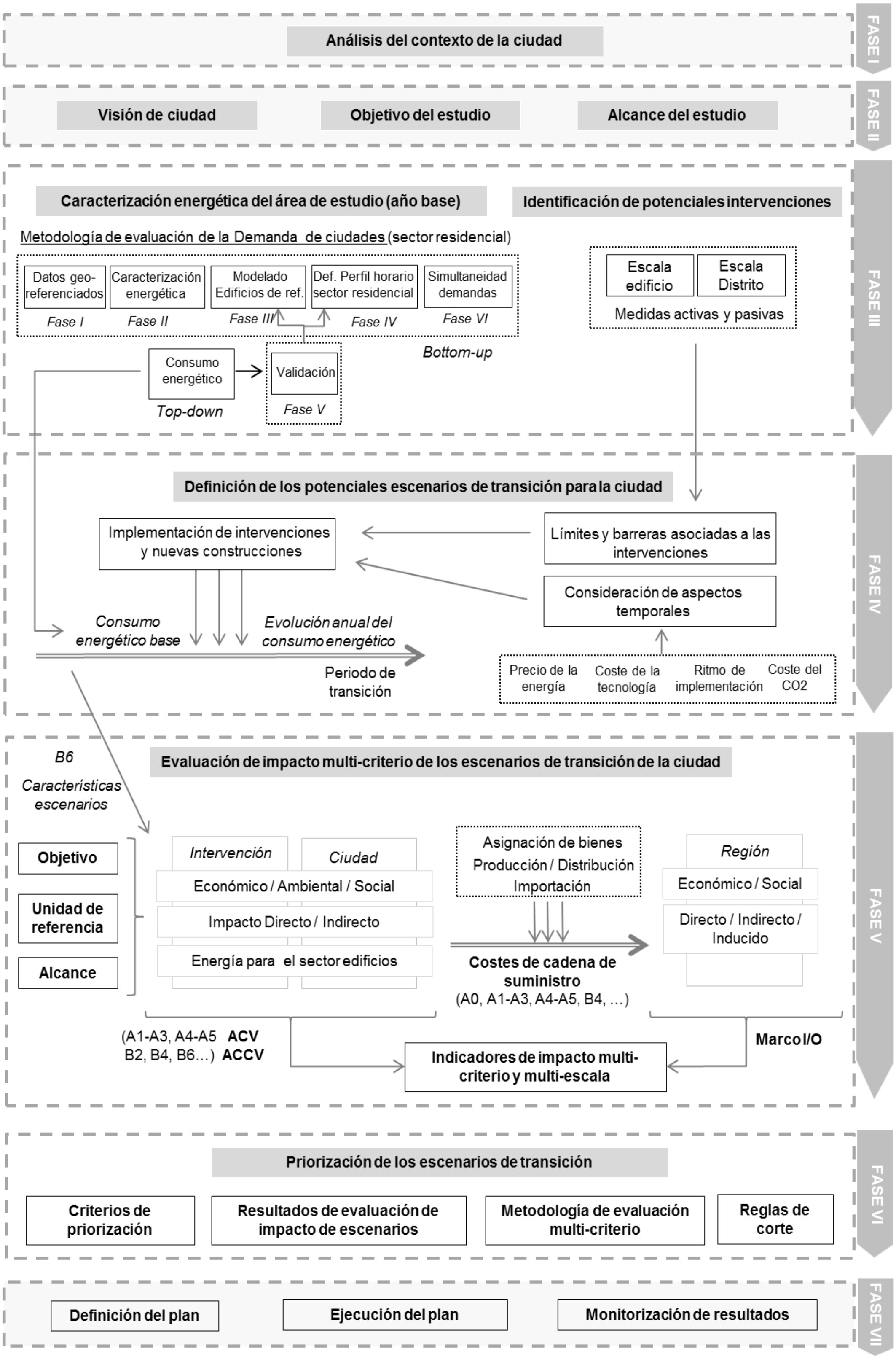

Figura 14. Fases principales detalladas del marco metodológico propuesto.

3.2. Análisis del contexto de la ciudad

La aproximación a la casuística particular de la ciudad en cuestión es el primer paso a considerar en el desarrollo de un plan de transición energética de ciudad. El objetivo principal de esta fase es obtener una visión clara de las particularidades inherentes a cada ciudad así como de sus principales necesidades y problemáticas. Comprender su pasado y presente ayudará a entender la visión de futuro.

Por lo tanto, en esta fase se llevará a cabo la recogida de información necesaria para la ejecución de las fases sucesivas. Tal y como se muestra en la Figura 15, se identifica la necesidad de asegurar la participación de los diferentes grupos y partes implicadas a lo largo del proceso. Entre ellos se encuentran las municipalidades, las empresas potencialmente interesadas en el proceso de planificación y ejecución del plan, las entidades financieras y la ciudadanía que mediante diferentes procesos de participación pueden ayudar a identificar las necesidades reales de la ciudad. De este modo, la obtención de información puede darse en muchos casos a través de entrevistas dirigidas realizadas a los agentes clave de la ciudad, a través de talleres de trabajo o en contacto directo con los técnicos de la municipalidad.

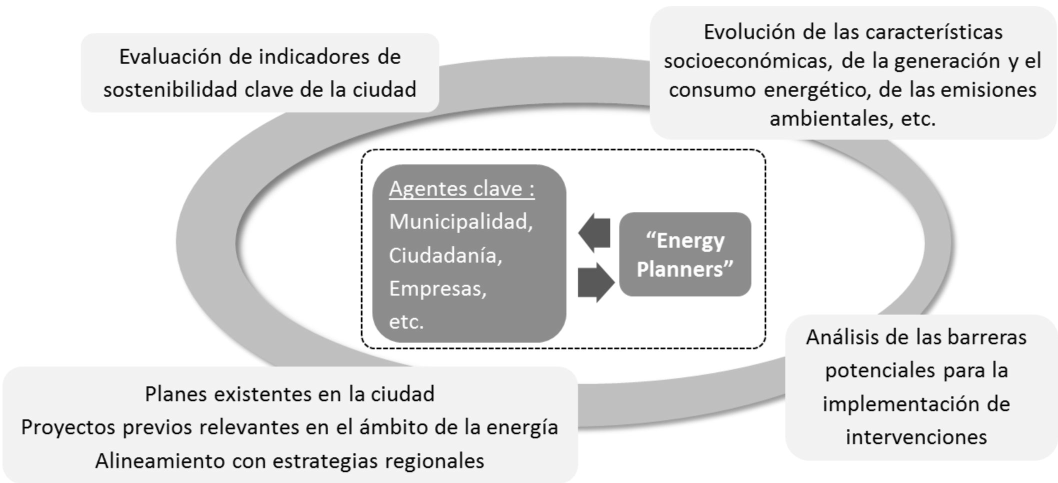

Figura 15. Aspectos principales a evaluar en una primera aproximación a la ciudad.

Resulta también interesante llevar a cabo un análisis en profundidad de los diferentes documentos de estrategia tanto generales como sectoriales que dispone la ciudad. Entre estos planes, se encuentran los planes de estrategia contra el cambio climático, planes de movilidad urbana sostenible, el Plan de Acción para la Energía Sostenible (PAES) o el Smart City plan. También es conveniente evaluar los principales proyectos que se han llevado a cabo en los últimos años así como el alineamiento de todos estos planes con las políticas locales, regionales y Europeas.

La información a recabar debe incluir además de una visión general de estrategia a futuro de la ciudad, otros aspectos socioeconómicos. Aspectos como la evolución de la demografía, el mercado de trabajo o la estructura económica y sectorial, así como otros aspectos relevantes para la planificación energética como el planeamiento urbano o las principales infraestructuras de la generación y el consumo energético de la ciudad deben ser contemplados.

Además de información técnica que podrá ser utilizada en las fases más analíticas de la metodología, se debe recoger también información complementaria que permita identificar las barreras y oportunidades que podrían influir en la viabilidad de la implementación real de las intervenciones y escenarios propuestos. Con este propósito, el marco que ofrece el análisis PESTEL (Political, Economic, Social, Technological, Environmental and Legal), puede ser utilizado para realizar una primera aproximación de las posibilidades que ofrece la ciudad evaluada para la implementación y el despliegue de determinados tipos de intervenciones. A continuación se describe brevemente el tipo de aspectos a considerar a la hora de evaluar cada una de las dimensiones propuestas en el marco PESTEL en el contexto de la planificación energética de ciudades.

Dimensión política:

Muchas de las intervenciones a implementar en la ciudad pueden ser consideradas controvertidas y pueden tener el riesgo de que algunos grupos intenten bloquearlas influenciando la opinión pública y política. Para llegar a identificar este tipo de intervenciones se debe evaluar si son susceptibles de atraer una gran crítica por parte de una sección de los políticos, grupos de presión o población local. El grado de estabilidad política existente también es un aspecto relevante a considerar y la existencia del apoyo político puede ser considerada también como una oportunidad. Una recomendación para transformar un riesgo en una oportunidad se basa en tratar de involucrar al mayor número de partes interesadas desde el momento de la concepción de los proyectos.

Dimensión económica:

Intervenciones relacionadas con determinada financiación disponible o que ofrecen un retorno de la inversión atractivo son más susceptibles de ser aprobadas. Por lo tanto, la identificación de mecanismos de financiación innovadores (financiación público privada, ESCO, etc.) puede considerarse como una oportunidad relevante. Además, el uso de componentes fabricados y distribuidos localmente así como del empleo de mano de obra local para los diferentes componentes de la cadena de suministro de las intervenciones también se considera positivo ya que en la mayoría de casos se persigue mejorar el desarrollo socio-económico de la propia ciudad.

Dimensión social:

Determinados aspectos sociales como la aceptación social se han vuelto críticos en varios casos a la hora de implementar algunas intervenciones a escala distrito y ciudad. Por lo tanto, a la hora de comparar diferentes tipos de intervenciones a llevar a cabo en la ciudad se deben considerar aspectos tales como si promocionan la igualdad en la ciudad, si benefician de forma transversal a todos los grupos de la sociedad o solo a unos pocos o si favorecen la cohesión social y promueven un estilo de vida saludable.

Dimensión tecnológica:

El grado de disponibilidad y madurez de la tecnología es también un aspecto clave a considerar. El uso de tecnologías que han sido demostradas suele estar unido a un riesgo menor, pero la posibilidad de que estas queden obsoletas después de un corto periodo de tiempo puede considerarse a su vez un obstáculo. Por lo tanto, considerando que las ciudades están en continuo cambio, aspectos como que la implementación de determinadas tecnologías pueda restringir el uso futuro de otras intervenciones debería considerarse como barrera.

Dimensión ambiental:

Los efectos medioambientales asociados a las intervenciones deben considerarse como críticos ya que además de ser uno de las principales objetivos de los planes energéticos sostenibles que en definitiva persiguen responder de un modo más eficiente a la consecución de los objetivos de reducción de emisiones de la ciudad, pueden considerarse detonantes de movimientos sociales que pueden terminar influenciando la opinión política.

Dimensión Legal:

Aspectos asociados a determinadas intervenciones como la necesidad de establecer algún nuevo marco legal o político para facilitar su implementación deben considerarse como barreras importantes. También se debe considerar cuidadosamente el efecto que puede llegar tener el cambio continuo de la legislación, especialmente en el sector energético (cese de los incentivos a determinadas renovables, etc.) sobre cada una de las inversiones. La alineación de las intervenciones a los objetivos políticos establecidos desde Europa puede ser una oportunidad para minimizar ese riesgo.

Finalmente, tal y como se ha mostrado en la sección 2.4.1 del documento, existen numerosos marcos de evaluación de la sostenibilidad de ciudades que pueden ser utilizados para evaluar de un modo cuantitativo la situación actual de la ciudad en cuanto a un amplio número de indicadores que cubren las principales dimensiones de las mismas.

El uso de estos marcos se identifica como potencialmente beneficioso sobre todo para el caso de ciudades cuyos objetivos a futuro no están claramente definidos. El hecho de caracterizar la ciudad con una perspectiva amplia, permitirá a través de una comparación respecto de los valores obtenidos por otras ciudades, determinar los ámbitos de la ciudad que están comportándose de peor modo. Esto a su vez, permitirá identificar los objetivos específicos que deben ser fijados por las ciudades para llegar a conseguir un mejor comportamiento en dicho ámbito, así como a identificar las principales barreras y las palancas de cambio sobre las que apoyarse para guiar el proceso de transición.

De los marcos de evaluación disponibles, se recomienda seleccionar aquel que ofrezca mayores garantías para la comparación de los resultados obtenidos con el de otras ciudades. Lamentablemente, por el momento no existe una fuente o base de datos con valores específicos de estos indicadores de suficientes ciudades como para llegar a establecer un valor de referencia con el que comparar los datos de la ciudad evaluada. Uno de los más relevantes y que potencialmente puede recoger mayor cantidad de información de diferentes ciudades es el estándar ISO 37120 descrito anteriormente, por lo que en este trabajo de cara los próximos años se recomienda su uso a pesar del alto número de indicadores que propone y la complejidad asociada actualmente a la recolección de los datos necesarios.

3.3. Visión de la ciudad y definición del objetivo y alcance del estudio

3.3.1. Visión de futuro de la ciudad

Una vez caracterizada la ciudad en su conjunto, se está en disposición de proceder a la definición de los objetivos generales que perseguirá la ciudad mediante la aplicación de la metodología. La Figura 16 muestra un esquema simple en el que se puede ver la relación entre la situación de partida, la estrategia general, el escenario de transición energética y las intervenciones que lo forman, con la visión de futuro de la ciudad.

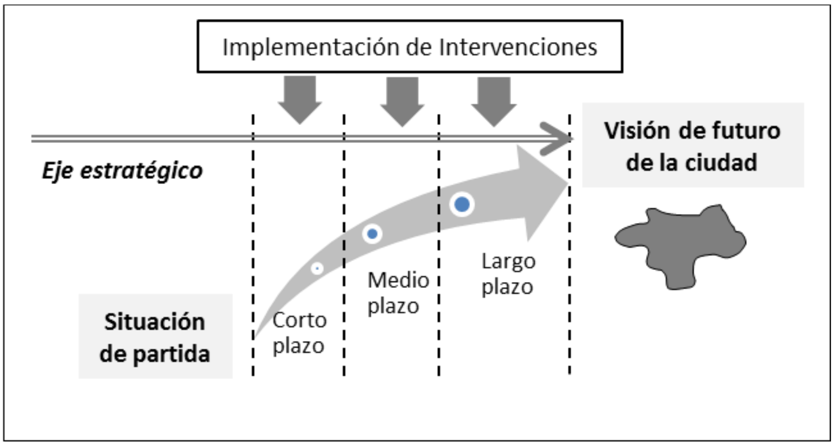

Figura 16. Esquema general de la relación entre la estrategia general, el escenario de transición y las intervenciones que lo forman y la visión de futuro de la ciudad.

Al igual que en la fase de contextualización de la ciudad, es aconsejable que el proceso de definición de la visión de futuro de la ciudad, se desarrolle de un modo participativo en el que se llegue a un consenso entre la municipalidad y la ciudadanía. Esta visión de futuro sentará las bases para la definición de los objetivos principales de la ciudad. Estos objetivos deben estar a su vez, alineados con las exigencias de reducción de emisiones a largo plazo que se han impuesto para la ciudad.

3.3.2. Definición del objetivo y alcance del estudio

Objetivo del estudio

A continuación se debe definir el objetivo principal que persigue el estudio. En este caso, el objetivo estará relacionado con la identificación del escenario de transición energética óptimo que permita llegar a transformar la ciudad en una ciudad baja en carbono a la vez que asegure un desarrollo socioeconomico adecuado de la misma. Este objetivo será relevante también en fases posteriores de la metodología donde se lleve a cabo el proceso de toma de decisiones para la priorización de escenarios.

Alcance del estudio

En un segundo paso se debe definir el alcance de la aplicación de la metodología. En el contexto de la planificación energética de ciudades, el concepto de alcance se puede abordar desde diferentes perspectivas. En este caso, se propone considerar para la definición del alcance una triple perspectiva;

- Alcance en cuanto a la escala de aplicación:

Los límites de la ciudad son generalmente geopolíticos y están definidos por uno o más gobiernos municipales. Es importante comprender que la mayor parte de actividades que ocurren dentro de los límites físicos de la ciudad afectan no solo a la propia ciudad sino que también tienen efectos sobre otras ciudades que comprenden la región e incluso sobre otros países en el caso de que se considere la perspectiva de ciclo de vida. A modo de ejemplo, la implementación de tecnologías de generación y las redes de distribución urbanas implicará la compra de numerosos componentes que muy probablemente hayan sido fabricados fuera de los límites de la ciudad. Por lo tanto los impactos ambientales asociados a la extracción de materias primas, manufactura de componentes o el transporte entre otras fases del ciclo de vida, ocurrirán en otras ciudades o países. Del mismo modo, los beneficios asociados a esas fases tales como la actividad económica inducida debido a la inversión realizada en componentes así como el empleo generado a lo largo de la cadena de suministro de la tecnología deben ser asignadas fuera de los límites de la ciudad cuando corresponda.

La Figura 17 utilizada para la definición de los límites de Gases de Efecto Invernadero de ciudades, permite comprender esta idea que puede extenderse al resto de categorías de impacto y dimensiones de la sostenibilidad. En la figura se puede apreciar el modo en el que se distinguen tres alcances, el correspondiente a los límites geopolíticos de la ciudad, el de la energía suministrada a la ciudad desde las redes regionales y el último que va más allá de los dos anteriores.

En este caso, la metodología distingue también tres escalas aunque bajo una perspectiva diferente: la escala de distrito o intervención, la escala de ciudad y la escala regional. La relevancia de considerar estas tres escalas y las conexiones entre las mismas han sido previamente discutidas en el capítulo 2.

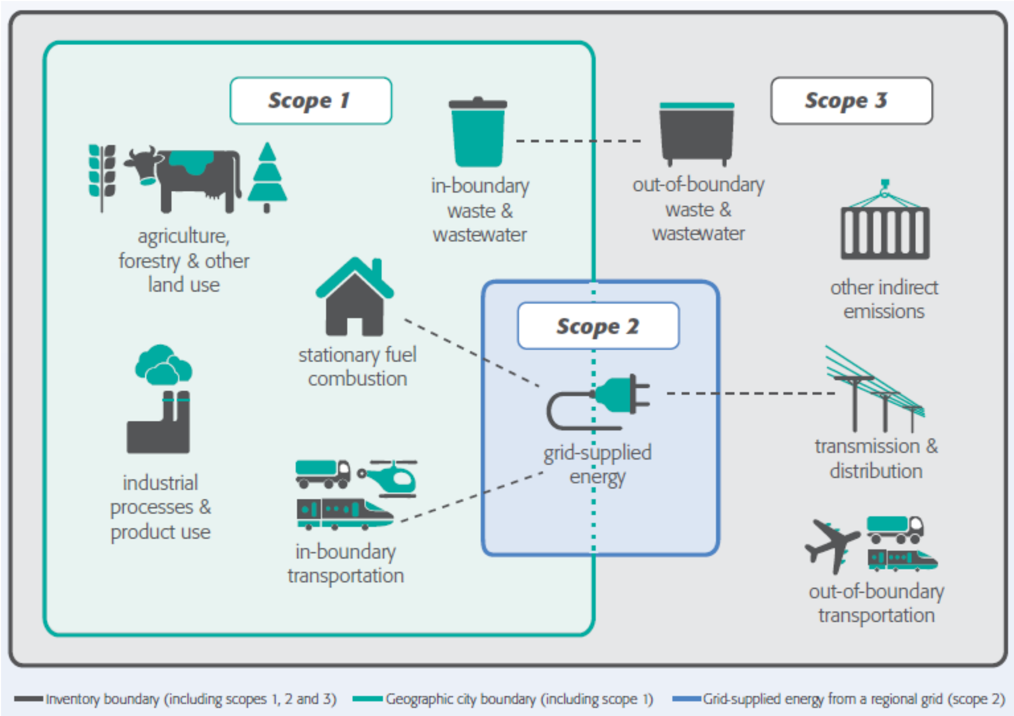

Figura 17. Límites del sistema de Gases de Efecto Invernadero en ciudades (World Resources Institute, 2014).

El análisis a escala de distrito resulta necesario debido a que la mayoría de intervenciones que se implementarán con el propósito de mejorar la ciudad suelen contemplar uno o varios distritos en lugar de la ciudad en su totalidad. Sin embargo, no se debe obviar que el efecto perseguido por la implementación de dichas intervenciones no se limita exclusivamente a la transformación del distrito en cuestión sino que se persigue producir un efecto en el conjunto de la ciudad. Es por ello por lo que es necesario establecer un marco de evaluación que combine ambas escalas de manera que permita trasladar el efecto que las diferentes intervenciones tienen sobre otros aspectos más amplios de la ciudad como su desarrollo económico, sobre la ciudadanía en general o sobre el medioambiente.

Finalmente, la metodología también debe permitir considerar evaluar el alineamiento de la estrategia de la ciudad con las estrategias regionales, ya que cada ciudad debe contribuir a su modo y en la medida de lo posible a la consecución de los objetivos establecidos en esta siguiente escala. Es por ello por lo que se debe analizar no solo la estructura económica y sectorial de la ciudad sino de la región a la que esta pertenece para proporcionar criterios específicos que permitan priorizar los diferentes escenarios de transición de la ciudad y su contribución a la región.

- Alcance en cuanto a las áreas de aplicación y las áreas estratégicas de la ciudad contempladas por la metodología:

Esta segunda categoría de alcance pretende definir de manera clara el alcance del trabajo en lo que se refiere a las diferentes áreas de aplicación y las áreas estratégicas de la ciudad que se pretenden abordar por la metodología. Como marco general, la Figura 18 representa una clasificación de las áreas estratégicas (líneas estratégicas de la ciudad que se pretenden mejorar por medio de las intervenciones) y de las áreas de aplicación (sectores de la ciudad sobre los que pueden influir las diferentes intervenciones) de una ciudad.

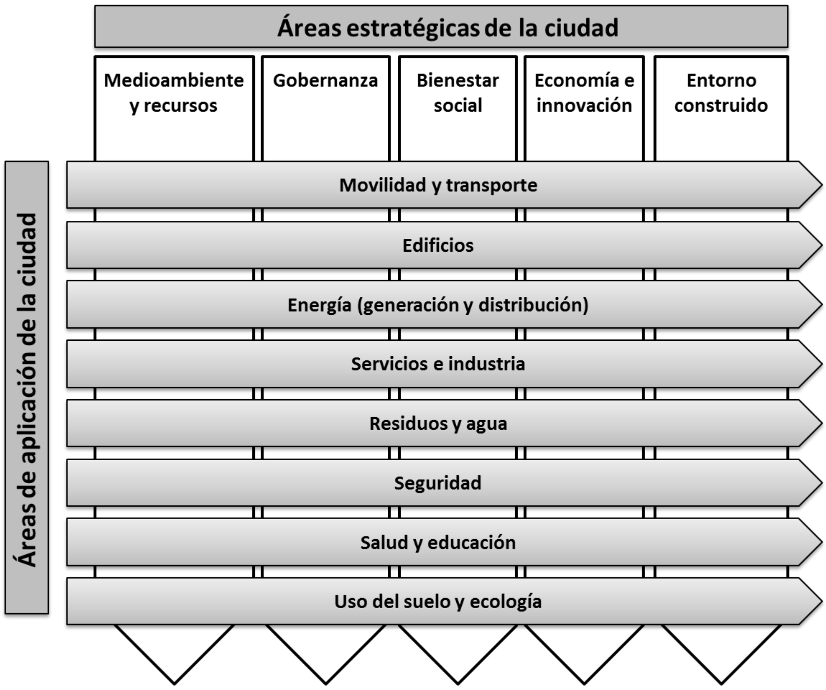

Figura 18. Ejemplo de áreas de aplicación y áreas estratégicas de la ciudad (A partir de la investigación llevada a cabo en el proyecto Europeo CYTyFied).

Este esquema puede ser utilizado para definir el alcance del estudio. A pesar de que el esquema presentado incluye todas las áreas a considerar en un análisis estratégico completo de ciudades, considerando el ámbito de la metodología desarrollada, en este caso el alcance se centrará en las áreas de aplicación de edificios y de generación y distribución de la energía.

- Alcance en cuanto a la las dimensiones y tipos de impactos evaluados:

Bajo esta última categoría, se define por un lado las dimensiones que se considerarán en el estudio para la evaluación de impacto de cada una de las escalas (distrito/intervención, ciudad, región). Desde un punto de vista de análisis de la sostenibilidad de ciudades, el análisis completo consideraría los tres pilares de la sostenibilidad; social, ambiental, económico. En esta fase se debe definir claramente cuáles de estas dimensiones o pilares se incluirán en el estudio.

Además, se debe definir el alcance de los impactos que se evaluarán para cada una de las dimensiones y para cada una de las escalas consideradas. Esto determinará en gran medida la complejidad de la aplicación de la metodología. En este sentido y siguiendo la clasificación mencionada en el Capítulo 2, se puede distinguir entre los impactos directos, impactos indirectos y los impactos inducidos. A continuación se describe brevemente, el alcance de cada una de las tres aproximaciones para el ámbito socioeconómico:

Efectos directo: Los efectos directos son los cambios generados en las ventas, ingresos o empleos que están asociados a un efecto inmediato originado por un cambio en la demanda final. Por ejemplo, los empleos y salarios de los trabajadores que ensamblan los componentes principales de la tecnología analizada.

Efectos indirectos: Una vez que los efectos directos interactúan con la economía regional ocurren los efectos indirectos e inducidos. Los efectos indirectos son los cambios generados en las ventas, ingresos o empleos en los sectores que intervienen en la cadena de suministro de esa tecnología dentro de la región. Por ejemplo, los empleos y salarios de los trabajadores de las empresas suministradoras de materiales y componentes de la tecnología.

Efectos inducidos: Cambios en las ventas, ingresos o empleos creados generados por el cambio originado en el patrón de gastos en los hogares, los negocios o el gobierno. Estos efectos se crean cuando los ingresos generados por los efectos directos e indirectos son re-invertidos en la economía local. Por ejemplo, el gasto extra realizado en la economía local por los trabajadores que ensamblan los componentes de la tecnología analizada, debido al aumento de sus salarios.

La Tabla 3 resume el alcance considerado por la metodología desarrollada en cuanto a las dimensiones y tipos de impactos evaluados para cada una de las escalas que engloba.

Tabla 3. Impactos considerados para cada una de las dimensiones y para cada una de las escalas de la metodología.

	Dimensión Ambiental		**Dimensión Económica**			**Dimensión Social**		
	Directo	Indirecto	Directo	Indirecto	Inducido	Directo	Indirecto	Inducido
Intervención	x	x	x	x				
Ciudad	x	x	x	x		x	x	
Región			x	x	x	x	x	x

3.4. Análisis de la ciudad a través de sus distritos e identificación de potenciales intervenciones

Entendiendo la ciudad como una agregación de los distritos que la forman, esta fase de la metodología detalla el modo de evaluar los distritos en los que se implementarán las diferentes intervenciones que forman parte del escenario de transición energético de la ciudad. En un primer paso, se define el proceso de caracterización de la situación inicial de las áreas de la ciudad sobre las que se pretende intervenir. Esta caracterización estará inevitablemente condicionada por la información que demandará la fase de evaluación de impacto multi-criterio.

Por otro lado, se proporcionan criterios para la identificación y preselección de las potenciales intervenciones a implementar en la ciudad. Considerando el ámbito de actuación definido, entre las intervenciones a considerar se contemplarán desde medidas de eficiencia energética hasta tecnologías de generación energética renovables y bajas en carbono.

3.4.1. Caracterización energética de los distritos evaluados

Con el objetivo de evaluar la contribución de cada una de las intervenciones sobre la reducción del consumo de energía primaria y de emisiones ambientales en la ciudad, se debe analizar en detalle la demanda energética y el consumo de la misma para el año base. Esta evaluación se llevará a cabo de manera que la distribución del consumo a lo largo del año así como la distribución por fuente energética y por uso final de la energía puedan ser diferenciadas.

En la sección 2.3.1 del Capítulo 2, se ha podido comprobar que mientras que a nivel de edificio, existen numerosas metodologías y herramientas que permiten estudiar la demanda y el consumo energético horario, la dimensión temporal de la demanda y el suministro a escala ciudad no está tan bien documentada. Es por ello por lo que a menudo los técnicos encargados de la planificación energética de ciudades tienen que combinar varias metodologías y herramientas con diferentes escalas y aproximaciones.

Atendiendo a esta necesidad, en esta sección se describe el desarrollo de una metodología flexible que permite estimar la curva horaria de la demanda y el consumo del sector de edificios de las ciudades de un modo desagregado y que pueda ser aplicada a diferentes escalas, desde la escala distrito hasta la escala de ciudad. Para ello se propone una doble aproximación *bottom-up* y *top-down*.

La aproximación bottom-up permite considerar de manera geo-referenciada los principales factores urbanos que afectan sobre el comportamiento energético de las áreas evaluadas en la ciudad. Factores tales como el uso de los edificios, el área de los bloques, el año de construcción, el tipo de instalaciones de generación y las últimas actuaciones de rehabilitación llevadas a cabo en los mismos son considerados. Otro aspecto clave de la metodología es la aproximación top-down que se adopta para la fase de validación donde se comparan los resultados calculados con los datos reales de consumo energético de la ciudad en su conjunto.

Esta metodología es precisamente la que se propone para evaluar la fase B6 de la metodología desarrollada para la evaluación de impacto de los escenarios de transición de la ciudad que se describe más adelante en la sección 3.6.4 de este capítulo.

La Figura 19 muestra de manera esquemática el marco metodológico propuesto para la estimación de la curva de demanda horaria de los distritos y de la ciudad.

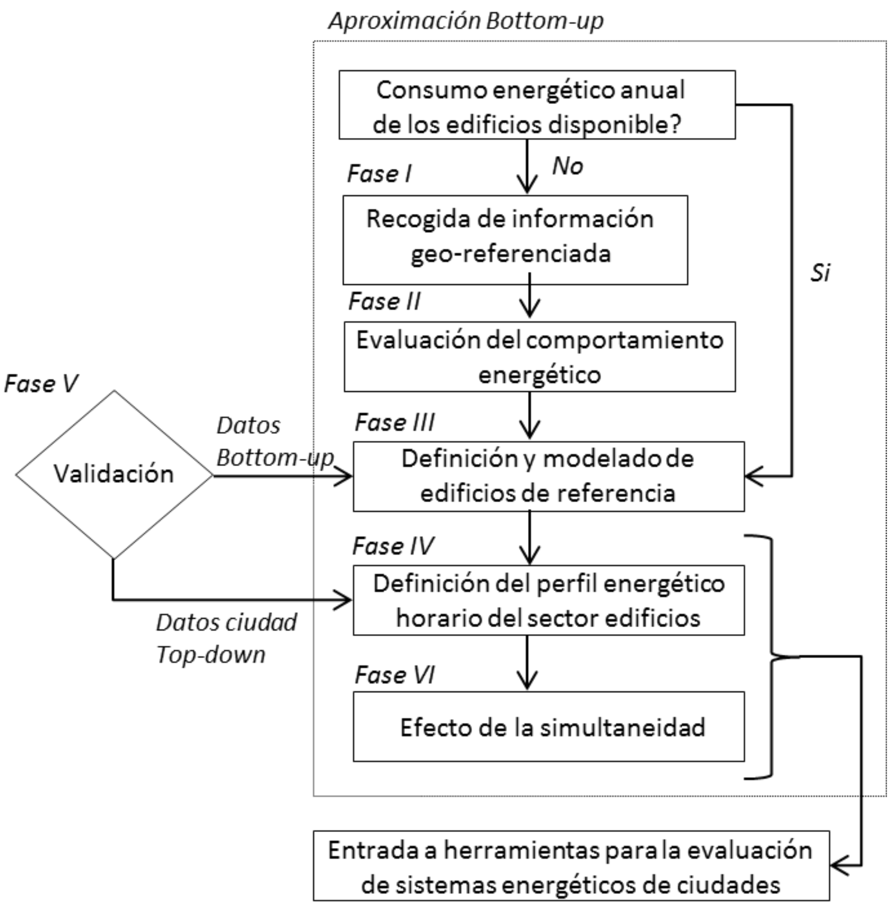

Figura 19. Marco metodológico para la estimación de la curva de demanda horario de distritos y ciudades.

La metodología está compuesta por las seis fases que se detallan a continuación.

Fase I: Recogida de información geo-referenciada

El objetivo principal de la fase es recabar la información necesaria para llevar a cabo la completa caracterización de los edificios en las áreas evaluadas en la ciudad. El resultado de esta fase será la información geo-referenciada y estática de cada bloque de edificio que se encuentra dentro de los límites definidos. La literatura existente está ampliamente documentada en cuanto a la definición de las características principales a considerar para la definición de la demanda energética de edificios. La revisión realizada por (Braulio-Gonzalo et al., 2016) por ejemplo, muestra que las variables clave a considerar son las propiedades térmicas de la envolvente y el año de construcción. En este caso, la metodología también pretende analizar el uso de energía, por lo que información adicional como los sistemas de generación de los edificios o las fuentes energéticas utilizadas resultan también de interés.

La complejidad del problema erradica principalmente en al volumen cálculos y a la dificultad en la obtención de datos reales. Es por ello por lo que se propone partir de una asignación de la calificación energética para cada uno de los edificios del área de estudio. Para ello se recogerá la información disponible de la calificación asignada a cada edificio a partir de la cual se determinará su demanda energética en función de su uso. El nivel de eficiencia energética de los edificios puede obtenerse de fuentes públicas como las web del Departamento del Desarrollo Económico y Competitividad destinadas al certificado de eficiencia energética (Departamento del Desarrollo Económico y Competitividad del Gobierno Vasco, 2017).

Esta información se encuentra disponible cada vez para más edificios de las ciudades ya que con la finalidad de fomentar la eficiencia energética de los edificios nuevos y existentes de la Unión Europea, la normativa comunitaria ha establecido la obligación de certificar la eficiencia energética de edificios a partir del 1 de junio de 2013. De este modo, los propietarios de los inmuebles deben disponer de un certificado de eficiencia energética para poder vender o alquilar sus viviendas. Para los edificios en los que la calificación energética no se encuentra disponible, la siguiente fase de la metodología detalla el método simplificado para la asignación de la calificación en función de determinada información recogida en esta fase. Información como la fecha de construcción, el número de plantas, el área del edificio, el tipo de sistema de generación y la ejecución previa de acciones de rehabilitación en los edificios.

Datos como la fecha de construcción, el número de plantas, el área de cada planta y el uso del edificio (tanto por bloque como por portal) serán obtenidos a partir del catastro de la ciudad. Esta información puede ser complementada con información disponible en otras fuentes como las aplicaciones GIS disponibles para la ciudad o para la provincia a la que pertenece. Otra opción es complementar esta información con otras fuentes existentes a nivel regional. Un ejemplo para la CAPV es la base de datos Eustat donde se ha puesto a disposición del usuario una web con una aplicación GIS para la difusión estadística de la región (Visor GeoEuskadi, 2017). Para el resto de la información como el tipo de sistemas de generación de los edificios, el combustible utilizado y las acciones de rehabilitación llevadas a cabo se recomienda contar con la colaboración de los técnicos del ayuntamiento de la ciudad objeto de estudio.

Fase II: Evaluación del comportamiento energético de los edificios

Tal y como se ha mencionado anteriormente, una de las variables más críticas recogidas en la primera fase es el grado de calificación energética de los edificios ya que este será el dato de entrada principal para determinar la demanda energética de los mismos. Siguiendo las especificaciones de la regulación española relativa a la certificación energética de edificios (IDAE, 2011), los límites de las demandas energéticas por metro cuadrado de área calefactada pueden ser calculadas para cada ciudad en función de la tipología de edificios. De este modo se pueden distinguir los edificios residenciales de los edificios con otros usos así como los diferentes edificios en función de su nivel de calificación (Figura 20).

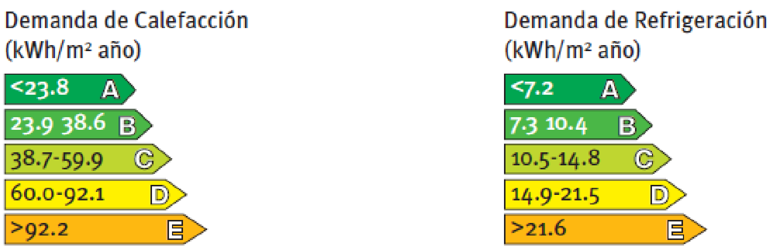

Figura 20. Ejemplo de los límites entre clases para la demanda de calefacción y refrigeración de viviendas unifamiliares de Madrid (IDAE, 2009).

Para aquellos bloques de edificios en los cuales no se dispone del certificado de eficiencia energética, la metodología establece el siguiente procedimiento. El primer paso se centra en la evaluación de los bloques de edificios situados alrededor del bloque en cuestión. El objetivo es encontrar similitudes entre ambos en lo que a las características constructivas se refiere e identificar la calificación energética que más se repite. En caso de respuesta positiva, esa será a calificación energética asignada al bloque evaluado. En caso de respuesta negativa, se evaluará el bloque en lo que se refiere al año de construcción. Considerando la relación existente entre la calificación energética más común para cada franja de años se asignará el nivel de eficiencia del edificio. De este modo, como norma general a los edificios más antiguos les corresponderán niveles de eficiencia bajos (E, F, G) y a los más nuevos construidos a partir de la entrada en vigor del Código Técnico de la Edificación se le asignará una calificación C o superior. Además del año de construcción, se debe evaluar si el edificio en cuestión ha sufrido alguna actuación de rehabilitación importante en los últimos años ya que este aspecto mejoraría la calificación asignada inicialmente.

Fase III: Definición y modelado de edificios de referencia

Disponer las demandas energéticas agregadas de forma anual por tipo de edificio y según su uso y área resulta útil para la caracterización de la ciudad, pero también presenta notables limitaciones a la hora de evaluar diferentes escenarios de abastecimiento. Aspectos como el desfase temporal existente entre la demanda y la generación o el efecto de las diferentes opciones de almacenamiento de energía, ambos aspectos de vital importancia para avanzar en la integración de las fuentes renovables en la ciudad, no pueden ser evaluados en detalle.

Bajo este contexto, esta fase se centra en la definición y el modelado de una serie de edificios de referencia que serán utilizados para calcular los perfiles horarios de las demandas para las diferentes tipologías de edificios y para los diferentes usos finales de la energía en los mismos. Combinando los resultados de esta fase con los resultados de la fase anterior se estará en disposición de definir la curva de demanda horaria de los distritos evaluados y de la ciudad en su conjunto para un año estándar.

En esta fase es importante llegar a un compromiso entre el esfuerzo dedicado a la definición de los edificios de referencia y la representatividad de tipologías de edificios obtenida para el área evaluada. Estos edificios de referencia se distinguirán por un lado según su uso; edificios residenciales, de oficinas, docentes, de salud y otros tipos de edificios terciarios. Una segunda clasificación distinguirá los edificios en función de su nivel de eficiencia.

En este caso, considerando la siguiente distribución por área en el stock de edificios de Europa, residencial: 67%, oficinas: 9%, salud: 4%, educación 5%, comercial: 9%, gastronómico: 3%, resto: 3% (Ecofys, 2012), se identifica la necesidad de definir edificios de referencia de uso residencial y de uso de oficinas ya que estos suman el mayor número de edificios. Además, para cada uso del edificio definido, se modelarán edificios de referencia correspondientes a los diferentes niveles de eficiencia energética. De este modo se obtendrán siguiendo la nomenclatura de la calificación energética de edificios, los siguientes edificios de referencia: residencial A, residencial B, residencial C, residencial D, residencial E, residencial F, residencial G, oficinas A, oficinas B, oficinas C, oficinas D, oficinas E, oficinas F y oficinas G.

Además de lo especificado en los documentos de certificación energética, las características de estos edificios se definirán de acuerdo a la regulación nacional (CTE, 2013). De este modo los edificios se modelarán en softwares de modelado energético de edificios como Design Builder que permite el análisis energético dinámico horario y sub-horario de edificios, considerando efectos como las ganancias internas, ganancias solares, perdidas por renovaciones de aire e infiltraciones o las características de la envolvente del edificio. Finalmente, se obtendrán mediante simulación las demandas no solo de calefacción y refrigeración sino también las de ventilación, iluminación y de otros equipos incluidos en los edificios analizados.

El resultado de esta fase será por lo tanto, el perfil horario genérico correspondiente a la demanda energética de cada edificio de referencia distinguiendo entre el tipo de energía consumida y su uso final (calefacción, agua caliente sanitaria, refrigeración, iluminación, ventilación y otros eléctricos).

Fase IV: Definición del perfil energético horario del sector edificios de los distritos y de la ciudad

El objetivo de esta fase es la caracterización final del perfil energético horario de los distritos y de la ciudad. Con este objetivo, los resultados de las fases II y III se combinan permitiendo la agregación de la demanda energética anual geo-referenciada de cada edificio dentro del área de estudio con los perfiles horarios definidos para cada edificio de referencia. De este modo, se obtiene la curva de demanda final de los distritos y por agregación de la ciudad, distinguiendo entre los usos finales anteriormente mencionados. La Ecuación 1 muestra a modo de ejemplo el cálculo de cada componente de la demanda horaria (*building heating hourly demand (BHHD)*) para un edificio de uso residencial con un nivel de eficiencia energética C. Donde $BAHED^{Res,C}$ *(building annual heating demand for residential use with an energy performance level of C)* es la demanda anual de un edificio de uso residencial con una calificación *C* obtenida de los límites definidos por la certificación energética de edificios y $HNf_t^{Res,C}$ *(heating normalized factor for the hour t of the reference building with residential use and an energy performance level of C)* es el factor de normalización de la demanda de calefacción del edificio de referencia de uso residencial y calificación C en la hora *t* obtenido a partir de la división de la demanda de esa hora respecto del máximo.

$$BHHD_t^{Res,C} = BAHD_t^{Res,C}\left(\frac{Kwh}{m^2}\right) x\ Heated\ area\ (m^2) x\ HNf_t^{Res,C}$$

Ecuación 1

Siguiendo con el ejemplo y aplicando este mismo procedimiento para el resto de usos finales de la energía en el edificio, la Tabla 4 muestra el modo en el que los edificios residenciales de calificación energética C quedarían representados a lo largo de la ciudad. Este proceso debe ser aplicado al resto de edificios con diferente nivel de eficiencia y uso. Esto permitirá mediante la agregación de los edificios del mismo tipo determinar la curva de demanda horaria de los distritos y de la ciudad tanto para edificios residenciales como de servicios. En la tabla también se muestra el modo en el que quedaría la demanda horaria para cada distrito evaluado y para la ciudad. Donde H corresponde a calefacción (Heating), DHW a agua caliente sanitaria (Domestic Hot Water), C a refrigeración (Cooling) y E a otros eléctricos (Other electric). Finalmente, $\sum(A)$ y $\sum(B)$, corresponden a todos los edificios de la ciudad con calificación energética A y B respectivamente.

Tabla 4. Ejemplo de obtención de la curva de demanda horaria de la ciudad obtenida siguiendo la metodología propuesta y desagregada por tipologías de edificios y usos finales.

Uso del edificio	**Residencial**												**Oficinas**							
Calificación	$\sum(\boldsymbol{A})$				$\sum(\boldsymbol{B})$				$\sum(\dots)$				$\sum(\boldsymbol{A})$				$\sum(\dots)$			
Uso final de la energía	H	DHW	C	E	H	DHW	C	E	H	DHW	C	E	H	DHW	C	E	…	…	…	…
Fecha y hora																				
01/01/2016 1:00	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
01/01/2016 2:00	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
01/01/2016 3:00	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
01/01/2016 4:00	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
…		…				…				…				…					…	
$\sum(\textit{\textbf{horas del año}})$		…				…				…				…					…	

Fase V: Validación:

Esta fase tiene como objetivo validar los cálculos realizados hasta el momento siguiendo la perspectiva *bottom-up*, comparándolos con los datos reales obtenidos con la aproximación *top-down* para los distritos y para la ciudad. Esta fase se verá muy condicionada por la disponibilidad de datos en la ciudad evaluada. Para el caso en el que únicamente se dispone datos de consumos totales a nivel de ciudad, la relación entre el número de edificios estudiados y el consumo energético total de todos los edificios de la ciudad debe ser cuidadosamente evaluada. Además, aspectos como la proporción de combustibles consumidos en el sector de edificios y el porcentaje de viviendas vacías deben ser considerados.

La Tabla 5 muestra a modo de ejemplo el tipo de información que habitualmente se encuentra dispone a escala ciudad. Esta información será utilizada para la validación del modelo.

Tal y como se aprecia en la tabla, el gap de predicción se obtiene en este caso para los edificios residenciales de la ciudad dividiendo el consumo energético real de la misma tanto para la electricidad como para el gas natural con el consumo energético obtenido del modelado. Resulta evidente que la proporcionalidad no debe cumplirse exactamente ya que la validación se realiza a partir de los datos agregados para toda la ciudad. Esto es debido a que el consumo utilizado para la validación se obtiene del consumo total real en función de la relación del número de edificios entre la ciudad y los distritos considerados. La proporcionalidad a partir del número de edificios conlleva hipótesis que crearán cierto error ya que las características de los edificios incluidos en el análisis pueden variar. A pesar de ello, esta fase permite identificar posibles desviaciones que se estén cometiendo.

Tabla 5. Ejemplo de información Top-down (provincial y de ciudad) a utilizar para la validación del modelo.

Sistema de calefacción (Datos provinciales)	**(%Elec.)**	**(%NG)**	**(%Otros)**	**(%Biom.)**	
Central	x	x	x	x	
Individual	x	x	x	x	
Puntual	x	x	x	x	
Energy carrier of the heating system & Nº of Buildings	**(%Elec.)**	**(%NG)**	**(%Otro)**	**(%Biom.)**	**Número de edificios**
Ciudad	x	x	x	x	x
Distrito 1	x	x	x	x	x
Distrito 2	x	x	x	x	x
…	…	…	…	…	…
Edificios desocupados x%					

Sector Residencial		**Consumo energético**		**Demanda energética**
	Ciudad	Ciudad/Distritos (Prop. al Nº de edificios)	Distritos/Ciudad (modelado)	Distritos/Ciudad (modelado)
Electricidad (GWh)	x	x	x	x
Gas Natural (GWh)	x	x	x	x

Tal y como se puede ver en la Tabla 5, para poder realizar esta validación es necesario obtener previamente el consumo energético de los edificios modelados. A continuación se describen las principales consideraciones para calcular el consumo energético del área de la ciudad evaluada.

- *Consumo energético*

Con el objetivo de determinar el consumo energético, se considerará en cada caso el rendimiento de los sistemas en función del uso final de la energía y de la fuente energética utilizada. Estos sistemas pueden clasificarse en dos grandes grupos. Por un lado los sistemas de generación de energía a escala de edificio y por otro lado los sistemas de generación de energía a escala de distrito.

Sistemas de generación de energía en el edificio:

En esta categoría se encuentran las calderas, los equipos de climatización, los calentadores eléctricos, los sistemas de micro-cogeneración, etc. En el caso de las calderas se deben diferenciar las calderas individuales de las centralizadas, así como las calderas alimentadas por diferentes fuentes de energía. Estas características así como la edad, las pérdidas de distribución y el estado de las instalaciones influirán sobre su rendimiento y por lo tanto sobre el consumo real del edificio. En el caso de los sistemas de climatización, el consumo de energía corresponderá a la electricidad y su coeficiente de operación dependerá de diferentes aspectos como las condiciones de funcionamiento y el tipo de fluido empleado. De este modo se deben considerar en la ciudad los rendimientos de todos los sistemas de generación de energía de los edificios.

Del mismo modo, el consumo energético de los edificios se verá reducido debido al uso de sistemas de generación de energía renovable. Entre ellos se encuentran los sistemas solares térmicos, los sistemas solares fotovoltaicos, la mini-eólica, etc. La disminución del consumo dependerá de la generación de energía útil de cada sistema. Este aspecto se verá condicionado en cada caso por la disponibilidad del recurso energético, del rendimiento de los sistemas y de la capacidad de los mismos para hacer frente al desfase temporal entre la demanda y la generación (ya sea a través de la optimización en el diseño de los sistemas de generación o a través del almacenamiento).

Por último, para la evaluación del consumo a escala de edificio se deben considerar también otro tipo de medidas de eficiencia energética que pueden influir sobre el consumo final. Este es el caso de los sistemas de gestión de la demanda que mediante la optimización de la operación de los equipos existentes reducen el consumo energético.

Sistemas de generación de energía a escala de distrito:

En el caso de existir dentro de los límites del área evaluado, edificios alimentados por sistemas de generación distribuida (como las redes de calefacción y refrigeración urbanas), para la evaluación del consumo energético se deberá considerar al igual que en el caso anterior el rendimiento del sistema. En este caso el rendimiento del sistema estará condicionado además de por los propios sistemas de generación por otros aspectos como las pérdidas en la distribución, el consumo de auxiliares o las pérdidas en el almacenamiento.

Los sistemas basados en las redes de calefacción y refrigeración urbana, pueden tener diferentes configuraciones. Estas configuraciones pueden incluir desde sistemas de calderas centrales con calderas de apoyo que serán utilizadas para cubrir los picos de demanda o con aprovechamiento de calor residual de alguna industria cercana, hasta sistemas de cogeneración que además de generar calor generan también electricidad. Otras configuraciones combinan la generación de energía renovable con calderas de apoyo y sistemas de almacenamiento térmico a gran escala, como es el caso de los STES (seasonal thermal energy storage).

También forman parte de esta categoría las micro-redes eléctricas. Estas pueden facilitar la integración de energía eléctrica distribuida generada en la ciudad mediante fuentes de energía renovable. La sección 6.2.1 del Anexo incluye información adicional sobre los métodos y modelos a utilizar para evaluar el consumo de las principales tecnologías consideradas en este trabajo.

Fase VI: Efecto de la simultaneidad:

El efecto de la simultaneidad de demandas energéticas puede tener una gran influencia sobre las cargas pico de los distritos y de la ciudad. Un análisis de este efecto puede ayudar a minimizar los costes de inversión asociados a los sistemas e infraestructuras energéticas. Esta fase de la metodología está orientada a la evaluación del efecto de la simultaneidad de las demandas energéticas de manera que los resultados obtenidos puedan servir como información adicional en el proceso de planificación energética. Por ejemplo, para el diseño y dimensionamiento de nuevos sistemas de generación energética a escala distrito.

Tal y como se ha descrito en el Capítulo 2, la consideración de este efecto ha sido previamente evaluado en diferentes estudios. En la metodología desarrollada se propone aplicar los factores de simultaneidad en función de la tipología de edificios evaluados. El número de viviendas consideradas para la determinación del valor de estos factores debe corresponder al número de viviendas que estarán conectadas a un mismo sistema de generación.

De este modo, se proponen factores de simultaneidad tanto para los edificios residenciales como para los edificios terciarios (oficinas) en función del uso final de la energía (calefacción, ACS, electricidad para iluminación y electricidad para otros aparatos domésticos). En el caso de los edificios residenciales y de oficinas, tanto para la calefacción como para el agua caliente sanitaria se propone utilizar las ecuaciones definidas por (Tol & Svendsen, 2011) que se muestran en la Ecuación 2. Q_{SHD} corresponde al consumo energético individual de cada consumidor, Q_{SHL} corresponde a la demanda energética total de calefacción y Q_{DHWL} a la demanda de agua caliente sanitaria total.

$$Q_{SHL(N)} = \left(0.62 + 0.38/CC_{(N)}\right) x\ CC_{(N)} x\ Q_{SHD}$$

$$Q_{DHWL(N)} = 1.19\ x\ CC_{(N)} +\ CC_{(N)}^{0.5} + 0.3$$

Ecuación 2. Ecuaciones para la determinación de los factores de simultaneidad de calefacción y ACS. (H. İ. Tol & Svendsen, 2011).

Por otro lado, como factor de simultaneidad para la electricidad residencial se tomará el propuesto por el Ministerio de Industria en el Reglamento Electrotécnico para Baja Tensión (Spanish National Ministry of Industry, 2003).

Nº Viviendas (n)	Coeficiente de Simultaneidad	Factor de Simultaneidad
1	1	1
2	2	1
3	3	1
4	3,8	0,95
5	4,6	0,92
6	5,4	0,9
7	6,2	0,886
8	7	0,875
9	7,8	0,87
10	8,5	0,85
11	9,2	0,836
12	9,9	0,825
13	10,6	0,815
14	11,3	0,81
15	11,9	0,793
16	12,5	0,78
17	13,1	0,77
18	13,7	0,76
19	14,3	0,753
20	14,8	0,74
21	15,3	0,729
n>21	15,3+(n-21).0,5	15,3/n + (n-21)/2n

Figura 21. Factor de simultaneidad para consumo eléctrico (Spanish National Ministry of Industry, 2003).

Finalmente, en el caso de los edificios de oficinas, se tomará un factor de 1 (no simultaneidad) para el caso del consumo eléctrico tal y como propone el Ministerio de Industria.

Como resultado de la aplicación de estos factores de simultaneidad, las demandas horarias evaluadas en las fases anteriores serán ajustadas con los nuevos valores obtenidos para las demandas pico en función del uso final de la energía. Esta fase del proceso puede ser aplicada tanto para los distritos evaluados como para toda la ciudad. Debe tenerse en cuenta que en cada caso se debe considerar el número de viviendas del mismo tipo que estén alimentadas por el mismo sistema de generación de energía.

3.4.2. Identificación de potenciales intervenciones

Una vez caracterizado el comportamiento energético de la ciudad y de sus distritos para la situación base, se debe definir el modo en el que se impulsará el cambio en la ciudad durante los próximos años para lograr los objetivos definidos a diferentes horizontes temporales. Para ello, la ciudad deberá cambiar de un modo significativo la manera en la que esta gestiona sus recursos. Durante este proceso de cambio los edificios se convertirán previsiblemente en activos desde un punto de vista energético y las redes de distribución se transformarán de tal forma que se fomente su 'smartización' y que faciliten la descentralización de la generación energética. Esto permitirá mejorar la integración entre tecnologías y componentes así como la integración con el resto de redes de servicios públicos de la ciudad como las redes de transporte, agua o residuos. De este modo se persigue la optimización del comportamiento global de la ciudad como un único sistema.

Cada ciudad puede ser considerada como un organismo caracterizado bajo el punto de vista energético según su producción, almacenamiento y consumo de energía con sus correspondientes redes de interconexión. En función de la situación de la que parte este organismo, se deberán identificar e implementar las intervenciones y tecnologías energéticas sostenibles óptimas para guiar la transformación de la ciudad hacia un sistema energético bajo en carbono al mismo tiempo que se asegure el bienestar de sus ciudadanos y el crecimiento económico. Una de las problemáticas actuales erradica en que las tecnologías energéticas de suministro urbano suelen estar diseñadas y optimizadas individualmente con lo que existen aún numerosos retos para asegurar su integración a gran escala, ya sea nivel de distrito o a nivel de ciudad. En este sentido, se identifica la necesidad de seguir trabajando para mejorar la combinación de tecnologías energéticas distribuidas con el objetivo de llegar a conseguir una integración eficiente y viable tanto técnica como económicamente. A este efecto, resulta interesante tener en cuenta a la hora de seleccionar las diferentes tecnologías energéticas (que en fases sucesivas conformarán los escenarios de transición), aspectos como las dinámicas de las tecnologías que permitan la convertibilidad de la energía y el acoplamiento entre las diferentes fuentes energéticas.

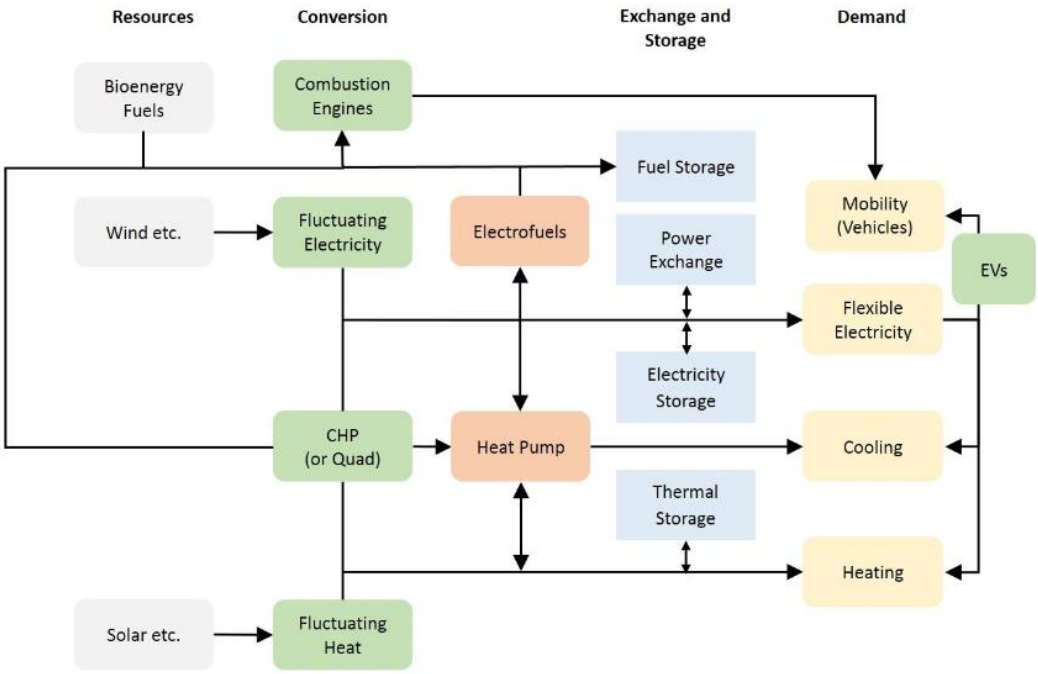

Figura 22. Interacción entre tecnologías en el marco de los sistemas energéticos inteligentes (Connolly et al., 2013).

La Figura 22 muestra la relación e interacción entre las diferentes tecnologías energéticas que pueden ser implementadas en el ámbito de la ciudad bajo el concepto anteriormente mencionado de ‘Smart energy systems’. En este caso se muestra el marco general en el que se tienen en cuenta los diferentes sectores de demanda de la ciudad. En cambio, considerando que la presente metodología se centra principalmente en la generación, distribución y el consumo de energía en el sector de edificios, el número de tecnologías a contemplar se ve reducido. Estas tecnologías se centrarán en el uso de fuentes de energía renovables o en medidas de eficiencia energética.

A la hora de preseleccionar el tipo de intervenciones que pueden ser incluidas en los escenarios, también debe tomarse en cuenta el diagnóstico inicial llevado a cabo en la ciudad. Este diagnóstico permite identificar además de las potenciales barreras que condicionarán la implementación de determinadas tecnologías en la ciudad, el grado de necesidades de energía según su tipo (calor/frio, electricidad). Esto proporcionará una visión de la tipología de tecnologías e intervenciones que pueden resultar más convenientes para cubrir las necesidades presentes y futuras de la ciudad.

Por otro lado, en la fase de diagnóstico se realiza también una evaluación de los diferentes documentos de estrategia y planes de acción de la ciudad como por ejemplo el Plan de Acción para la Energía Sostenible (PAES). Estos planes, identifican una serie de actuaciones y tecnologías como potencialmente beneficiosas para reducir las emisiones ambientales de la ciudad. A pesar de que en los PAES no se realice ningún tipo de priorización de intervenciones resulta interesante tenerlos en cuenta.

Con todo ello se identifican las tecnologías energéticas e intervenciones recogidas en la Figura 23 como potencialmente relevantes para la composición de escenarios. Tal y como se observa en la imagen, estas intervenciones se pueden clasificar según su escala (intervenciones a escala edificio e intervenciones a escala distrito).

Cabe destacar que no es objeto del este trabajo describir en detalle todas las posibles intervenciones aplicables en la ciudad ya que existe una amplia variedad de documentos disponibles en la literatura al respecto. Entre otros, la descripción y los datos tecno-económicos proporcionados en (ETRI, 2014) para diferentes horizontes temporales 2010-2050, el documento de *‘Best available technologies for the heat and cooling market in the European Union’* de (SETIS, 2012) o el documento (EC-JRC, 2012) *‘Report on EU-27 District Heating and Cooling Potentials, Barriers, Best Practice and Measures of Promotion’* ofrecen una visión completa sobre la temática.

i) Intervenciones de generación y distribución de energía a escala distrito

- Calefacción solar de distrito
- Almacenamiento térmico estacional
- Calefacción de distrito con calor residual
- Calefacción de distrito con calderas de biomasa
- Calefacción de distrito con calderas de gas natural
- Calefacción de distrito mediante geotermia
- Cogeneración conectada a una red de distrito
- Refrigeración de distrito
- Bombas de calor a gran escala

ii) Intervenciones y medidas a escala de edificio

- Sustitución de calderas (individuales/centrales, de GN/biomasa)
- Sistemas solares térmicos
- Sistemas geotérmicos
- Sistemas solares fotovoltaicos
- Mini-eólica
- Micro-cogeneración
- Sistemas de climatización
- Bomba de calor
- Intervenciones pasivas en edificios (sustitución de ventanas, mejora del aislamiento de la envolvente, etc.)
- Medidas de eficiencia energética en edificios (sustitución de luminarias, etc.)
- Sistemas de gestión inteligente de la demanda

Figura 23. Potenciales intervenciones a considerar en el ámbito de generación y distribución de energía del sector edificios, para la composición de escenarios de transición energética de ciudad**.**

3.5. Definición de los potenciales escenarios de transición energética

La implementación de tecnología a lo largo de la ciudad, en sí misma y realizada de manera puntual, no asegura el cumplimiento de los objetivos de reducción de emisiones establecidos a medio y largo plazo. Por lo tanto, las ciudades deben definir y evaluar una serie de potenciales escenarios de transición energética, compuestos por combinaciones de intervenciones que se implementaran de un modo planificado a lo largo del periodo de transición para obtener la transformación deseada.

Tal y como se ha podido comprobar en el Capítulo 2, la literatura existente se centra principalmente en la definición de escenarios a gran escala (nacional, europea, global). Además, tal y como destaca (Trutnevyte et al., 2016), a pesar del uso generalizado de escenarios y de los numerosos trabajos llevados a cabo en este ámbito, se ha prestado muy poca atención al modo en el que se lleva a cabo la selección de escenarios de entre la infinidad de potenciales escenarios que pueden ser construidos. Este es precisamente el aspecto sobre el que se centra este apartado aunque aplicado a una escala más reducida (escalas de distrito y ciudad). Además, en este caso el objetivo de la creación de escenarios no es el de predecir cómo evolucionarán las diferentes macro-magnitudes sino el de evaluar de forma comparativa el impacto que las diferentes alternativas de transición pueden tener sobre la ciudad.

Es por ello por lo que en este apartado se describen las principales consideraciones para la definición de escenarios partiendo de la aproximación bottom-up que se ha seguido para la caracterización energética de la ciudad. Cada escenario se define partiendo de una combinación de intervenciones implementadas durante el periodo de transición en los diferentes distritos tal y como se puede ver en la Figura 24.

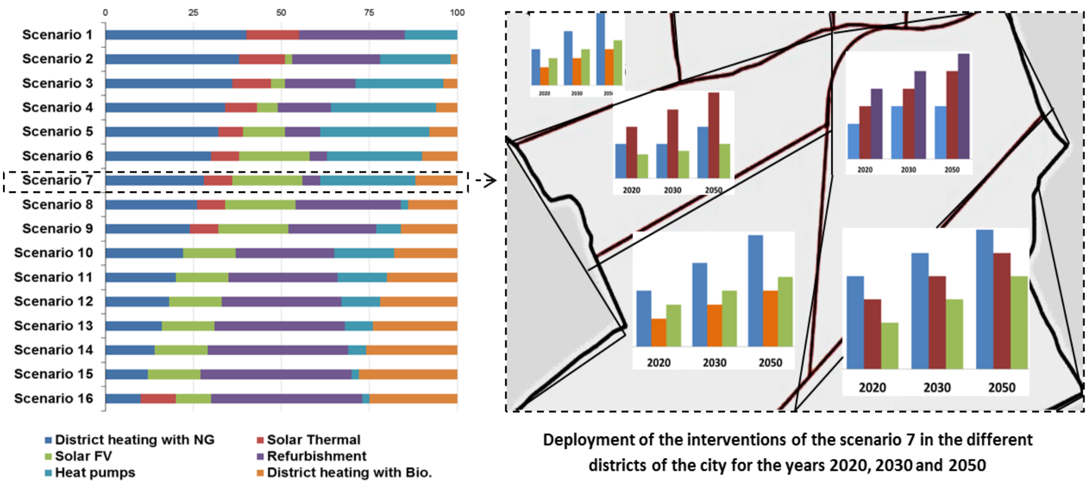

Figura 24. Aproximación a la definición de escenarios alternativos para ciudades (Elaboración propia).

A continuación se proporcionan una serie de criterios específicos que permitirán definir los diferentes escenarios de transición. En un primer paso se describe el modo de considerar la fase de uso de la ciudad a la hora de tratar con los escenarios de transición.

Evolución del consumo energético de la ciudad en el escenario de transición

En la sección 3.4.1 se ha descrito la metodología de evaluación de la demanda y el consumo para el año base de la ciudad. La demanda y el consumo evolucionarán a lo largo del periodo de transición influenciados en gran medida por el despliegue de intervenciones que conforma cada escenario de transición y por las posibles nuevas edificaciones que se realicen en la ciudad.

La Figura 25 muestra el marco general y la aproximación a seguir para la evaluación del consumo energético de la ciudad a lo largo del periodo de transición energética. Esta aproximación es la que se propone como método de evaluación para determinar el valor de la fase B6 de la metodología de evaluación de impacto.

Tal y como muestra la figura, partiendo del consumo energético base de la ciudad (CE base), se evalúa el consumo energético para los años sucesivos considerando que este podrá verse modificado por los ahorros asociados a la implementación de las intervenciones planificadas en el escenario de transición para dicho año (interv. Año 1) y debido a un posible aumento del consumo debido a aspectos tales como la nueva construcción de edificios.

De este modo el consumo energético base en el año 2 (CE año 2) se obtiene sumando al CE base el posible incremento de consumo energético y restándo el ahorro obtenido gracias a las intervenciones implementadas en el año 1 (AE año 1). Del mismo modo, el ahorro energético obtenido en el año 2 del escenario de transición se calculará partiendo del consumo base de la ciudad en la nueva situación (CE año 2) que se verá modificado por los ahorros energéticos obtenidos por las intervenciones implementadas en dicho año (interv. Año 2) y el posible incremento del consumo en dicho año. En este caso, se debe considerar también el ahorro debido a las intervenciones implementadas en el año 1, ya que estas seguirán en funcionamiento. Este proceso se repetirá para cada año de periodo evaluado. En la figura también se puede ver el ahorro energético de la fase de uso acumulado a lo largo del periodo de transición.

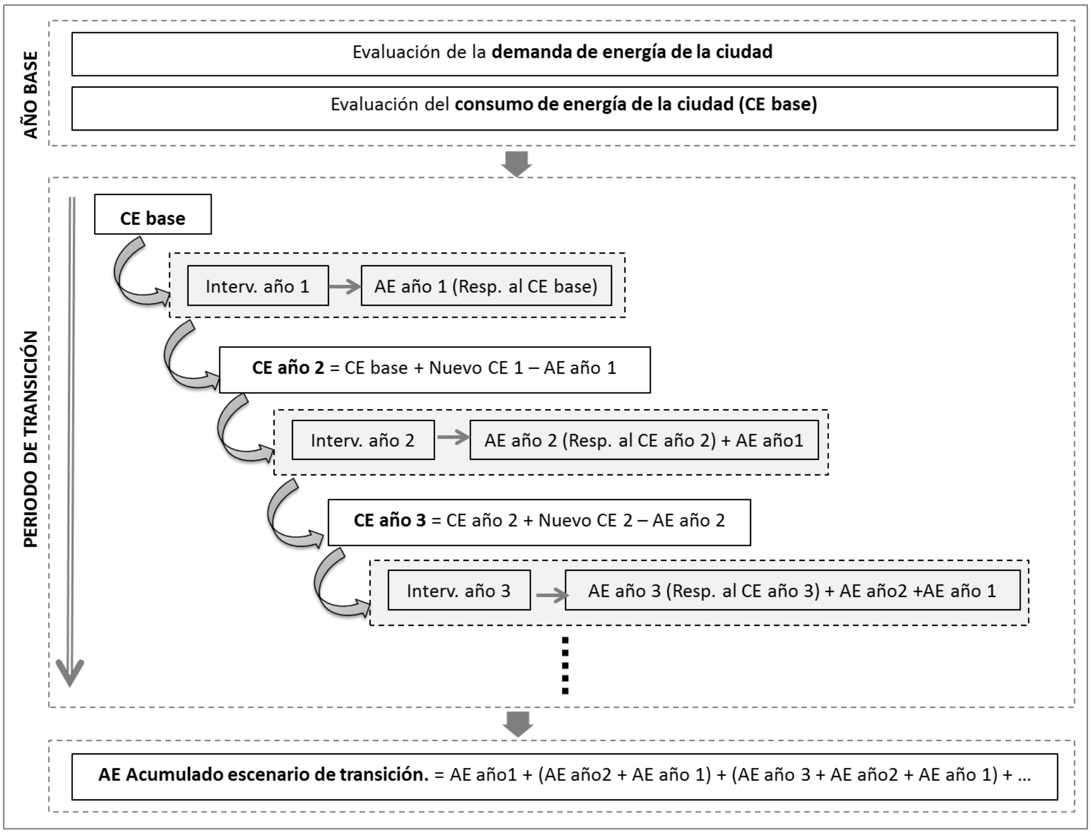

Figura 25. Marco de evaluación de la demanda y el consumo energético anual de ciudades durante el periodo de transición (Elaboración propia).

Límites y barreras asociadas a las intervenciones

Otro aspecto a considerar a la hora de definir los escenarios, es la existencia de posibles barreras o limitaciones que puedan condicionar la implementación y el despliegue de intervenciones en la ciudad. Estas limitaciones pueden estar concentradas en muchos casos en diferentes zonas o distritos de la ciudad, lo que ayudará a determinar el tipo de intervenciones que pueden llevarse a cabo en cada distrito.

En algunos casos, los condicionantes pueden estar asociados a la concentración de determinados usos de edificios en la ciudad, lo que puede influir sobre el tipo de energía más demandada en dicha zona. En otros casos, aspectos como la densidad de población o la densidad de demanda energética de diferentes distritos de la ciudad puede condicionar la viabilidad tecno-económica de determinadas intervenciones como las redes de calefacción de distrito. También cabe considerar ciertas restricciones urbanísticas como la existencia de edificios protegidos que pueden resultar en barreras insalvables para la implementación de intervenciones que requieran modificaciones de la envolvente del edificio como es el caso de algunas actuaciones de rehabilitación.

Una vez identificados los limitantes asociados a las intervenciones a evaluar resulta necesario también identificar las posibles barreras asociadas a la implementación conjunta de dichas intervenciones, ya que en muchos casos existirá interrelación entre las mismas. Esto permitirá preseleccionar escenarios entre las múltiples opciones y combinaciones posibles reduciendo el volumen de escenarios a evaluar.

Para ello se deben considerar aspectos como el propósito principal de cada una de las intervenciones (reducción del consumo de calefacción, generación eléctrica renovable, etc.) así como su complementariedad con el resto de las intervenciones. A modo de ejemplo, se puede entender que en un distrito donde se implementará una red de calefacción de distrito para el suministro de calefacción y agua caliente sanitaria, carece de sentido proponer una intervención relacionada con la sustitución de las calderas existentes por calderas individuales más eficientes. Otro caso sería el de los límites asociados a la combinación de sistemas solares térmicos y fotovoltaicos debido a problemas de espacio en las cubiertas de los edificios.

La Tabla 6 muestra un ejemplo del modo de establecer una relación entre las barreas existentes y las intervenciones a las que estas afectan.

Tabla 6. Relación entre las barreras existentes y las intervenciones que potencialmente pueden verse afectadas por las mismas.

Potenciales barreras evaluadas		**Intervenciones afectadas**
Densidad energética del distrito	→	Intervenciones relacionadas con redes de calor y frio a nivel de distrito
Área disponible en cubiertas de edificios	→	Sistemas solares térmicos y fotovoltaicos
Grado de protección de los edificios	→	Rehabilitación de viviendas
Existencia de sistemas de generación de calor centrales (nivel de edificio)	→	Sistemas eficientes de generación de calor y ACS
…	→	…

Consideración de aspectos temporales

El aspecto temporal es tal vez el más relevante o al menos el más característico a la hora de definir los escenarios de intervenciones para la transición energética de las ciudades. Resulta necesario que las variables principales utilizadas en el modelado de escenarios sean definidas como funciones dependientes del tiempo de cara a evaluar los efectos creados en la ciudad a diferentes horizontes temporales. A continuación se detallan las variables y características principales para las cuales se debe considerar el aspecto temporal.

- *Evolución del precio de la energía*

Este es un aspecto relevante que debe ser considerado en la definición de escenarios debido a su influencia directa sobre aspectos como la viabilidad y el retorno económico de las intervenciones. A pesar de ello no resulta fácil llegar a un consenso sobre los datos a utilizar para el modelado.

En base a las proyecciones que ofrecen estudios como EU Energy, Transport and GHG Emissions Trends to 2050, se prevé que el coste de la electricidad aumentará significativamente hasta el 2020. En cambio, se espera que se mantendrá estable hasta el año 2035 y que disminuirá moderadamente hasta el año 2050.

Los combustibles fósiles en cambio, han sido el foco de numerosas revisiones desde las trayectorias propuestas en el pasado (EC, 2009). Su precio está fuertemente influenciado por el mercado incluyendo aspectos tales como el coste de las emisiones de CO_2, las medidas internacionales de lucha contra el cambio climático, la disponibilidad de recursos y el incremento de las fuentes renovables en la generación eléctrica. En las proyecciones presentadas por la Comisión Europea, el recurso de gas natural en particular, incrementa debido a los recursos adicionales no descubiertos incluido el gas no convencional. Las proyecciones estudiadas muestran que a largo plazo, el gas natural no seguirá la creciente tendencia del precio del petróleo y que tenderá a estabilizarse. La Figura 26 muestra las proyecciones para la evolución de precio de las diferentes fuentes de energía.

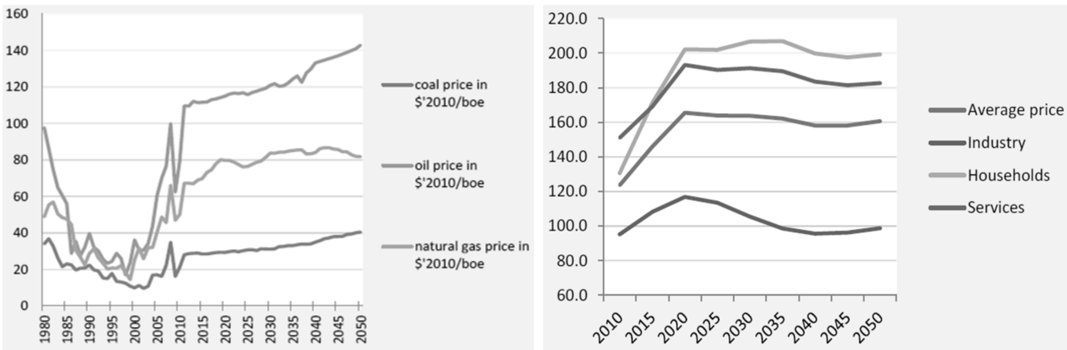

Figura 26. Precios de importación de combustibles fósiles (izquierda) y precio de la electricidad (antes de tasas) por sector (derecha). Fuente: EU Energy, Transport and GHG Emissions Trends to 2050. (EC, DG for Energy, DG for Climate Action and DG for Mobility and Transport, 2013).

- *Tasa de descuento*

La tasa de descuento es la tasa de interés utilizada para descontar los costes y beneficios futuros a valores en el presente. Este factor varía en función del sector. Para cálculos financieros de edificios nuevos y existentes por ejemplo, una tasa de descuento entre 7%-10% es propuesta en algunos casos (Ministerio de Fomento de España, 2013). En cambio, para el caso de tasas de descuento sociales utilizadas en la planificación social a largo plazo, se recomienda utilizar valores entre 3% y 5% (EC, 2009).

- *Tendencias en el coste de tecnologías*

Debido al amplio alcance temporal considerado en este tipo de análisis, a la hora de plantear escenarios resulta necesario considerar la evolución de los costes asociados a las tecnologías que los conforman.

La disminución de costes de las tecnologías a lo largo del tiempo está asociada a aspectos como la economía de escala y lo que se conoce como 'learning-by-doing'. Se considera que la evolución tecnológica, la investigación o determinadas políticas pueden afectar a los costes futuros de las tecnologías energéticas que se irán implementando en la ciudad. La incorporación de este aspecto en el modelado, puede ayudar a reflejar en los estudios a largo plazo, el potencial de algunas tecnologías energéticas que al inicio del periodo de transición pueden ser descartadas por su alto coste pero que pueden ser de interés de cara al medio y largo plazo.

En cualquier caso, hay que tener presente la incertidumbre asociada a la definición de las curvas de aprendizaje de las diferentes tecnologías energéticas, por lo que se deben utilizar con precaución sobre todo en el coto y medio plazo. A la hora de aplicar la metodología desarrollada se recomienda utilizar proyecciones de costes disponibles en estudios como Energy, Transport and GHG Emissions Trends to 2050 o las que se incluyen en la Tabla 7 a modo de ejemplo. Proyecciones asociadas a otras tecnologías energéticas pueden ser consultadas en (ETRI, 2014) y (Danish Energy Agency and Energinet.dk, 2012).

Tabla 7. Valores de referencia de CAPEX para diferentes tecnologías energéticas (2013 - 2050).

Tecnología energética	Unidad	2013-15	2020	2030	2040	2050	Fuente
Solar fotovoltaica	€/kWe	1310	1100	990	930	880	1
Solar térmica	€/kWth	4100	3158	2560	2261	1963	1
Bomba de calor	€/kWth	800	780	730	690	650	1
Caldera de biomasa para DH	M€ per MJ/s	0,06	0,06	0,05	-	0,05	2
Caldera de GN para DH	M€ per MJ/s	0,5	0,5	0,5	-	0,5	2
Cogeneración-biomasa	€/kWe	3670	3300	2990	2750	2540	1
Cogeneración-GN	€/kWe	1010	1000	990	980	970	1
Almacenamiento térmico a gran escala	€/100 m3	3500	3500	3400	-	3000	2

Fuentes: (1): (ETRI, 2014) y (2): (Danish Energy Agency and Energinet.dk, 2012)

- *Ritmo de implementación de tecnologías en la ciudad*

Resulta necesario también que el modelado de escenarios de transición permita evaluar el efecto de la variación del ritmo implementación y el despliegue de cada una de las intervenciones a lo largo del periodo de transición. Esto supondrá una gran oportunidad para las ciudades que podrán identificar entre otros, los momentos oportunos para realizar las inversiones de manera que se optimice el control del flujo de caja previsto así como los momentos clave en los que interesa intensificar determinadas acciones para poder llegar a cumplir con los objetivos establecidos dentro de los plazos fijados.

De este modo, en la evaluación se deben definir aspectos como el ritmo de conexión de las viviendas a la red de calefacción de distrito, el ritmo de rehabilitación de viviendas en la ciudad, y la evolución del ritmo del despliegue de las tecnologías energéticas renovables a lo largo del periodo fijado.

- *Evolución del coste de las emisiones de CO_2*

En el caso de incluir en el análisis de costes de los escenarios el coste asociado a las emisiones ambientales de CO_2, es necesario considerar el modo en el que este se verá previsiblemente incrementado a lo largo del tiempo. La Tabla 8 muestra los valores propuestos para cada rango de años (Ministerio de Fomento de España, 2013).

Tabla 8. Evolución de los costes de emisiones de CO_2.

Año	Coste de emisiones de CO_2 (€/ton)
2012-2020	18.6
2021-2025	22.5
2026-2030	40.5
2031-2035	56.3
2036-2040	58.5
2040-2045	57.4
2046-2050	56.3

3.6. Análisis multi-criterio de los escenarios de transición energética de ciudades

3.6.1. Marco metodológico propuesto para la evaluación de impacto

En la revisión de literatura ha quedado patente la necesidad de avanzar en el desarrollo de nuevos marcos de evaluación de impacto aplicables a ciudades. Este apartado se centra en describir los desarrollos metodológicos llevados a cabo a este respecto en el presente trabajo.

Dado que la mayor parte de los estudios realizados en el ámbito de la evaluación de impacto con perspectiva de ciclo de vida se centran en la evaluación ambiental y económica de edificios, tecnologías y sistemas energéticos a pequeña y mediana escala, la posible conexión entre la evaluación de impacto ex-ante y la toma de decisiones estratégicas a escala de ciudad y regional queda en gran medida difuminada.

A la hora de abordar la problemática desde el punto de vista de la municipalidad en cambio, el hecho de integrar la predicción de impactos bajo una perspectiva amplia como pilar central del análisis que proporcione criterios que podrán ser utilizados como apoyo en la toma de decisiones, abre un nuevo abanico de posibilidades en el ámbito de la planificación energética de ciudades.

Considerando que existen infinidad de posibilidades a la hora de potenciar la transformación de las ciudades hacia una economía baja en carbono, la municipalidad debe poder evaluar los escenarios potenciales teniendo en cuenta los efectos directos, indirectos e inducidos que la implementación de los mismos tendrá sobre la ciudad, efectos que a priori son difíciles de prever.

Para ello, la metodología de evaluación de impacto debe ofrecer la sensibilidad necesaria para considerar los muy diversos efectos que se originarían una vez tomada la decisión de apostar por el despliegue de determinadas tecnologías energéticas en lugar de por otras alternativas existentes.

Con este objetivo en mente, la metodología desarrollada combina diferentes aproximaciones a la evaluación de impacto, que mediante su interrelación permiten evaluar el efecto de los potenciales escenarios de transición energética de ciudades desde un punto de vista multi-criterio y multi-escala.

La Figura 27 muestra gráficamente el marco metodológico propuesto. Este marco de evaluación aglutina una serie de dimensiones, escalas de actuación, horizontes temporales de la estrategia y alcances para la evaluación de impactos que deben ser considerados a la hora de abordar esta problemática.

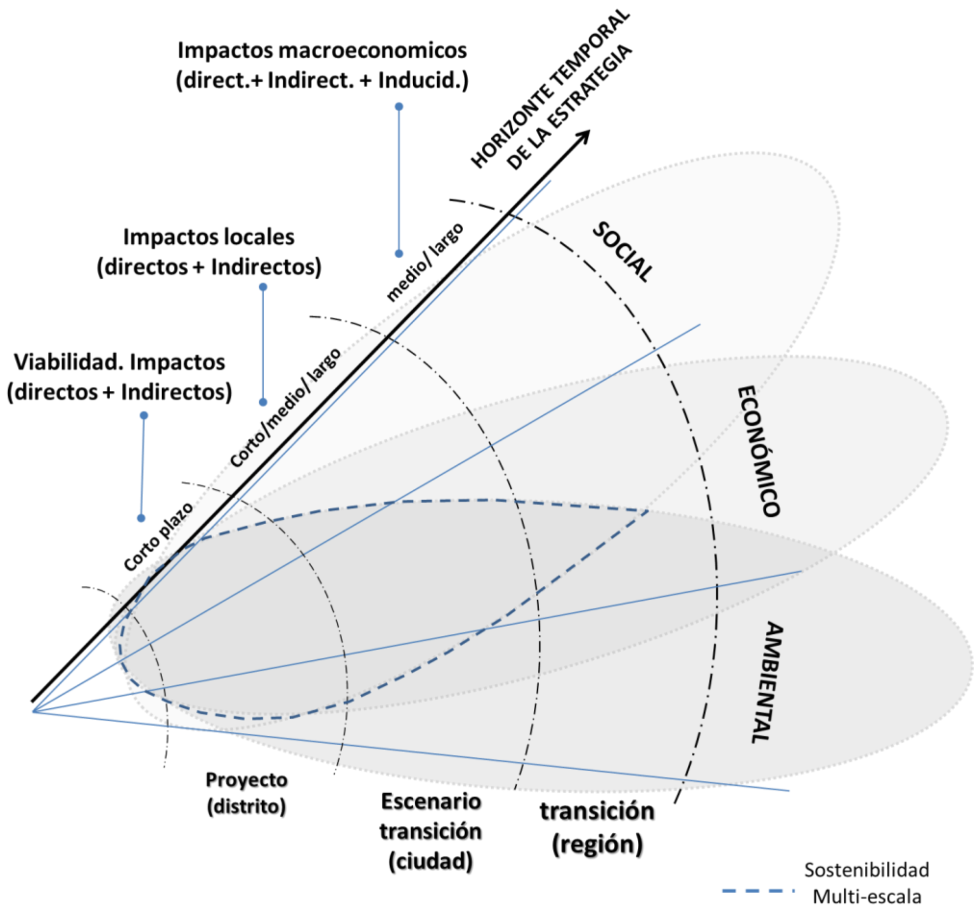

Figura 27. Marco metodológico de la metodología de evaluación de impacto multi-criterio de escenarios de transición energética de ciudades (Elaboración propia).

En primer lugar, se puede ver que la metodología cubre los tres pilares de la sostenibilidad evaluando los impactos económicos, sociales y ambientales de los escenarios de transición. A su vez, para la evaluación de cada una de estas dimensiones pueden distinguirse diferentes ondas que representan las escalas o niveles de actuación del análisis. Se puede distinguir entre el nivel de proyecto (asociado en muchos casos a intervenciones a escala de edificio y distrito), el nivel de ciudad y el nivel regional.

Finalmente, se puede ver que cada una de las ondas mencionadas, está asociada un horizonte temporal de la estrategia y a una profundidad o alcance de la evaluación de impactos. De esta manera, se puede distinguir entre la evaluación de impactos cortoplacista (correspondiente principalmente a la escala proyecto), la de medio plazo y la de largo plazo (correspondientes ambas a las escalas de ciudad y regional).

Nivel de proyecto (distrito)

Analizando más en profundidad el propósito de cada una de las ondas, se puede decir que la primera de ellas responde a la necesidad de evaluar los impactos desde un punto de vista de viabilidad y que ofrecerá información relevante para la empresa, entidad o el particular que realice la inversión. De esta forma se evaluarán entre otros, aspectos como la rentabilidad de la inversión o el periodo de retorno en cuanto a la dimensión económica, la cuantificación de impactos ambientales desde un punto de vista meramente informativo y de cumplimiento de requisitos medioambientales en la dimensión ambiental y otros aspectos sociales como la aceptación social o las condiciones laborales de los trabajadores. Este nivel de análisis es el más estudiado hasta el momento mediante metodologías de evaluación de impacto como el análisis de ciclo de vida, el análisis de costes de ciclo de vida o el análisis de ciclo de vida social.

Nivel de ciudad

La segunda onda corresponde a la escala de ciudad. Esta incluye varios horizontes temporales de la estrategia, desde acciones aisladas más cortoplacistas a nivel de proyecto, hasta la implementación de escenarios de transición de la ciudad que pretenden transformar la ciudad a medio y largo plazo. A este nivel, el propósito de la evaluación de la viabilidad desde un punto de vista empresarial pierde protagonismo y se puede ver como la evaluación de los efectos creados en la sociedad, en la economía y en el medioambiente en su conjunto cobran mayor relevancia. En este caso, la evaluación de aspectos como la influencia del escenario de transición sobre el grado de autoabastecimiento energético de la ciudad, sobre la diversificación de la matriz energética, la creación de empleo local, la pobreza energética o sobre el cumplimiento de los objetivos establecidos de reducción de emisiones de CO_2 caben ser considerados. Estos aspectos están más relacionados con características particulares de la ciudad como la estructura de producción y consumo de bienes y servicios o la calidad de vida de los ciudadanos. Para su evaluación, la metodologías mencionadas anteriormente deben ser adaptadas tal y como se muestra en los siguientes apartados.

Nivel regional

Por último, la tercera onda representa la relación entre las acciones llevadas a cabo a escala de ciudad a lo largo del periodo de transición energética y su efecto a escala regional. Esta onda pretende responder a la necesidad de evaluar la influencia que tendrá el modo en el que se llevará a cabo la transformación de la ciudad sobre aspectos más estratégicos como;

- El impulso y la diversificación de la industria regional de manera que se disminuya su vulnerabilidad frente a posibles crisis económicas.
- La mejora de la calidad de vida y el nivel de renta de los diferentes estratos sociales.
- La generación de actividad económica estable y de alto valor añadido que permita mejorar la competitividad en los mercados exteriores.

- El alineamiento con políticas de adaptación y mitigación del cambio climático que contribuyan a limitar los impactos tanto locales como globales.

En este caso, la evaluación de impacto ex-ante permitirá determinar la estrategia de transición más adecuada a medio largo plazo para la ciudad, considerando no solo los efectos directos e indirectos futuros sino también los efectos inducidos en el plano macroeconómico. Efectos como el crecimiento inducido en el PIB regional, en el valor añadido por sector de actividad económica y en la creación de empleo serán evaluados en este nivel.

Resulta evidente que para ello, las metodologías basadas en el análisis de ciclo de vida, tal y como se utilizan habitualmente no ofrecen el marco metodológico necesario. Por lo tanto, la presente metodología desarrolla el método mediante el cual, la perspectiva de ciclo de vida podrá ser combinada a través de la evaluación de la cadena de suministro de las tecnologías energéticas con los métodos de evaluación macroeconómicos para dar respuesta a esta problemática.

3.6.2. Objetivo

El objetivo de la evaluación de impacto debe ser definido de manera clara en este apartado. En el caso de la metodología desarrollada, el objetivo principal es comparar el impacto asociado a la implementación de los potenciales escenarios de transición energética de la ciudad (centrado en la generación, distribución y consumo de energía de los edificios). El propósito es llegar a priorizar aquel escenario que ofrezca mayor beneficio para el desarrollo socio-económico y ambiental de la ciudad y de la región a la que pertenece.

3.6.3. Unidad de referencia

Se propone el uso de dos unidades de referencia que se emplearan en fases diferentes y con fines diferentes a lo largo de la metodología de evaluación de impacto.

La primera de ellas corresponde a la unidad de referencia a emplear para la comparación de las diferentes tecnologías energéticas e intervenciones que formarán parte de los escenarios de transición. Es decir, esta unidad de referencia se empleará únicamente en la primera onda y corresponde a:

‘El consumo de energía primaria de origen no renovable evitado (kWh EP-NR) a lo largo del ciclo de vida de la intervención’.

La segunda unidad de referencia propuesta en cambio, pretende servir para comparar entre sí los diferentes escenarios de transición energética. La literatura existente muestra cómo diferentes estudios de evaluación de impacto con perspectiva de ciclo de vida realizados a escala de distrito proponen utilizar como unidad funcional el propio distrito referido a su extensión en km^2 (Stephan et al., 2013), referido al número de habitantes del mismo (Nichols &

Kockelman, 2014), o incluso referido al número de viviendas (Li & Wang, 2009). Siguiendo con ésta aproximación y ampliando la escala a la ciudad, se podría adoptar como unidad funcional la propia ciudad, referida a su población, a su extensión en Km^2 o al número de viviendas.

En cambio, el objetivo de la metodología no es el de evaluar la sostenibilidad de los distritos y de las ciudades con el propósito de compararlas entre sí en términos de sostenibilidad, sino el de comparar el impacto acumulado en la ciudad y en la región a lo largo del periodo de transición debido a la implementación del escenario priorizado. Es por ello por lo que la unidad propuesta en esta metodología se distancia de las anteriormente mencionadas y se define de la siguiente manera:

‘Un escenario de transición energética de ciudad con un periodo de 50 años’.

Vida útil considerada

El periodo de transición se ha fijado por lo tanto en 50 años de acuerdo a la vida útil máxima de las intervenciones que formarán parte de los mismos.

A este respecto, teniendo en cuenta que el objeto principal de la evaluación es el escenario de transición, no resulta tan necesario debatir sobre la vida útil de propia ciudad. Además, las ciudades crecen evolucionan y cambian desde el momento que se crean hasta cientos o miles de años después. En el caso de reducir la escala del estudio al distrito y entendiendo la ciudad como agregación de sus diferentes zonas o distritos, estudios como el de (Lotteau et al., 2015) muestran los muy diferentes valores utilizados a lo largo de los años, desde una vida útil de 50 años (utilizada también para la evaluación a escala de edificios) hasta 60, 80 o 100 años.

Considerando el objetivo de la metodología, resulta más necesario definir la duración del propio análisis, es decir, el periodo para el que se planificará la transición energética de la ciudad. A lo largo de este periodo, las diferentes tecnologías e infraestructuras que forman el escenario, deberán ser implementadas y sustituidas cuando corresponda en función de su vida útil. De este modo, las intervenciones pueden tener una vida útil muy diversa desde los 30 años correspondientes a sistemas energéticos renovables como la solar térmica y fotovoltaica, hasta los 50 años correspondientes a intervenciones como la rehabilitación energética de edificios.

Además, la duración propuesta para el análisis, es la misma que el periodo propuesto comúnmente para la evaluación de escenarios de transición energética a escala nacional y europea que comprende entre los 30 y los 50 años, en función de carácter temporal del que se quiera dotar al estudio.

3.6.4. Límites del sistema

Considerando que el propósito del estudio es evaluar los diferentes escenarios que transformarán la forma en la que la ciudad genera y consume la energía de sus edificios, los límites del sistema se ven ampliados desde el edificio hasta un entorno donde se integran también los diferentes sistemas de generación descentralizada. Es por ello por lo que los límites del sistema incluirán a diferencia de la evaluación a escala de edificio, todas las infraestructuras y tecnologías necesarias para la generación de energía local dentro de los límites físicos de la ciudad, incluida la generación de energía local mediante combustibles no locales (Figura 28). Además, se deben incluir todas las fases que intervienen entre la generación y el consumo de energía en la ciudad, incluidas la transformación, distribución, almacenamiento y el suministro hasta las viviendas.

Para el análisis social y macroeconómico a escala regional en cambio, dentro de los límites del sistema también se considerarán todos los sectores de actividad económica de la región así como la sociedad en su conjunto.

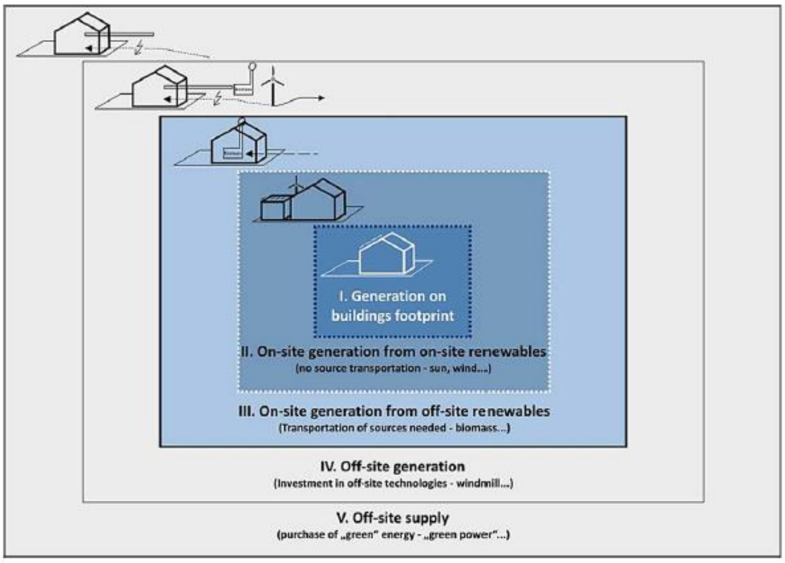

Figura 28. Límites del sistema para diferentes opciones de suministro energético (Marszal & Bourrelle, 2010).

Para la definición de las fases y los módulos de información a considerar en la presente metodología, se han tenido en cuenta las perspectivas propuestas tanto por el (IPCC, 2013) que se muestra en la Figura 29, como en la norma UNE-EN 15978 para la evaluación del comportamiento ambiental de los edificios.

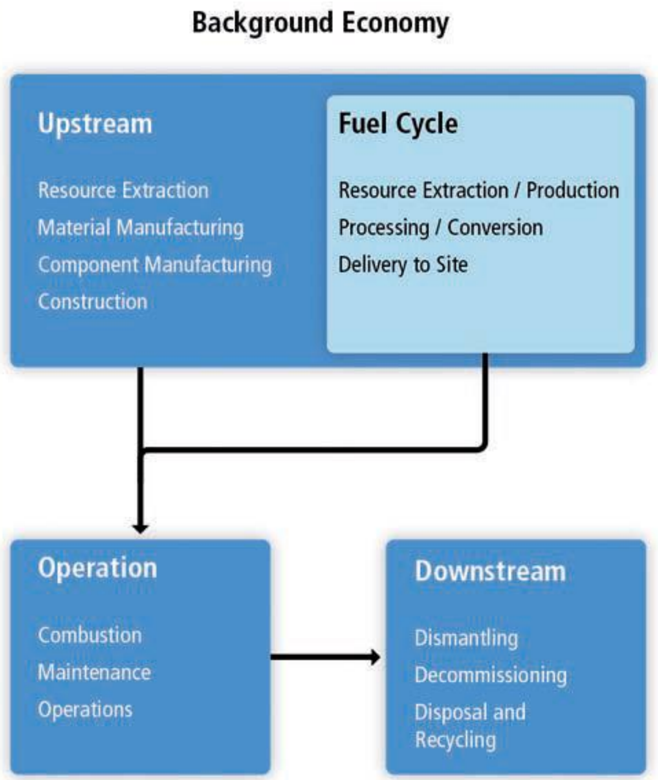

Figura 29. Fases del ciclo de vida de sistemas de generación de energía (IPCC, 2013).

Los dos marcos mencionados son de interés a la hora de evaluar la sostenibilidad de edificios y sistemas de generación y tecnologías energéticas individuales implementados en un determinado año. En cambio, no establecen el modo de considerar las diferentes fases a la hora de evaluar bajo la perspectiva de ciclo de vida la idoneidad de un escenario de transición de una ciudad que implementará progresivamente diferentes grupos de intervenciones a lo largo del periodo de transición. Por lo tanto, resulta necesario adaptar este marco de manera que permita evaluar la interacción entre varias intervenciones que se implementarán simultáneamente y progresivamente en la ciudad. Esto permitirá determinar la influencia de aspectos como el orden y el ritmo de implementación de las intervenciones. La Figura 30 muestra el marco definido en este trabajo.

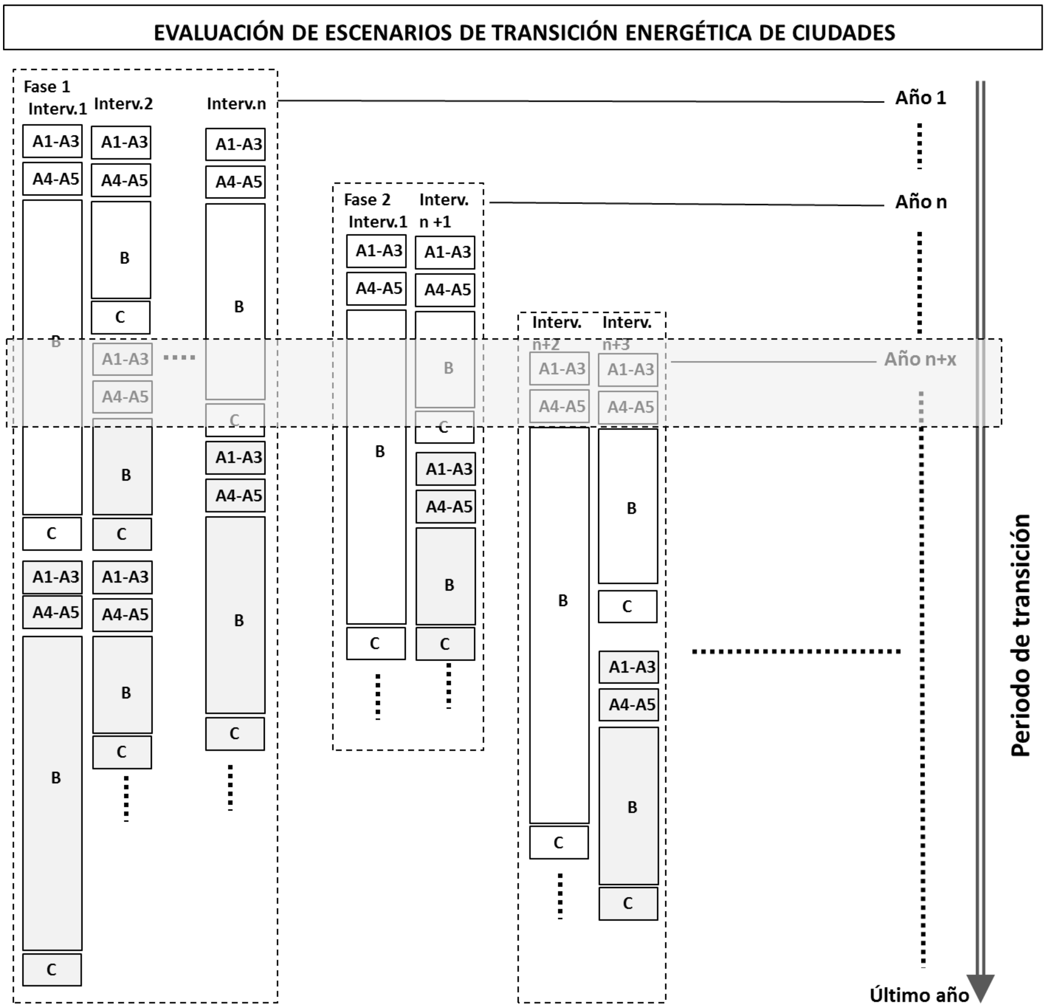

Figura 30. Módulos de información para la evaluación de las diferentes fases de los escenarios de transición energética de ciudades (Elaboración propia).

Las fases a incluir en cada una de las escalas y dimensiones del análisis se resumen en la Tabla 9. Se incluyen (en máximos) las fases que deberían considerarse en el análisis.

En función de la disponibilidad de información para cada caso, el proceso de evaluación podría simplificarse, de manera que algunas de las fases del ciclo de vida podrían no ser consideradas. De hecho, tal y como demuestra (Oregi et al., 2017) varias de las fases podrían ser obviadas en el análisis ya que su contribución es en muchos casos poco relevante sobre todo para la dimensión ambiental (en especial para las fases A4, A5, B2).

Tabla 9. Módulos de información y fases del ciclo de vida a considerar en cada una de las escalas y dimensiones de la metodología.

	Escala	A0	A1-A3	A4-A5	B2	B4	B6	C1-C4
Ambiental	Proyecto/Intervención		X	X	X	X	X	X
	Ciudad		X	X	X	X	X	X
Económico	Proyecto/Intervención	X	X	X	X	X	X	X
	Ciudad	X	X	X	X	X	X	X
	Regional	X	X	X	X	X	X	X
Social	Ciudad	X	X	X	X	X	X	X
	Regional	X	X	X	X	X	X	X

La Figura 30 refleja el modo de considerar en el análisis el año en el que se implementará cada una de las intervenciones. Comenzando desde la izquierda del esquema, se puede ver el primer grupo de intervenciones (o escenario de intervenciones) que se implementarán simultáneamente en el primer año del periodo de transición de la ciudad. Cada una de ellas con sus fases y su vida útil correspondientes. Se observa cómo en función de la duración de periodo de transición planificado y de la vida útil de las intervenciones, cada intervención puede requerir una renovación completa una vez finalizada su vida útil (fases marcadas en gris).

Del mismo modo, en el año siguiente (o en el caso de la figura, en el año ‘n’ pasado un periodo de tiempo determinado), se debe considerar la implementación del siguiente grupo de intervenciones (o escenario de intervenciones del año n). Este proceso se repite sucesivamente hasta implementar todas las intervenciones planificadas para el periodo de transición.

Tal y como se puede apreciar en la figura, la evaluación de impacto se debe realizar año a año ya que los procesos a considerar en cada caso serán diferentes. De este modo, se deberán incluir por ejemplo para el caso del año ‘n + x’ las siguientes fases: la fase B de la intervención 1 (en su primera fase de implementación), las fases A1-A5 de la intervención 2, la fase B de las intervenciones n, 1 y n+1 (en su segunda fase de implementación) y finalmente las fases A1-A5 de las intervenciones n+2 y n+3 que se implementarían ese mismo año. Este proceso permitirá dotar a cada una de las fases de cada intervención de características específicas para el año evaluado.

Del mismo modo esto permite evaluar una misma intervención que se implementará a lo largo del escenario en dos fases diferentes. Esto resulta interesante a la hora de evaluar la influencia de grandes intervenciones a escala distrito como es el caso de las redes de calefacción urbanas que pueden en un comienzo cubrir la demanda de un determinado número de edificios y algunos años después en una segunda fase ampliar su potencia y número de conexiones para cubrir nuevas áreas en la ciudad. Este es el caso de la intervención 1.

La forma de denominar las diferentes fases del esquema es la siguiente: $(fase)_{x,y}$. Siendo 'fase' la fase del ciclo de vida analizada, 'x' el identificador de cada intervención e 'y' el año en el que se llevan a cabo las fases correspondientes a dicha intervención. A modo de ejemplo la fase $(A1\text{-}A3)_{1,1}$ se refiere a las fases entre A1, A2 y A3 de la intervención 1 que se implementa en el año 1. De esta forma se pueden diferenciar las intervenciones que se implementan simultáneamente en cada escenario referido a su vez al año en el que se realizan. Con ello se dota a la evaluación de un nuevo carácter temporal que resulta necesario a la hora de evaluar los escenarios de transición ya que muchos de los parámetros que se utilizan en la evaluación son dependientes del tiempo (coste de la energía, reducción de costes de la tecnología debido a la innovación tecnológica, etc.).

A continuación se describen las diferentes fases propuestas.

Fase A0

La fase A0 corresponde a la fase previa a la implementación de las intervenciones del escenario de transición y está relacionada principalmente con la dimensión económica. Esta fase incluye los procesos relacionados con los trabajos de consultoría, estudios y permisos necesarios para llevar a cabo sobre todo grandes intervenciones así como los costes de compra o alquiler del terreno necesario para la implantación de las infraestructuras asociadas a grandes intervenciones.

Fases A1-A3

La fase de producto incluye los procesos desde la 'cuna hasta la puerta de fábrica' de los materiales y servicios utilizados en la fabricación de todos los componentes utilizados en los sistemas e infraestructuras implementados en la ciudad tanto para la generación y transformación de energía como para el almacenamiento y la distribución de energía hasta los edificios. Del mismo modo se incluyen los procesos de los materiales y servicios utilizados por otras tecnologías e intervenciones que se implementarán dentro de los límites de la ciudad con el objetivo de reducir el consumo energético de los edificios. Intervenciones tales como la integración de sistemas de generación energética renovable o las medidas de eficiencia energética pasivas o activas.

A1: Extracción de materias primas

A2: Transporte

A3: Manufactura

Fases A4-A5

La fase de construcción incluye todos los procesos desde la puerta de fábrica hasta completar el trabajo de construcción e instalación de todos los componentes que intervienen en las intervenciones implementadas. También incluye todos los componentes necesarios para llevar a cabo la instalación y construcción de dichos componentes. Al igual que en las fases anteriores, se contemplará la instalación y los trabajos de construcción de los componentes necesarios tanto para la generación (p.ej. la construcción del edificio donde se integrarán los sistemas de generación, monitorización y control) como para la distribución (p. ej. trabajos de obra civil para la instalación de las tuberías de distribución y de las subestaciones de intercambio) y el almacenamiento de energía así como para el suministro de energía a las viviendas. También se contemplará la instalación de los sistemas y equipos que se integren en los edificios con el fin de reducir su consumo energético.

A4: Transporte

A5: Construcción - Instalación

Fase B

La fase de uso cubre el periodo desde que se termina la fase de construcción hasta que llega la fase de deconstrucción. La metodología incluye las siguiente tres sub-fases: B2, B4 y B6.

B2: Mantenimiento. La fase de mantenimiento debe incluir todos procesos que intervienen en el mantenimiento de los equipos y sistemas que componen las intervenciones (desde la generación, distribución y almacenamiento de energía hasta el suministro y consumo en los edificios).

B4: Sustitución. Esta fase debe incluir todos los procesos que intervienen en la sustitución de componentes de los equipos y sistemas que componen las intervenciones.

B6: Operación. Esta fase debe incluir todos los procesos que intervienen en la operación de las intervenciones desde la generación, distribución y almacenamiento de energía hasta el suministro y consumo de energía en los edificios.

Para el caso del análisis energético-ambiental, esta fase incluirá todos los procesos relacionados con la generación y el consumo de energía u otros recursos incluyendo en cada caso también el ciclo del combustible así como los procesos relacionados con la monitorización y control de la energía.

Para el análisis económico, esta fase incluirá los costes tanto fijos como variables del consumo de energía u otros recursos así como los costes de operación y gestión de los sistemas cuando corresponda. Del mismo modo, deben considerarse los posibles beneficios económicos tanto fijos como variables asociados a la generación, venta o autoconsumo de energía cuando así se requiera.

Finalmente, cabe destacar que para la evaluación ambiental y económica de esta fase, se considerarán como datos de partida tanto el consumo energético del escenario de transición como los ahorros obtenidos anualmente respecto al escenario base de la ciudad tal y como está detallado en el apartado 3.4.1.

Con el objetivo de poder generar los escenarios para la ciudad de forma que la evaluación de impactos pueda hacerse de la manera más ágil posible, se identifica el beneficio asociado a la creación de un modelo integrado que disponga de un enlace directo entre la fase de uso de las intervenciones y el resto de las fases del ciclo de vida de los componentes que intervienen en dichos escenarios. De este modo, una variación originada en el escenario (como puede ser la selección o no de una determinada intervención, la intensificación de la implementación de una determinada medida o la variación del ritmo de implementación de una intervención a lo largo del periodo de transición), modificará automáticamente las necesidades de los componentes así como la energía u otros recursos asociados al resto del ciclo de vida de las intervenciones. Para ello, se deberá modelar cada fase de del ciclo de vida de cada intervención de manera que sea dependiente a la fase de uso de las mismas. Por ejemplo se definirá el impacto tanto ambiental y económico de dichas fases en función de la potencia instalada o energía generada para el caso de los sistemas de generación, en función de la distancia para el caso de los sistemas que intervienen en la distribución de la energía o en función de la capacidad de almacenamiento para el caso de los tanques.

<u>Fase C</u>

La fase de fin de vida comienza a la hora de desmantelar los equipos y sistemas de las intervenciones del escenario una vez que no vayan a tener más uso. Este módulo incluye los siguientes sub-módulos:

C1: Deconstrucción de las intervenciones

C2: Transporte de los materiales y equipos de las intervenciones hasta su lugar de disposición final

C3: Procesado de residuos para su reutilización, recuperación y/o reciclado

C4: Disposición final que incluye los posibles tratamientos previos a la disposición

3.6.5. Indicadores de evaluación de impacto

A continuación se presentan los indicadores seleccionados para abordar la problemática en cuestión. El trabajo realizado combina la revisión de literatura con un nuevo enfoque que se detallará en la descripción de cada indicador. La selección y el refinamiento de indicadores se han llevado a cabo considerando los siguientes criterios;

- Deben ser cuantitativos y medibles a través de métodos de evaluación consistentes sin incurrir en un exceso de tiempo y esfuerzo considerando los datos disponibles.
- Deben aportar información relevante para la toma de decisiones durante el proceso de evaluación y priorización de escenarios de transición para ciudades.
- No deben proporcionar información que pueda estar duplicada en otros indicadores.
- Deben ser capaces de considerar los principales aspectos temporales definidos para la evaluación de los escenarios de transición de ciudades.

La Figura 31 muestra de forma gráfica los indicadores incluidos en la metodología ordenados en función de la dimensión y del nivel que abordan en cada caso.

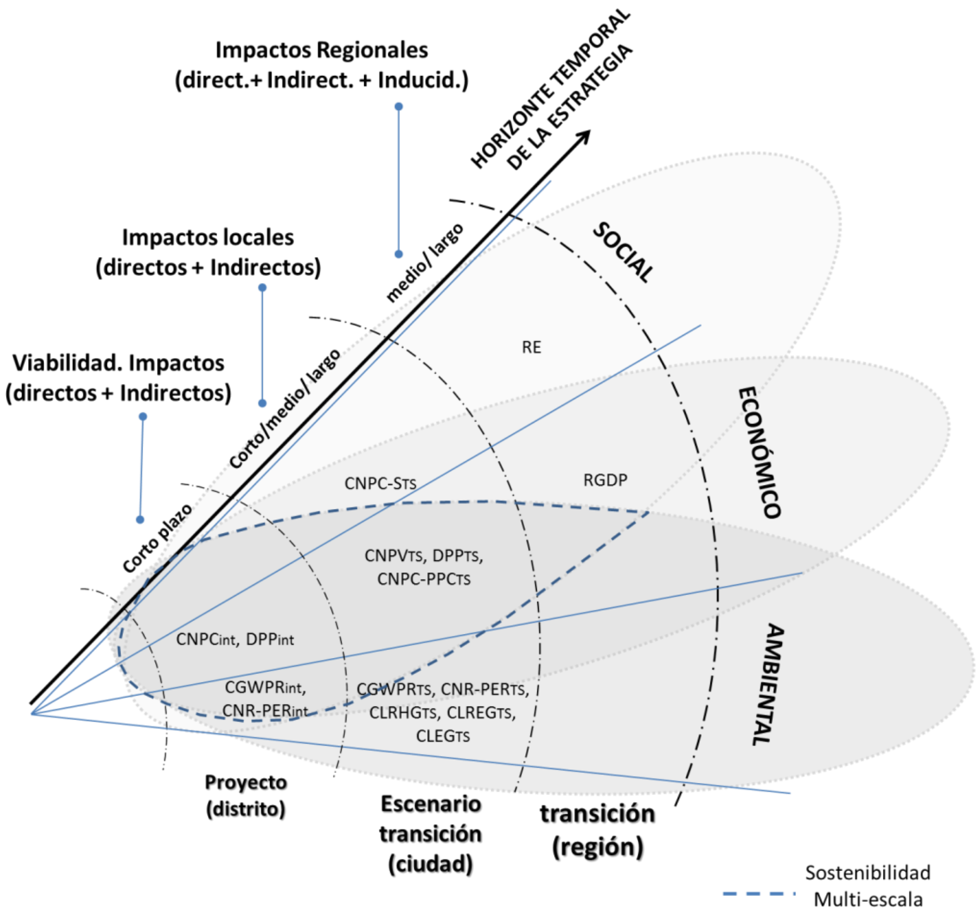

Figura 31. Indicadores de evaluación de impacto utilizados en la metodología representados sobre el marco metodológico propuesto (Elaboración propia). *Nota: El significado de la nomenclatura utilizada para los indicadores se presenta más adelante en esta sección.*

Cabe destacar que a pesar de haber clasificado cada uno de los indicadores en una de las tres dimensiones de la sostenibilidad, difícilmente se puede afirmar que cada una de ellas responda o se limite exclusivamente a dicha dimensión. Como es sabido, estas tres dimensiones están fuertemente ligadas y los límites entre ellas no son fácilmente definidos en muchos casos.

A continuación se describe más en detalle cada uno de los indicadores seleccionados:

Indicadores de nivel intervención/proyecto:

En este nivel se lleva a cabo la evaluación de los impactos asociados a la implementación de las intervenciones individuales considerando en cada caso como periodo de evaluación la vida útil correspondiente a cada intervención. Los indicadores seleccionados corresponden a medidas estándar tanto en el análisis de ciclo de vida ambiental como económico. La evaluación de estos indicadores para las diferentes intervenciones que pueden ser incluidas en los escenarios de ciudad proporcionará criterios que permitirán hacer un análisis comparativo entre dichas intervenciones.

- **Económico**

COSTE ACTUAL NETO ACUMULADO / CUMULATIVE NET PRESENT COST (CNPC$_{int}$)

El indicador de Coste Actual Neto se evalúa al igual que el indicador del valor actual neto salvo porque este considera únicamente los costes incurridos, obviando los posibles beneficios resultantes de la implementación de la intervención. El Valor Actual Neto es un método estándar en la planificación de inversiones a largo plazo y su evaluación permite analizar la viabilidad de determinadas inversiones. En este caso, los resultados se darán en función de la unidad de referencia definida para esta escala (€/kWh de EP-NR evitada). Por lo tanto, el indicador de Coste Actual Neto al final del periodo de evaluación proporcionará un criterio de todos los costes asociados a cada intervención por cada kWh de Energía Primaria de Origen No Renovable evitado.

PERIODO DE RETORNO DINAMICO / DYNAMIC PAYBACK PERIOD (DPP$_{int}$)

El periodo de retorno dinámico (en años) de una inversión que genera ahorros energéticos en comparación con la situación base, se define como el horizonte temporal mínimo que causa un valor no negativo del valor actual neto. Este indicador proporciona información sobre los años necesarios para retornar la inversión inicial realizada.

- **Ambiental**

REDUCCIÓN ACUMULADA DEL IMPACTO DE POTENCIAL DE CALENTAMIENTO GLOBAL / CUMULATIVE GLOBAL WARMING POTENTIAL REDUCTION (CGWPR$_{int}$)

El indicador de Potencial de Calentamiento Global (GWP-100 years) se utiliza para cuantificar el impacto que las emisiones de gases de efecto invernadero tienen sobre el cambio climático. El cambio climático es definido como el impacto de las emisiones humanas en la capacidad de absorción de radiación de la atmósfera, que puede tener impactos adversos en la salud humana y aumentan la temperatura de la superficie de la tierra. Este estudio adopta el método de cálculo '*midpoint'* o de efectos de impacto intermedio. Este método proporciona un perfil ambiental del proceso evaluado cuantificando su efecto sobre diversas categorías (como el potencial de calentamiento global) en contraposición a las metodologías '*endpoint'* o de impactos de efecto final que se centran en analizar el efecto último (daño) del impacto ambiental sobre el hombre y los sistemas naturales. Por lo tanto, este indicador se cuantificará en KgCO_2-eq/unidad de referencia de acuerdo con la metodología Descrita en (IPCC, 2013) que recoge los factores de caracterización a considerar.

El indicador propuesto en este caso es la reducción acumulada de este efecto debido a la implementación de la intervención analizada.

$$CGWPR_{int} = -\left(\left(GWP^{A1-A5}\right) + \left(GWP^{B}\right) + \left(GWP^{C1-C4}\right)\right)/RU$$

Ecuación 3

Donde;

$$GWP^{B} = \left(GWP^{B2} + GWP^{B4} + GWP^{B6,3} - GWP^{B6,4}\right)$$

$$GWP^{B6,3} = \left(EC^{y}_{int,t} \times GWPf^{y}\right)$$

$$GWP^{B6,4} = \left(ER^{y}_{int,t} \times GWPf^{y}\right)$$

Y donde;

GWP^{A1-A5} = Impacto de Potencial de Calentamiento Global de las fases A1-A5 de la intervención

$GWP^{B6,3}$ = Impacto de Potencial de Calentamiento Global asociado al consumo energético del nuevo sistema en la fase de uso

$GWP^{B6,4}$ = Impacto de Potencial de Calentamiento Global asociado al ahorro energético debido a la implementación del nuevo sistema (respecto al sistema de referencia) en la fase de uso

EC^{y} = Consumo de energía del combustible '*y'* de la intervención

ER^{y} = Consumo de energía del combustible '*y'* equivalente al que ha sido desplazado o evitado debido a la intervención (ya sea por generación de energía o por mejora de la eficiencia energética)

$GWPf^{y}$= Factor de conversión al Potencial de Calentamiento Global del combustible '*y'*

REDUCCIÓN ACUMULADA DEL USO DE ENERGÍA PRIMARIA DE ORIGEN NO RENOVABLE / CUMULATIVE NON RENEWABLE PRIMARY ENERGY USE REDUCTION (CNRPER$_{int}$)

Este indicador engloba todos los recursos energéticos no renovables (uranio, petróleo, carbón, gas natural, lignito, etc.) consumidos para la generación energética a lo largo de todo el ciclo de vida de un producto o sistema. Al igual que en el caso anterior, se adopta el método de cálculo *midpoint* o de efectos de impacto intermedio. El indicador se evalúa de acuerdo al método CML (Guinée et al., 2001) y el resultado se cuantificará en MJ-eq/unidad de referencia.

El indicador definido representa la reducción del consumo de energía primaria de origen no renovable asociado a la implementación de la intervención analizada. Para ello se considerará además de la energía embebida del sistema la energía primaria desplazada por el mismo.

$$CNRPER_{int} = -\left(\left(NRPE^{A1-A5}\right) + \left(NRPE^{B}\right) + \left(NRPE^{C1-C4}\right)\right)/RU$$

Ecuación 4

Donde;

$$NRPE^{B} = \left(NRPE^{B2} + NRPE^{B4} + NRPE^{B6,3} - NRPE^{B6,4}\right)$$

$$NRPE^{B6,3} = \left(EC_{int,t}^{y} \times NRPEf^{y}\right)$$

$$NRPE^{B6,4} = \left(ER_{int,t}^{y} \times NRPEf^{y}\right)$$

Y donde;

$NRPE^{A1-A5}$ = Uso de energía primaria de origen no renovable de las fases A1-A5 de la intervención

$NRPE^{B6,3}$ = Uso de energía primaria de origen no renovable asociado al consumo energético del nuevo sistema en la fase de uso

$NRPE^{B6,4}$ = Energía primaria de origen no renovable asociado al ahorro energético debido a la implementación del nuevo sistema (respecto al sistema de referencia) en la fase de uso

EC^{y} = Consumo de energía del combustible ‘*y’* de la intervención

ER^{y} = Consumo de energía del combustible ‘*y’* equivalente al que ha sido desplazado o evitado por la intervención (ya sea por generación de energía o por mejora de la eficiencia energética)

$NRPEf^{y}$ = Factor de conversión a energía primaria no renovable del combustible ‘*y’*

Indicadores de nivel de ciudad:

En este segundo nivel donde se evalúan los impactos que tendrán en la ciudad los diferentes escenarios de transición energética propuestos, cobra mayor relevancia el efecto de la implementación conjunta de las diferentes intervenciones así como los aspectos temporales detallados anteriormente. Es por ello por lo que a pesar de que algunos de los indicadores propuestos se asemejen en cierto modo a los definidos para el nivel de intervención, el proceso a seguir para su evaluación es diferente.

- **Económico (socioeconómico)**

VALOR ACTUAL NETO ACUMULADO / CUMULATIVE NET PRESENT VALUE ($CNPV_{TS}$)

Tal y como se ha mencionado anteriormente, el Valor Actual Neto permite analizar la viabilidad de determinadas inversiones. Una inversión será viable siempre y cuando el valor presente de la suma de todos los flujos de caja positivos menos el valor presente de todos los flujos de caja negativos durante un periodo de tiempo estipulado sea mayor que cero.

A continuación se detalla la ecuación a emplear para la evaluación del Valor Actual Neto Acumulado del Escenario de Transición o *'Cumulative Net present Value of the Transition Scenario ($CNPV_{TS}$)'* en M€/RU.

$$CNPV_{TS} = -\sum_{int}\left[\sum_{i=0}^{T} C_{I,i}(int)\,R_d(i) + \sum_{i=1}^{T}\left(C_{a,i}(int)\,R_d(i) + C_{c,i}(int)\right) - V_{f,T}(int)\right]/RU$$

Ecuación 5

Esta ecuación se define partiendo de la ecuación que representa los costes globales en términos del valor actual neto en la norma EN 15459. En este caso la ecuación se ha adaptado para la evaluación de escenarios de transición de ciudades.

$C_{I,i}(int)$ corresponde al coste asociado a las inversiones iniciales de las intervenciones realizadas en el año i que se implementarán a lo largo del periodo de transición *T*. En este caso a la hora de evaluar cada intervención se deben incluir todas las actuaciones (en relación a dicho tipo específico de intervención) que se lleven a cabo en paralelo en diferentes zonas de la ciudad. Además, este parámetro se ha hecho dependiente del tiempo de manera que en cada año durante el periodo de transición se puedan considerar nuevas implementaciones. Esto permitirá evaluar el efecto del ritmo de implementación de las intervenciones. Esto permite a su vez incluir la evolución temporal de los costes de inversión de las intervenciones a lo largo del periodo definido. Dado que se tratan de costes futuros se integra el factor $\mathrm{R_d(i)}$, factor de descuento para el año i basado en el ratio de descuento *r* a partir de $\frac{1}{(1+r/100)^t}$. El parámetro $\mathrm{C_{I,i}(int)}$ está asociado a los costes correspondientes al módulo de información A.

Por otro lado, $V_{f,T}(int)$ se mantiene como valor residual del grupo de intervenciones al final del periodo (descontado al año inicial 0). Del mismo modo $C_{c,i}(int)$ se mantiene como coste de emisiones de carbono del grupo de intervenciones durante el año i. Este parámetro será incluido en el análisis únicamente para los cálculos macroeconómicos.

Finalmente, $C_{a,i}(int)$ corresponde al flujo de caja neto anual de la intervención correspondiente durante el año i. Este factor está compuesto por varios sub-costes en función de la fase del ciclo de vida a la que corresponde, incluyendo desde la fase B hasta la C tal y como se muestra en la siguiente ecuación.

$$C_{a,i}(int) = C_{int,i}^{B2} + C_{int,i}^{B4} - C_{int,i}^{B6,1} + C_{int,i}^{B6,2} + C_{int,i}^{B6,3} - C_{int,i}^{B6,4} + C_{int,i}^{C1-C4}$$

Ecuación 6

Cabe mencionar que en este caso la fase operación B6, ha sido dividida en cuatro componentes. El térmico $C_{int,i}^{B6,1}$ corresponde a los beneficios anuales fijos asociados a la operación de cada intervención en el año t. $C_{int,i}^{B6,2}$, corresponde a los costes anuales fijos asociados a la operación. $C_{int,i}^{B6,3}$, corresponde a los costes asociados a la energía consumida en la operación (incluyendo todos los tipos de combustible).

Finalmente, $C_{int,i}^{B6,4}$ corresponde a los beneficios económicos obtenidos respecto al sistema de referencia debido a la generación de energía (tanto para la venta como para el autoconsumo) o a la mejora de la eficiencia energética obtenida por dicha intervención. Para calcular estos últimos dos componentes de coste se emplearán las siguientes ecuaciones donde '$energy\ price_{\ y,i}$' es el precio del fuel 'y' en el año 'i' y donde 'K' es el número de tipos de fuel consumido.

$$C_{int,i}^{6,3} = \sum_{y=1}^{K} (Energy\ consumption_{\ y,i} \times energy\ price_{\ y,i})$$

$$C_{int,i}^{6,4} = \sum_{y=1}^{K} (Energy\ savings_{\ y,i} \times energy\ price_{\ y,i})$$

Ecuación 7

PERIODO DE RETORNO DINAMICO / DYNAMIC PAYBACK PERIOD (DPP_{TS})

El periodo de retorno dinámico del escenario de transición se define como el horizonte temporal mínimo que causa un valor no negativo del valor actual neto. Es decir, es el primer año en el que el $CNPV_{TS}$ comienza a ser positivo.

COSTE ACTUAL NETO ACUMULADO / CUMULATIVE NET PRESENT COST ($CNPC_{TS}$)

El indicador $CNPC_{TS}$ (en M€/RU) es similar al Cumulative Net Present Value con la salvedad de que este considera únicamente los costes, obviando los posibles beneficios resultantes de la implementación del escenario de transición. Este indicador resulta interesante para identificar la dimensión de las inversiones iniciales que se llevarán a cabo en cada escenario de transición así como el resto de costes anuales asociados a la operación de los mismos.

$$CNPC_{TS} = \sum_{int}\left[\sum_{i=0}^{T} C_{I,i}(int)\, R_d(i) + \sum_{i=1}^{T}\left(C_{a,i}(int)\, R_d(i) + C_{c,i}(int)\right)\right]/RU$$

Ecuación 8

Donde en este caso;

$$C_{a,i}(int) = C_{int,i}^{B2} + C_{int,i}^{B4} + C_{int,i}^{B6,2} + C_{int,i}^{B6,3}$$

Ecuación 9

En la metodología propuesta este indicador se divide en dos en función de cuál es el punto de vista adoptado.

- *COSTE ACTUAL NETO ACUMULADO POR LA SOCIEDAD / CUMULATIVE NET PRESENT COST-SOCIAL (CNPC-S_{TS})*: Este indicador responde al punto de vista de la ciudadanía (social) y tiene en cuenta únicamente los costes sobre los que incurren los propios ciudadanos. Este indicador resulta interesante para comprender el coste total (tanto de inversión inicial como de operación, mantenimiento, sustitución, etc.) que va a tener que soportar la sociedad en función del escenario evaluado.
- *COSTE ACTUAL NETO ACUMULADO POR COMPAÑIAS / CUMULATIVE NET PRESENT COST OF PUBLIC/PRIVATE COMPANIES (CNPC-PPC_{TS})*: Este indicador en cambio responde a un punto de vista de la compañía, ya sea pública o privada. El indicador resulta interesante para comprender todas las inversiones públicas o privadas que deberán ser aseguradas y llevadas a cabo a lo largo de cada uno de los escenarios de transición evaluados.

- **Ambiental:**

De la amplia variedad de posibles indicadores que se pueden emplear en la evaluación de la sostenibilidad ambiental de las ciudades, a continuación se describen los indicadores seleccionados en esta metodología.

REDUCCIÓN ACUMULADA DEL IMPACTO DE POTENCIAL DE CALENTAMIENTO GLOBAL / CUMULATIVE GLOBAL WARMING POTENTIAL REDUCTION (CGWPR$_{TS}$)

El indicador de Reducción Acumulada del Potencial de Calentamiento Global (GWP-100 years) del escenario de transición de la ciudad se utiliza como uno de los indicadores principales en la dimensión ambiental y se evalúa mediante la siguiente ecuación.

$$CGWPR_{TS} = -\sum_{i=1}^{T}\left(\sum_{int=1}^{Y}\left(GWP_{int,i}^{A1-A5}\right) + \sum_{int=1}^{X}\left(GWP_{int,i}^{B}\right) + \sum_{int=1}^{Z}\left(GWP_{int,i}^{C1-C4}\right)\right)/RU$$

Ecuación 10

Donde;

$$\sum_{int=1}^{X}\left(GWP_{int,t}^{B}\right) = \sum_{int=1}^{X}\left(GWP_{int,i}^{B2} + GWP_{int,i}^{B4} + GWP_{int,i}^{B6,3} - GWP_{int,i}^{B6,4}\right)$$

$$GWP_{int,i}^{B6,3} = \sum_{y=1}^{K}\left(EC_{int,i}^{y} \times GWPf^{y}\right)$$

$$GWP_{int,i}^{B6,4} = \sum_{y=1}^{L}\left(ER_{int,i}^{y} \times GWPf^{y}\right)$$

Ecuación 11

Y donde;

$GWP_{int,i}^{A1-A5}$ = Impacto de Potencial de Calentamiento Global de las fases A1-A5 de la intervención correspondiente durante el periodo de tiempo i.

$EC_{int,i}^{y}$ = Consumo de energía del combustible *y* de la intervención correspondiente en el periodo de tiempo i

$ER_{int,i}^{y}$ = Consumo de energía del combustible '*y*' equivalente al que ha sido desplazado o evitado por la intervención implementada en el periodo de tiempo i (ya sea por generación de energía o por mejora de la eficiencia energética)

K = Número de combustibles consumidos

L = Número de combustibles desplazados

$GWPf^{y}$= Factor de conversión al Potencial de Calentamiento Global del combustible '*y*'

REDUCCIÓN ACUMULADA DEL USO DE ENERGÍA PRIMARIA DE ORIGEN NO RENOVABLE / CUMULATIVE NON RENEWABLE PRIMARY ENERGY USE REDUCTION (CNR-PER$_{TS}$)

Al igual que en el caso de la evaluación a nivel de intervención, este indicador aplicado a la evaluación de escenarios de transición a escala de ciudad proporciona información energético-ambiental relevante para la toma de decisiones en el ámbito municipal. Para este caso la ecuación previamente utilizada para la evaluación de intervenciones individuales ha sido modificada del siguiente modo.

$$CPER_{TS} = -\sum_{i=1}^{T}\left(\sum_{int=1}^{Y}\left(NRPE_{int,i}^{A1-A5}\right) + \sum_{int=1}^{X}\left(NRPE_{int,i}^{B}\right) + \sum_{int=1}^{Z}\left(NRPE_{int,i}^{C1-C4}\right)\right)\Big/RU$$

Ecuación 12

Donde;

$$\sum_{int=1}^{X}\left(NRPE_{int,i}^{B}\right) = \sum_{int=1}^{X}\left(NRPE_{int,i}^{B2} + NRPE_{int,i}^{B4} + NRPE_{int,i}^{B6,3} - NRPE_{int,i}^{B6,4}\right)$$

$$NRPE_{int,i}^{B6,3} = \sum_{y=1}^{K}\left(EC_{int,i}^{y} \times NRPEf^{y}\right)$$

$$NRPE_{int,i}^{B6,4} = \sum_{y=1}^{L}\left(ER_{int,i}^{y} \times NRPEf^{y}\right)$$

Ecuación 13

Y donde;

$NRPE_{int,i}^{A1-A5}$ = Uso de Energía Primaria de origen no renovable de las fases A1-A5 de la intervención correspondiente durante el periodo de tiempo i

$NRPEf^{y}$ = Factor de conversión a energía primaria no renovable del combustible *y*

GENERACIÓN ACUMULADA DE CALOR LOCAL Y RENOVABLE / CUMULATIVE LOCAL RENEWABLE HEAT GENERATION INCREASE (CLRHG$_{TS}$)

Este indicador proporciona una visión del modo en el que la ciudad aumenta su grado de autoabastecimiento de calor mediante la generación de calor renovable debido al despliegue de intervenciones propuestas en cada escenario de transición. Este aspecto es relevante para disminuir el grado de dependencia de la ciudad respecto al uso de combustibles fósiles comúnmente extraídos y procesados fuera de los límites de la ciudad.

Para su cálculo se sumará todo el calor generado de forma renovable en la ciudad a lo largo del periodo de transición energética. $CLRHG_{TS}$ será por lo tanto la generación de calor renovable acumulada en la ciudad (kWht/RU) una vez implementado el escenario de transición.

A través de este indicador se puede evaluar también el modo en el que evoluciona a lo largo del periodo de transición el grado de autoabastecimiento de calor en la ciudad *(heat self-sufficiency degree of the city, $HSSD_{city}$).* Para ello se dividirá el calor generado de forma renovable y local en el año i debido a la implementación del escenario de transición por el consumo de calor total de la ciudad para el sector evaluado.

GENERACION ACUMULADA DE ELECTRICIDAD LOCAL Y RENOVABLE / CUMULATIVE LOCAL RENEWABLE ELECTRICITY GENERATION INCREASE ($CLREG_{TS}$)

Del mismo modo que en el caso anterior, este indicador proporciona una visión del modo en el que la ciudad aumenta su grado de autoabastecimiento de electricidad *(electricity self-sufficiency degree, $ESSD_{city}$)* mediante la generación eléctrica renovable debido al despliegue de intervenciones propuestas en cada escenario de transición evaluado.

Para su cálculo se sumará toda la electricidad generada de forma renovable en la ciudad a lo largo del periodo de transición energética. $CLREG_{TS}$ será por lo tanto la generación de electricidad renovable acumulada (kWhe/RU) una vez implementado el escenario de transición.

GENERACIÓN ELECTRICA LOCAL ACUMULADA / CUMULATIVE LOCAL ELECTRICITY GENERATION ($CLEG_{TS}$)

Este indicador permite comparar el potencial de diferentes escenarios de transición para aumentar la generación eléctrica local ya sea renovable o no. De este modo, a diferencia del indicador anterior, se incluiría por ejemplo la energía generada a través de cogeneración alimentada por fuentes no renovables.

Este indicador proporciona criterios sobre el aumento del grado de autoabastecimiento de electricidad, sobre la diversificación de la matriz energética de la ciudad y sobre la disminución de la dependencia de combustibles fósiles importados.

<u>Indicadores del nivel regional</u>

La evaluación a escala ciudad es complementada y conectada mediante la metodología que se describe más adelante en la sección 3.6.6, con una evaluación a escala regional orientada a la mejora del desarrollo socioeconómico y al fomento de la competitividad de los diferentes sectores de actividad económica de la región. Por lo tanto, esta sección incluye la selección y definición de los indicadores macroeconómicos, y la siguiente sección detalla la aproximación propuesta para su evaluación.

IMPACTO EN EL PRODUCTO INTERIOR BRUTO REGIONAL / REGIONAL GROSS DOMESTIC PRODUCT (RGDP)

El producto interior bruto (PIB) es una magnitud macroeconómica que expresa el valor monetario de la producción de bienes y servicios de demanda final de un país (o región) durante un período determinado de tiempo. El indicador propuesto corresponde a: *'la acumulación de impacto tanto directo como indirecto e inducido en el crecimiento del Producto Interior Bruto regional debido a la implementación del escenario de transición energético de la ciudad'.* Expresado en M€/RU.

La evaluación de este impacto de manera que el Valor Añadido Bruto de los diferentes sectores de actividad económica de la región puedan ser analizados de un modo desagregado, proporcionará criterios que ayudarán a comprender cuál de los potenciales escenarios de transición creará un efecto más positivo sobre determinados sectores que se pretendan potenciar a escala regional.

IMPACTO EN EL EMPLEO REGIONAL / REGIONAL EMPLOYMENT (RE)

Este indicador expresado en Número de empleos/RU representa uno de los aspectos socio-económicos más relevantes ya que evalúa el incremento de la creación de empleo regional tanto directo, como indirecto e inducido debido al aumento de la producción acumulada asociada a la implementación del escenario de transición de la ciudad.

No todos los escenarios evaluados influirán del mismo modo en la creación de empleo ni en cantidad ni en su distribución sectorial. Por lo tanto, la evaluación de este indicador proporcionará criterios relevantes para la toma de decisiones.

3.6.6. Aproximación a la evaluación de impacto macroeconómico regional de los escenarios de transición energética de ciudades

Tal y como se ha mostrado en el Capítulo 2, la evaluación de impactos macroeconómicos regionales está ligada al uso de otro tipo de aproximaciones y modelos. En esta metodología se opta por partir de la aproximación de los modelos basados en las tablas IO extendidas y se recomienda trabajar con modelos existentes flexibles con los que se puede establecer un enlace que refleje la influencia de las inversiones llevadas a cabo en la ciudad a lo largo del periodo de evaluación sobre la economía regional. En este caso se utiliza el modelo MIOCIM desarrollado por Kratena (Kratena, 2015) que integra mecanismos básicos macroeconómicos que evitan algunas de las carencias asociadas al uso de los modelos simples de impacto IO creando un modelo complejo, similar a un modelo de equilibrio general.

Tal y como describe Kratena, MIOCIM integra algunas mejoras que permiten evitar efectos tales como la subestimación realizada por los modelos IO simples sobre los efectos a corto plazo debido a la introducción de una nueva actividad económica al no tener en cuenta los multiplicadores macroeconómicos de renta disponible. Además, el consumo no se limita a seguir un simple mecanismo de renta Keynesiano, sino que también incluye propiedades dinámicas. Por otro lado, MIOCIM evita la sobreestimación de los efectos del empleo que ocurre al utilizar los modelos IO simples, ya que estos no consideran que el aumento de la demanda de trabajo puede no ser absorbida por la oferta de mano de obra real en la región, y que por lo tanto se puede producir un aumento de los salarios reduciendo en parte el efecto en la creación de empleo. Una descripción más detallada del modelo puede encontrarse en (Kratena, 2015). Además, un mayor grado de descripción de la base metodológica de la aproximación seguida por el modelo, puede ser consultada en (Kratena & Streicher, 2009).

El primer problema a la hora de tratar de conectar los escenarios de transición energética de ciudades evaluados hasta el momento mediante metodologías de análisis de ciclo de vida, con los modelos basados en IO, es el nivel de desagregación de las tablas IO. Este nivel de desagregación varía en función del caso particular (región) evaluado, pero en cualquier caso se aleja del necesario para llegar a evaluar cada una de las intervenciones o tecnologías energéticas que forman el escenario de transición de una ciudad. A modo de ejemplo, en las tablas IO el sector eléctrico está en la mayoría de los casos representado por un único sector. Por lo tanto, por cada euro invertido, se obtendría el mismo efecto en el caso de realizar una inversión en una central térmica que en un aerogenerador. En cambio, el impacto real asociado a la implementación de ambas opciones resultará diferente en cuanto al empleo generado o al aumento del PIB. Esto es debido a que cada región tiene unas características particulares de estructura productiva y de servicios y que por lo tanto puede darse el caso de que la región sea capaz de dar respuesta a las necesidades productivas asociadas a la cadena de suministro de una tecnología pero en cambio no a la de otras. Es decir, que puede ser capaz de producir por ejemplo los componentes asociados a la fabricación de aerogeneradores pero a lo mejor no los componentes de la central térmica. Además, la mano de obra necesaria para la fabricación de cada opción puede ser diferente en cuanto a cantidad o a la especialización requerida. Esta dificultad se ve incrementada en el caso de intervenciones para ciudades ya que el tipo de tecnologías energéticas y medidas de eficiencia a implementar son muy específicas y de menor escala. Estudios como (Cameron & Van Der Zwaan, 2015) o (Kammen et al., 2004) identifican este reto como una de los principales motivos para emplear otras aproximaciones a la evaluación de impacto.

El método utilizado tradicionalmente, llevaría a tratar de desagregar en las tabas IO los sectores relacionados con la generación de energía tanto térmica como eléctrica, pero el llevar a cabo esa desagregación para todas las posibles intervenciones aplicables en una ciudad es un trabajo muy laborioso que podría en sí misma constituir para cada región un trabajo de doctorado y queda por lo tanto fuera del alcance y del propósito de este trabajo.

El método propuesto en cambio, pretende relacionar la aproximación de la perspectiva de ciclo de vida adoptada en las fases iniciales de la metodología, con este tipo de metodologías de evaluación macroeconómica, a través de un proceso simplificado y flexible que pueda ser adaptado para el análisis de diferentes ciudades y regiones de manera ágil. El objetivo es poder considerar de forma comparativa el efecto potencial de diferentes escenarios de transición de la ciudad para generar efectos sobre la región.

Para ello, se identifica la evaluación de la cadena de suministro de las intervenciones que forman cada escenario de transición de la ciudad como nexo de unión entre las metodologías de análisis de ciclo de vida y los modelos IO adaptados como el MIOCIM.

De este modo, a través de la evaluación de costes de ciclo de vida de los escenarios y de la evaluación de la cadena de suministro de cada intervención y escenario, se creará un shock multisectorial que podrá ser introducido en el modelo MIOCIM adaptado a la región en cuestión, en forma de aumento de la demanda endógena. De este modo, una vez simulado el modelo, se podrán evaluar los efectos directos, indirectos e inducidos originados en el empleo y en el PIB de la región debido a este aumento de demanda. La Figura 32 enumera los pasos principales de la metodología propuesta para la composición del Shock de los escenarios de transición energética de la ciudad.

Metodología para la composición del *shock* de los escenarios de transición energética de la ciudad

- Bloques de información a considerar en la evaluación de la cadena de suministro de las intervenciones
- Definición de los costes de la cadena de suministro de las intervenciones
- Asignación de los bienes y sectores a cada partida de coste de la cadena de suministro del escenario
- Evaluación de los costes de la cadena de suministro
    - Transformación del shock a precios básicos
    - Asignación de la cuota de importación
- Definición del shock del escenario de transición

Figura 32. Pasos principales de la metodología para la composición del shock de los escenarios de transición energética de la ciudad**.**

A continuación se detalla cada uno de los pasos;

Bloques de información a considerar en la evaluación de la cadena de suministro de las intervenciones y nivel de desagregación del shock

La composición de los 'shock' que representarán la variación de la demanda endógena de bienes de los sectores de la actividad económica de la región es precisamente el paso principal que permitirá conectar la evaluación de las tecnologías implementadas en la ciudad con la evaluación socioeconómica a escala regional. Tal y como se ha mencionado previamente, la composición del shock que representará cada intervención se obtendrá a través de la evaluación de la cadena de suministro de dicha intervención. Esto permitirá desglosar los componentes de los costes y asociarlos a determinados sectores. La Figura 33 resume de forma esquemática los principales bloques de información a evaluar durante la evaluación de la cadena de suministro de cada intervención y muestra la relación entre estos y los diferentes módulos de información definidos para la evaluación de análisis de costes de ciclo de vida de los escenarios.

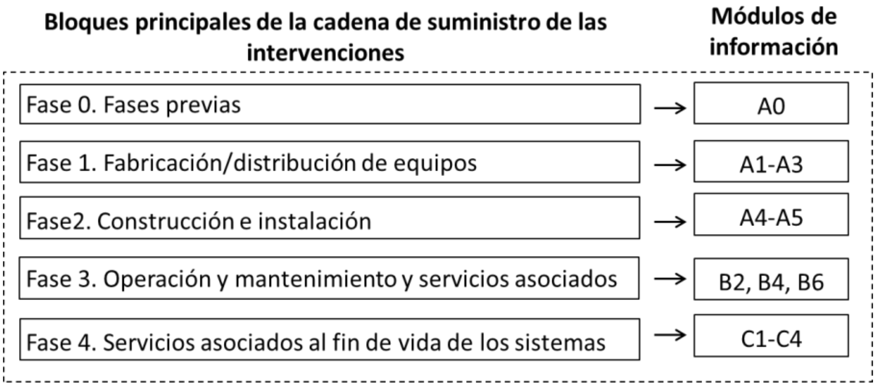

Figura 33. Conexión entre los bloques principales de la cadena de suministro/cadena de valor de las intervenciones y módulos de información y fases del ACCV (Elaboración propia).

Resulta necesario debatir sobre el grado de desagregación necesario en la composición del shock, ya que esto será lo que permitirá un mayor grado de definición de la intervención. En cambio, una mayor desagregación conllevará un mayor uso de recursos para su definición.

Como primer paso se deben analizar las tablas origen y destino que se utilizan en la composición de la matriz IO simétrica de la región, ya que esto definirá el mayor grado de desagregación con el que se podrá introducir el shock en el modelo. Tanto la matriz de origen como la matriz de destino son matrices asimétricas cuyas filas y columnas están referidas a los bienes y sectores que intervienen en la economía de la región. Lo más común es que el grado de desagregación de los bienes sea mayor que el grado de desagregación de los sectores. Además, en muchos casos resulta más sencillo relacionar los costes de las intervenciones a los bienes (sobre todo en el momento en el que se desagregan los costes de la fase 1 de fabricación y distribución de equipos).

Definición de los costes de la cadena de suministro de las intervenciones

A continuación se define el procedimiento para evaluar los costes de cada una de las fases de la cadena de suministro que aplican a cada intervención. En este caso, considerando que el shock final corresponderá a un escenario de transición que incluirá la implementación de diferentes intervenciones a lo largo del periodo de transición, los costes a considerar para cada intervención incluirán todos aquellos costes asociados a las mismas incurridos a lo largo de este periodo. Siguiendo la misma clasificación y nomenclatura utilizada en el apartado de la evaluación de costes de ciclo de vida, las siguientes ecuaciones describen el modo de definir los costes acumulados y descontados de la cadena de suministro de una intervención de modo que facilite la composición final del shock.

- Fase 0: Fases previas

Esta fase incluye los costes asociados a las fases previas a la fabricación de los componentes de las intervenciones. Costes asociados a la promoción del proyecto, a los estudios previos (estudios de viabilidad, medioambientales o de I+D, diseño de las soluciones), a permisos, a seguros, etc. Esta fase está relacionada con la fase A0 definida en la sección de análisis de ciclo de vida. La siguiente ecuación detalla el modo de evaluar esta fase.

$$Fase\ 0_{int} = \begin{bmatrix} \sum_{i=0}^{T} C_{I\,A0,i}^{a}(int)\, R_d(i) \\ \sum_{i=0}^{T} C_{I\,A0,i}^{b}(int)\, R_d(i) \\ \dots \\ \dots \\ \sum_{i=0}^{T} C_{I\,A0,i}^{z}(int)\, R_d(i) \end{bmatrix}$$

Ecuación 14

En la ecuación cada fila del vector desde la *a* hasta la *z* corresponde a una partida de costes diferente (estudios de viabilidad, seguros, etc.) que intervienen en la Fase 0 de la intervención analizada. Estas partidas corresponden a costes en precios de adquisición acumulados a lo largo de todo el periodo de transición y descontados al presente *(Cumulative Discounted Cost in Purchase Prices,* CDC^{PP}*).* Cada fila del vector puede ser extraída del estudio de ACCV llevado a cabo para cada intervención en cada escenario.

- Fase 1: Fabricación /distribución de equipos

Esta fase incluye todos los costes asociados a la compra de los equipos y sistemas que forman parte de cada una de las intervenciones y está relacionada con los módulos de información A1-A3 del análisis de costes de ciclo de vida.

Es en esta fase precisamente donde la correcta desagregación de los sistemas cobra mayor importancia. Se desagregará cada intervención en sus componentes principales. El criterio a seguir para determinar el nivel máximo de desagregación de los costes de cadena de suministro de una intervención, responde a la siguiente cuestión:

¿El nuevo nivel de desagregación conlleva un mayor nivel de definición del shock a introducir en el modelo, dividiendo los costes en una nueva clasificación de bienes?

Una respuesta positiva supondría la mejora de la definición del shock de manera que se pueda diferenciar con mayor detalle del shock correspondiente a otras intervenciones. Es decir, el hecho de obtener un mayor nivel de desagregación de componentes de la intervención no asegura que esto se vea reflejado en un aumento de la definición del shock ya que puede no suponer una disposición de costes diferente en cuanto a su distribución en la clasificación de bienes del modelo IO.

La siguiente ecuación detalla el modo de evaluar esta fase, donde cada fila del vector corresponde al coste acumulado y descontado asociado a cada componente (bien) de la cadena de suministro de la intervención analizada, desde la *a* hasta la *z*.

$$Fase\ 1_{int} = \begin{bmatrix} \sum_{i=0}^{T} C_{I\,A1-A3,i}^{a}(int)\, R_d(i) \\ \sum_{i=0}^{T} C_{I\,A1-A3,i}^{b}(int)\, R_d(i) \\ \dots \\ \dots \\ \sum_{i=0}^{T} C_{I\,A1-A3,i}^{z}(int)\, R_d(i) \end{bmatrix}$$

Ecuación 15

- Fase 2: Construcción e instalación

Esta fase incluye los costes asociados a los trabajos de construcción e instalación de los diferentes sistemas y componentes que forman parte de las intervenciones desde la generación de energía hasta el almacenamiento, distribución y el consumo. Esta fase está directamente relacionada con los módulos A4 y A5 de la evaluación de costes de ciclo de vida y se debe evaluar tal y como muestra la siguiente ecuación.

$$Fase\ 2_{int} = \begin{bmatrix} \sum_{i=0}^{T} C_{I\ A4,i}(int)\ R_d(i) \\ \sum_{i=0}^{T} C_{I\ A5,i}(int)\ R_d(i) \end{bmatrix}$$

Ecuación 16

- Fase 3: Operación, mantenimiento y servicios asociados

La fase 3 incluye todos los costes económicos asociados a la operación y mantenimiento de los sistemas de cada intervención así como de los posibles servicios que puedan surgir durante la operación de los mismos. Esta fase está relacionada con los módulos de información B2, B4 y B6 del ACCV. La siguiente ecuación detalla el modo de evaluar esta fase donde los factores desde la *a* hasta la *z* representan cada uno de los componentes que forman la intervención y los subíndices desde *y=1* hasta *k* representan el tipo de combustible.

$$Fase\ 3_{int} = \begin{bmatrix} \sum_{i=1}^{T} C_{aB2,i}(int)\ R_d(i) \\ \begin{bmatrix} \sum_{i=1}^{T} C_{aB4,i}^{a}(int)\ R_d(i) \\ \sum_{i=1}^{T} C_{aB4,i}^{b}(int)\ R_d(i) \\ \cdots \\ \cdots \\ \sum_{i=1}^{T} C_{aB4,i}^{z}(int)\ R_d(i) \end{bmatrix} \\ \sum_{i=1}^{T} C_{aB6.2,i}(int)\ R_d(i) \\ \begin{bmatrix} \sum_{i=1}^{T} C_{aB6.3,i}^{y=1}(int)\ R_d(i) \\ \sum_{i=1}^{T} C_{aB6.3,i}^{y=2}(int)\ R_d(i) \\ \cdots \\ \cdots \\ \sum_{i=1}^{T} C_{aB6.3,i}^{y=k}(int)\ R_d(i) \end{bmatrix} \end{bmatrix}$$

Ecuación 17

- Fase 4: Servicios asociados al fin de vida de los sistemas

Esta fase incluye los costes asociados a los trabajos de la fase de fin de vida de las intervenciones desde los sistemas de generación de energía hasta los de almacenamiento, distribución y consumo. Esta fase está directamente relacionada con los módulos C1-C4 de la evaluación de costes de ciclo de vida y se debe evaluar tal y como muestra la Ecuación 18 donde cada una de las fases puede ser desagregada en diferentes partidas de costes en caso de que así fuera requerido.

$$Fase\ 4_{int} = \begin{bmatrix} \sum_{i=1}^{T} C_{aC1,i}(int)\, R_d(i) \\ \sum_{i=1}^{T} C_{aC2,i}(int)\, R_d(i) \\ \sum_{i=1}^{T} C_{aC3,i}(int)\, R_d(i) \\ \sum_{i=1}^{T} C_{aC4,i}(int)\, R_d(i) \end{bmatrix}$$

Ecuación 18

De este modo los costes de cadena de suministro de cada una de las intervenciones para el periodo de transición se obtendrán considerando simultáneamente todas las fases descritas. Obteniendo de esta forma el coste acumulado y descontado de la intervención en precios de adquisición *(Cumulative discounted costs of the intervention in purchase prices $CDCint^{PP}$).*

$$CDCint^{PP} = \begin{bmatrix} [Fase\ 0] \\ [Fase\ 1] \\ [Fase\ 2] \\ [Fase\ 3] \\ [Fase\ 4] \end{bmatrix}$$

Ecuación 19

<u>Asignación de los bienes y sectores a cada partida de coste de la cadena de suministro del escenario</u>

Este paso responde a la necesidad de vincular cada una de los costes definidos para las diferentes fases de la cadena de suministro de la intervención con su correspondiente bien o sector de la clasificación de bienes y sectores empleadas en las tablas origen y destino de la región. Esto es necesario debido a que el shock debe tener forma de vector, cuyas filas correspondan a los bienes de la región para poder ser introducido en el modelo como un aumento de la demanda final de producción.

Por lo tanto se debe asociar cada partida de costes con el bien que mejor lo represente. Este paso puede realizarse teniendo en cuenta el código NACE utilizado para la clasificación estadística de actividades económicas de la Comunidad Europea (Eurostat, 2008).

Evaluación de cada coste de la cadena de suministro

Se debe llevar a cabo la evaluación de cada uno de los componentes de coste de la cadena de suministro de la intervención para la región analizada. Esta evaluación se realizará en base a un análisis de las características de dicha región en cuanto a su estructura productiva y a la capacidad que tiene para dar respuesta a cada una de los componentes de costes.

El objetivo principal del análisis es el de determinar cuáles de los costes que finalmente conformarán el shock, pueden suponer un aumento real del consumo doméstico de la región. Por lo tanto se analizará cada uno de ellos (o su bien correspondiente) desde el punto de vista de si existen o no en la región empresas que puedan producir, distribuir u ofrecer servicios relacionados con los mismos. También se analizará cada coste en función de la cuota de importación media asociada a su bien correspondiente. Los pasos a seguir en esta fase se muestran en la Tabla 10.

Tabla 10. Pasos principales del proceso de evaluación del coste de cadena de suministro para la composición del shock de las intervenciones.

Clasificación de bienes	$CDCI^{PP}$	Márgenes	Producido localmente	$CDCI^{BP}$	$CDCI_D^{BP}$
Nº 26	2.32	0.81	✓	1.51	0.39
Nº 61	7.64	0.94	✓	6.70	6.70
Nº 40	4.86	1.67	✓	3.19	1.39
Nº 44	0.69	0.28	✓	0.42	0.15
…	…	…	✓	…	…
Nº 63	-	-	✓	1.82	1.54
Nº 64	-	-	✓	5.23	4.53

Para determinar si el bien analizado puede ser producido o únicamente distribuido localmente (en la región) resulta útil comprobar para las empresas identificadas como potenciales fabricantes o distribuidoras de dichos bienes, aspectos como su sede social y la actividad específica a la que se dedican, comprobando su clasificación en el registro de la Clasificación Nacional/Regional de Actividades Económicas. Además, dado que estos modelos corren a precios básicos (BP) y los costes que componen el shock se disponen a precios de adquisición *(Cumulative discounted costs of the intervention in purchase prices* $CDCI^{PP}$*)*, estos deben ser transformados a precios básicos *(Cumulative discounted costs of the intervention in basic prices $CDCI^{BP}$)*. Para ello, se debe extraer de cada partida de coste los márgenes correspondientes al comercio y transporte ya que estos no contribuyen directamente a un aumento de actividad productiva de dichos sectores. El factor entre los precios de básicos y los precios de adquisición (obtenida a partir de las tablas Input Output) determina los márgenes a considerar para cada clasificación de bienes. Estos márgenes substraídos serán incorporados a continuación en los bienes correspondientes al comercio y transporte de manera proporcional (representados en el ejemplo de la Tabla 10 por los Nº63 y Nº64).

Finalmente, a pesar de que exista la capacidad de producción local de un bien, teniendo en cuenta que los costes considerados pueden contener bienes importados, se aplicará el vector de importación (en el caso de que no se disponga información más específica al respecto). Este vector es la cuota de importación media de cada uno de los bienes, representado por el factor entre el consumo privado importado y el consumo privado total. De este modo se obtiene el vector final que considera únicamente el componente doméstico del shock *(Cumulative domestic discounted costs of the intervention in basic prices $CDCI_D^{BP}$)*.

En el caso de que un bien no sea producido localmente (pero sí distribuido), se seguirá un proceso similar, pero en este caso el componente específico del vector $CDCI^{BP}$ correspondiente a dichos bienes no producidos localmente sería igual a 0, y únicamente se considerarían los efectos de los márgenes correspondientes a dicho bien. Finalmente, se aplicaría la cuota de importación.

<u>Definición del shock del escenario de transición</u>

Este es el último paso en la definición del shock que representa el escenario de transición a evaluar de manera que pueda ser directamente introducido en el modelo. Para ello se considera simultáneamente (manteniendo la distribución por bienes, desde 1 hasta *n*) el efecto de cada shock de las intervenciones (desde 1 hasta *x*) previamente evaluadas, para crear un único shock *(Cumulative discounted and domestic costs of the transition scenario in basic prices $CDCTS_D^{BP}$).*

$$CDCTS_D^{BP} = \begin{bmatrix} \sum_{int=1}^{X} CDCI_D^{BP}\,(commodity.1) \\ \sum_{int=1}^{X} CDCI_D^{BP}\,(commodity.2) \\ \vdots \\ \sum_{int=1}^{X} CDCI_D^{BP}\,(commodity.n) \end{bmatrix}$$

Ecuación 20

3.7. Priorización de escenarios

Una vez evaluados cada uno de los escenarios potenciales de la ciudad, se obtienen para cada uno de ellos una serie de resultados de indicadores de impacto que pueden ser utilizados como criterios para la comparación. El objetivo principal de esta comparación es el llegar establecer una priorización de los escenarios alternativos que sirva como apoyo a la toma de decisiones y que identifique el escenario óptimo para cada ciudad en función de sus necesidades y particularidades.

Este es un problema donde existen un conjunto de alternativas (escenarios potenciales) y un conjunto de criterios (representados por indicadores de impacto) que pueden entrar en conflicto entre sí ya que a menudo coexisten varios puntos de vista. Por lo tanto, se puede decir que no existe una solución óptima y que se debe llegar a una solución de compromiso.

Para dar respuesta a esta problemática, la metodología propone apoyarse en la teoría de evaluación multi-criterio que comprende un conjunto de modelos, metodologías y herramientas de apoyo a la toma de decisiones. En este caso se propone seguir el método de jerarquías analíticas (Analytic Hierarchy process, AHP) que se basa en la jerarquización de los problemas sobre los cuales se debe tomar decisiones para su resolución en base a múltiples criterios. De este modo, en la parte superior se representaría el objetivo principal del problema y debajo se estructuran los criterios en base a los cuales se tomarán las decisiones y finalmente debajo del todo las diferentes alternativas a evaluar. Este método se encuentra entre los métodos complejos debido al conocimiento que se requiere tener sobre el problema, pero al mismo tiempo ofrece una mayor fiabilidad de los resultados. Cabe destacar que se requiere una importante interacción con el órgano denominado centro decisor con el objetivo de comparar y valorar por pares los diferentes niveles definidos tanto para los criterios como para las alternativas.

Los aspectos metodológicos y matemáticos a seguir para la aplicación de este método pueden ser consultados en detalle en varias publicaciones y libros (Coyle, 2004). En esta sección se describen brevemente los pasos principales y el modo en el que estos deben ser considerados para el caso específico de la metodología desarrollada.

- Descomposición del problema de decisión en una jerarquía de elementos interrelacionados identificando la meta general, los criterios de evaluación y las alternativas posibles.
  En este caso, el problema principal es la priorización de los diferentes escenarios de transición de la ciudad por lo que la meta general es identificar la solución de compromiso que represente el escenario óptimo para la ciudad.

En cuanto a los criterios, estos han sido previamente descritos en detalle ya que corresponden a los indicadores de impacto seleccionados para la evaluación de impacto multi-criterio llevado a cabo.

Finalmente, las alternativas en este caso corresponden a cada uno de los escenarios de transición definidos y evaluados para la ciudad.

- Desarrollar la Matriz de Comparación por pares de los criterios estableciendo la importancia relativa entre los dos criterios comparados en cada caso siguiendo el *rating scale* entre 1 y 9 propuesto por Saaty.
- Desarrollar la Matriz Normalizada dividiendo cada valor de cada fila de la Matriz de Comparación por Pares por la suma total de cada fila correspondiente.
- Desarrollar el vector de Prioridad *(Eigenvector o Relative Value Vector)* para cada Criterio calculando el promedio de cada fila de la Matriz Normalizada.
- Evaluar la consistencia de la evaluación llevada a cabo en la Matriz de Comparación por Pares a través de la evaluación del cociente de consistencia.
- Desarrollar para cada una de los criterios a evaluar una Matriz de Comparación de Alternativas de manera similar a la llevada a cabo para el caso de la Matriz de Comparación de Criterios, pasos (2)-(3)-(4). En este caso las alternativas serán cada uno de los escenarios alternativos de transición.

  El valor de cada alternativa para cada criterio se obtendrá de los resultados de los indicadores que se han evaluado en la fase de evaluación de impacto. Estos valores proporcionan un criterio cuantitativo que puede ser utilizado como base para determinar la importancia relativa de cada una de las alternativas para cada uno de los criterios. Es decir, se pueden utilizar los resultados de cada alternativa para la normalización de los diferentes criterios. Para ello uno de los procedimientos comúnmente utilizados es el de dividir los valores de cada alternativa para cada criterio por su valor óptimo considerando todas las alternativas (escenarios) evaluadas. Este paso lo realizará el analista mediante la interpretación de los resultados obtenidos en el modelo.
- Desarrollar la matriz de prioridad de las alternativas *(Option Performance Matrix)* con los resultados *(Eigenvector)* obtenidos en el paso anterior para cada criterio. Esta matriz tendrá las alternativas por fila y los criterios por columna.
- Desarrollar un vector de prioridad global *(Value For Money Vector)* multiplicando el vector de prioridad de criterios por la matriz de prioridad de las alternativas.

3.8. Definición, ejecución y monitorización del plan

Una vez llevadas a cabo las fases anteriores que incluyen la evaluación necesaria para establecer un plan de transición energética sostenible de ciudades, quedaría pendiente la propia ejecución del plan con las correspondientes implementaciones de tecnologías e intervenciones a lo largo del periodo de transición. Además, se deberá llevar a cabo la monitorización del proceso de implementación con el objetivo de hacer un seguimiento del cumplimiento de los hitos establecidos y de la consecución de los objetivos establecidos por el plan.

El plan deberá incluir de manera descriptiva el resultado de la aplicación de las fases anteriores, incluyendo la información de contexto de la ciudad, el análisis de la situación base, los objetivos y la visión de futuro. También deberá incluir una breve descripción del proceso seguido para la identificación y selección de intervenciones así como del proceso de definición y priorización de escenarios. De este modo el escenario seleccionado será detallado a nivel técnico incluyendo también aspectos relacionados con la implementación de intervenciones como la fecha de inicio de las obras y la duración esperada para las mismas.

La fase de ejecución del plan es el periodo en el cual se llevan a cabo las implementaciones reales de todas las intervenciones que han sido finalmente seleccionadas. La fase de monitorización en cambio debe comprobar que el plan se está llevando a cabo según lo previsto y que se están obteniendo los resultados esperados. Esta monitorización puede distinguirse en dos grandes bloques. Por un lado se debe contemplar la monitorización de las propias intervenciones a un nivel más específico donde se medirán para cada caso los parámetros técnicos (temperaturas, flujos de calor, consumos, etc.). Estas medidas servirán como base para la evaluación del comportamiento energético de los sistemas así como para la optimización de su operación. En esta misma fase se llevará a cabo la monitorización tanto ambiental como social y económica de cada una de las intervenciones. El segundo nivel de monitorización corresponde a la ciudad en su conjunto. Los KPI definidos a nivel de ciudad y que han sido utilizados para hacer una evaluación de la situación inicial de la ciudad deben ser evaluados a lo largo del periodo de transición. El objetivo es comprender el modo en el que estos indicadores evolucionan a lo largo del tiempo, ya sea por la implementación de las intervenciones contempladas en el escenario de transición como por otros aspectos asociados a la evolución de cada ciudad. Mayor detalle del proceso a seguir para la monitorización puede ser consultado en las guías de CONCERTO así como en los entregables públicos del proyecto Replicate (Replicate project, 2017) a los que se ha contribuido activamente con la investigación llevada a cabo en esta tesis.

CHAPTER 4

Validation of the methodology

4. Chapter 4: Validation of the methodology

In this chapter, the sustainability assessment framework of city energy transition scenarios defined in this research is applied to the case study of Donostia-San Sebastián. The chapter aims to test the different stages of the methodology with a real case study and discusses its usability and sensitivity in terms of the prioritisation of city energy transition scenarios.

Following the steps proposed in the methodology, the validation begins with an overview of the city context. The current status and the long-term vision of the city are evaluated, focusing mainly on the socioeconomic aspects and on the use of energy. Once the objectives and the scope of the study are defined in the second step, the evaluation focuses on the analysis of the selected six districts, identifying the potential interventions for the composition of scenarios. Finally, the defined 68 potential scenarios are evaluated and prioritised in order to fulfil the city's objectives. The definition, execution, and monitoring stages are beyond the scope of the validation.

The next figure shows the stages of the energy planning framework included in the analysis of this chapter.

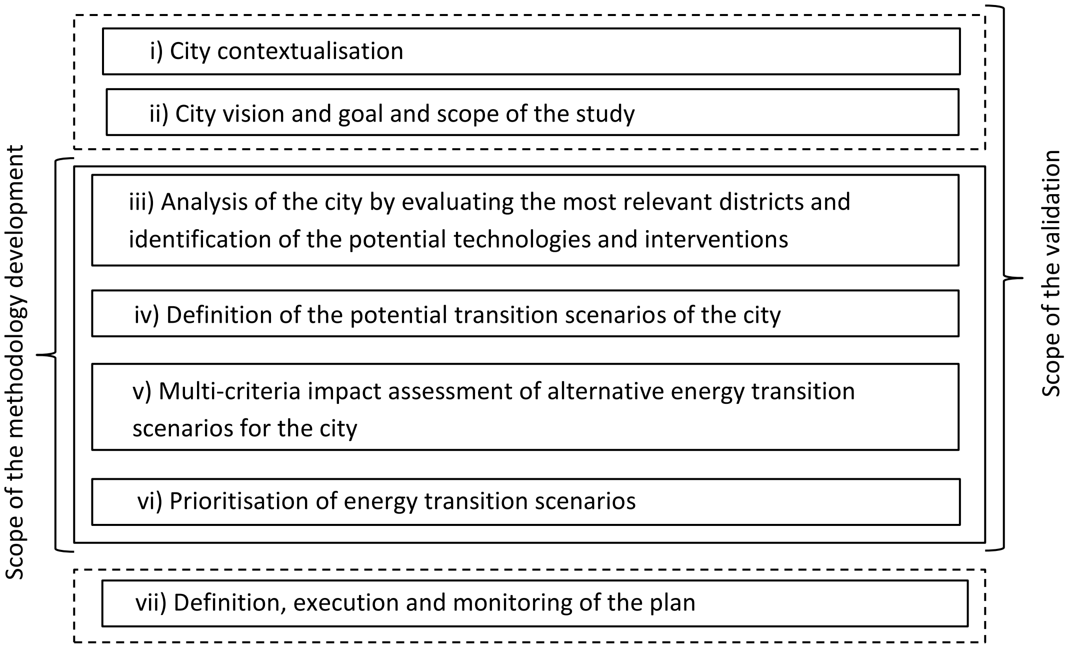

Figure 34. Stages of the methodology included in the validation chapter.

4.1. City contextualisation

4.1.1. General description of the city

Donostia-San Sebastián is the capital of the province of the Basque Country in the north of Spain. The population of the city is 186095, and it covers an area of 61km^2. It also has an important influence on its metropolitan area of over 436500 inhabitants. The city has expanded over the years from its historical centre, as a conglomeration of a series of built-up areas with very diverse characteristics, ages and uses.

Currently, the city is well known for its tourism, gastronomy, and cultural events as well as for its various research & development centres that contribute to implementing and developing new business opportunities and offering high-quality jobs to over 4000 people. The specialisation strategies of the city began to be consolidated as a consequence of the urban clustering policies lead by the municipality in 2008. Since then, the city has been gaining experience in the fields of smart energy and sustainable mobility, among other areas, and has received awards several times at the national and international level.

There is a wide range of indicators and measurements that are used to describe the characteristics of a given population. Here, the most relevant aspects of the general contextualisation of the city are described.

The population decrease that occurred in the 1970s has been reversed and the city has gradually grown in population in the last few decades. In recent years, the city has seen an annual population growth rate of 0.3%.

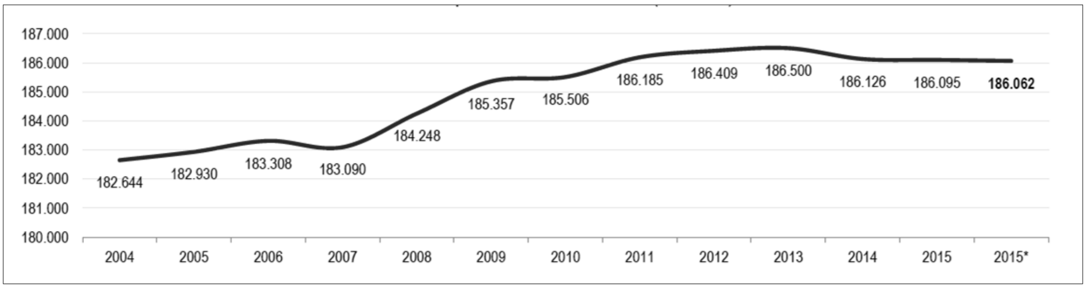

Figure 35. Demographic trend in Donostia-San Sebastián from 2004 to 2015 (INE, 2015).

The age pyramid of the city has also changed to a progressive trend of an aging population.

One of the reasons for this is that the city's fertility rate has decreased to a level lower than the European average.

Moreover, life expectancy has increased due to improvements in the quality of life. This is illustrated in the Figure 36 for both the male and female population.

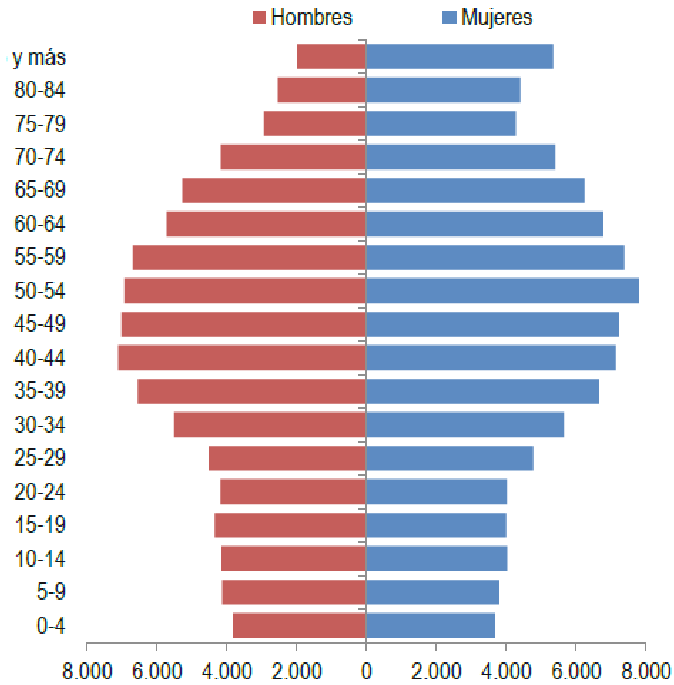

Figure 36. Age pyramid of Donostia-San Sebastián in 2015 (INE, 2015).

In contrast to the situation in the rest of the Basque region, industrial activity in the city is not so important. In fact, the service sector is the most important one for economic activity and employment in the city. This is reflected in city's economic activities and the sectoral added value, where the relevance of sanitary activities, education, commerce, hostelry, and financial activities, among others, is evidenced (Table 11). It is also remarkable that the total economic effort of the city dedicated to R&D activities was the 2.36% of GDP in 2014 (Eustat, 2015).

The recovery of economic activity in the city is reflected by an increase of 3.1% in GDP generated in 2015 (Fomento San Sebastián, 2015).

Regarding the evolution of the city's employment, despite the losses that have occurred in the industrial, energy, and construction sectors, the new jobs created in the services sector have produced an overall positive trend in the last few years, with a rate of increase of 2.5% being achieved. The main reason for this is the high relative importance of the service sector in employment with more than 91% of all employees employed in that sector. The construction and the energy sectors only account for 3.9% and 4.3% of employment respectively and primary sector activities are responsible for 0.2%. Therefore, the needs of the productive structure of the city and the citizens are the core of the service activity.

Table 11. Sectoral distribution of the GDP of Donostia-San Sebastián in 2013-2014 (Fomento San Sebastián, 2015).

Sectoral distribution of the GDP of Donostia (%)	**2013**	**2014**
Services to other productive activities	**27.1**	**27**
- Financial and insurance activities	8	8.2
- Consultancy and technical activities and engineering	5.7	5.7
- Transport and storage	4	3.9
- Administrative and auxiliary services	3	3
- Programming and consulting and computer services	1.7	1.6
- Other professional services activities	1.4	1.4
- Investigation and development	1.1	1
- Editing, image, radio and television	1.2	1.2
- Financial and insurance activities	1	1
Non-market services	**35.5**	**35.6**
- Health activities	12.9	12.8
- Education	11.8	12
- Public administration	8.5	8.4
- Social services	2,3	2.4
Market services to people	**22.7**	**23.1**
- Trade (wholesale and retail, sales / vehicles)	11.7	12
- Hostelry	5.5	5.7
- Artistic, recreational and entertainment activities.	2.1	2
- Other services to people	2	2
- Activities of households as employers	1.4	1.4
Industry	**5.9**	**5.5**
Construction	**5.6**	**5.7**
Energy and water	**3.1**	**2.9**
Primary sector	**0.1**	**0.1**

The recovery in economic activity and employment is reflected also in the increase in the number of businesses in recent years. Current figures show that there are 18870 businesses (DIRAE, Eustat, 2015). These businesses relate mainly to the service sector (87.3%). The remainder corresponds to construction and industrial activities. In general, San Sebastián has had the best labour market performance of the Basque cities in 2015, with an unemployment rate of 11.2% (Lanbide, 2015).

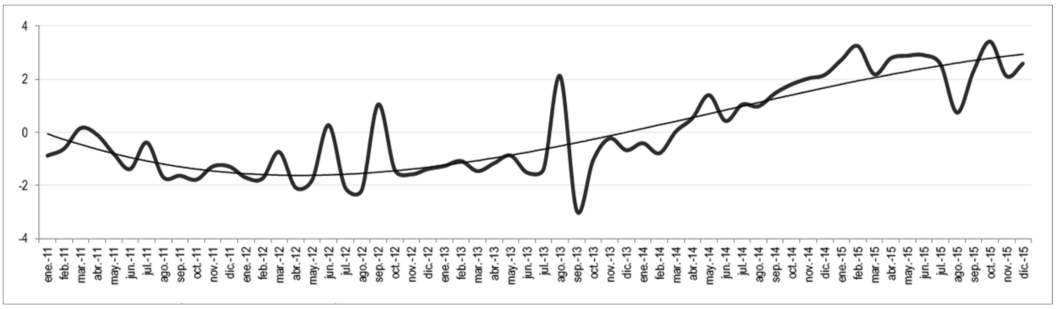

Figure 37. Monthly trends in employment in Donostia-San Sebastián from 2011 to 2015 (Fomento San Sebastián, 2015).

Figure 37 shows the development of the city's labour market where a positive trend over the year can be observed. The unemployment rate has decreased but the effect was more notable among males than females and among the population aged under 25 and between 25 to 44 than for the population aged over 44.

City's energy consumption, on the other hand, has seen an increase in recent decades. In 2014, with a 3420 GWh/year of final energy consumption, the city's main energy user sector was the transport one (58%), followed by the residential (20%) and services sectors (14%). The industrial sector used 8%. One of the characteristics of the residential sector is that a significant part of the existing building stock is more than 50 years' old, so has much potential for energy savings. With regard to fuel type, as is shown in Figure 38, the main one corresponds to gas oil and electricity, followed by natural gas.

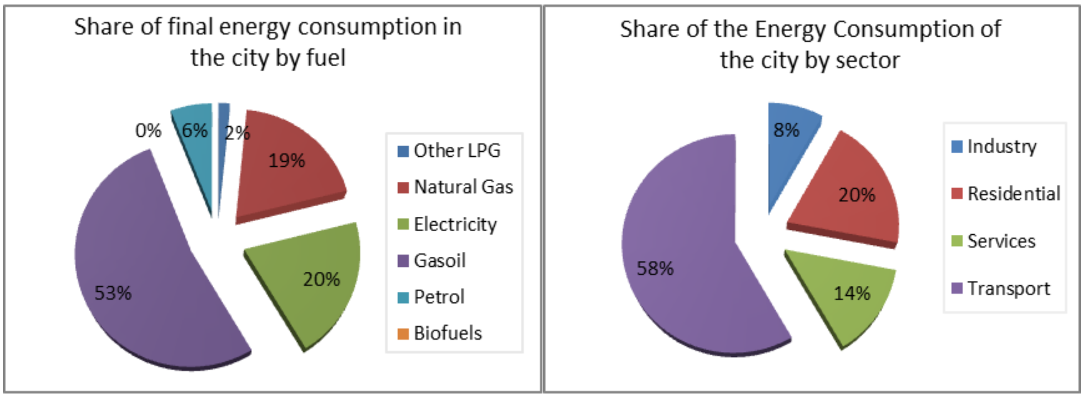

Figure 38. Share of the primary energy consumption by fuel (left) and share of the energy consumption by sector (right) of Donostia- San Sebastián in 2014. Adapted from (Replicate project, 2017).

The change in the city's electricity and natural gas consumption is presented in Figure 39. Electricity consumption saw an annual increase of around 3% until 2009, when this tendency changed. In 2014, energy consumption started increasing again, reaching its current profile. The service sector is the main contributor to this electricity consumption at 51%, followed by the residential sector, at 35% and industry, at 14%. Natural gas consumption, on the other hand, rose in 2009 after the sharp decline suffered in 2008. The consumption stabilised from then until 2013, when it started changing to the current profiles. The residential sector is the main one responsible for natural consumption in the city, at 45%, followed by the services sector at 31%, and the industrial, at 24%.

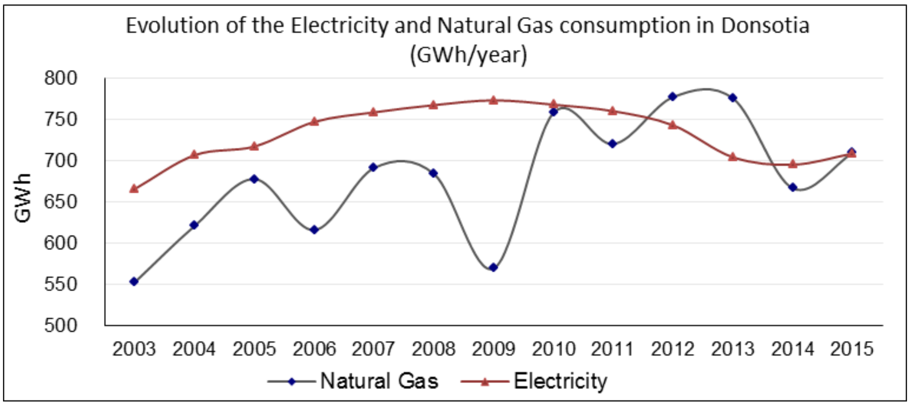

Figure 39. Electricity and natural gas consumption in Donostia-San Sebastián from 2003 to 2015. Adapted from (Fundación Cristina Enea, 2015).

Renewable energy generation in the city is low. Figure 40 shows the change in energy generation by source. The most remarkable change is the decrease in biogas generation in the San Marcos landfill site since 2009. The proportion of generation types has changed in the last decade. Currently, 30% of the generation is biogas; 26% biomass; 20% solar photovoltaic; 17% geothermal; 7% solar thermal; and the remainder, small wind turbines.

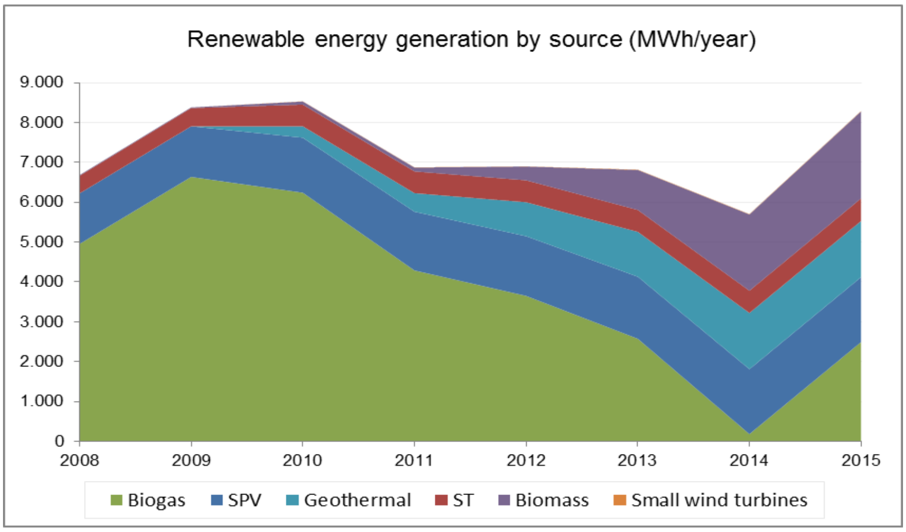

Figure 40. Renewable energy generation in Donostia-San Sebastián between 2008 and 2015. Adapted from the (Fundación Cristina Enea, 2015).

Despite being outside the scope of the study, mobility in the city is also relevant for contextualizing energy use in the city. In this sense, private cars and motorbikes are clearly the most used vehicles in the city (92%). However, the modal split of the city shows that most of the trips in the city are on foot and that public transport and bicycle usages is increasing in recent years. Moreover, although the current rates are low, alternative transport is being introduced around the city in the last few years with hybrid and electric vehicles as well as the EV-charging infrastructures.

Finally, in terms of (GHG) emission per capita, the city has seen a constant decreasing tedency since 2007. In the last two years, these values have stabilised.The transport (42%) and industrial (28%) sectors are the main contributors, followed by residential (13%), services (9%) and waste (8%).

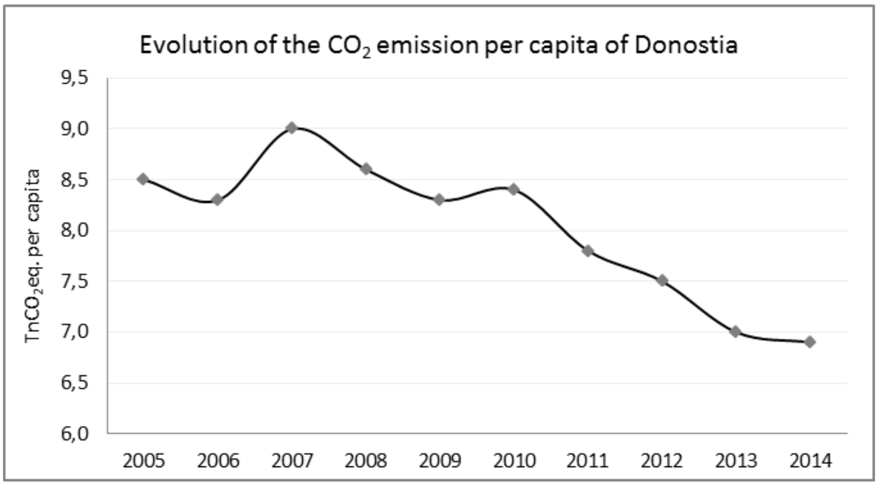

Figure 41. Change in CO_2 emissions per capita in Donostia-San Sebastián in the period 2005-2014. Adapted from (Fundación Cristina Enea, 2015).

4.2. City vision and goal and scope of the study

4.2.1. City vision and objectives

In terms of a socioeconomic and environmental context, the Donostia-San Sebastián authorities are aware that they must play their part in reducing carbon emissions. This will contribute to meet the Paris Agreement target of keeping a global temperature rise below two degrees Celsius in this century. The long-term city vision of Donostia-San Sebastián has guided the decisions of the municipality in the last few decades in aligning the priorities for the formulation of all its strategies and plans. In this sense, the city has been a pioneer in the development and implementation of policies oriented to sustainability. These are the main initiatives in this regard:

- 2002: Approval of the plan, Local Agenda 21 (2002-2007)
- 2004: Strategic Plan 2004-2010
- 2007: Second Action Plan, Local Agenda 21 (2008-2013)
- 2007: Local Plan against Climate Change (2008-2013)
- 2008: Sustainable Urban Mobility Plan (2008-2024)
- 2008: Signature of the Covenant of Mayors
- 2011: 2020 Strategic Plan of Donostia
- 2011: Sustainable Energy Action Plan (SEAP)
- 2015: Environment Strategy 2030. Donostia Hiri Berdea 2030
- 2015: Smart City Donostia 2016-2020. Strategy and Action Plan

The last strategic plan of the city is the outcome of work carried out from a holistic viewpoint and engaging over 160 stakeholders/citizens. The plan shows that Donostia-San Sebastián remains committed to embedding sustainability across all the activities of the city. Based on current activities, on the idea of smart specialisation, and with the aim of developing local capacities, the city seeks to increase its productive activity in a more sustainable way. Smart energy, ICTs, creative economy, and R&D are important element of the city's strategy.

To conclude, the plans show that the city is committed by 2030 to reducing 30% of CO_2 emissions, to increasing the share of the renewable energy to 20%, and to reducing energy consumption by 20% compared to 2007. For the long term, there are no specific targets (to 2050) that can be used for this study. Nevertheless, on the energy axis, the following actions can be identified as general priorities for the city:

- Polygeneration and distributed generation
- Participation in the generation, distribution and commercialisation of energy
- Development of close to zero energy consumption districts
- Exemplarity and efficiency in municipal facilities

4.2.2. Goal and scope definition

Goal of the study

The study's goal is to identify the optimum energy transition scenario for Donsotia-San Sebastián that will guide the city towards a low carbon future. The results will be used to provide criteria to the municipality for the prioritisation of alternative scenarios during decission-making in the context of the city's energy planning.

Scope of the study

The study's scope is limited in this case by the system boundaries. System boundaries determine the aspects that are taken into account for the object of assessment, which in this case, is the multi-criteria analysis of city energy transition scenarios.

In the study, a triple perspective is proposed for defining the boundaries:

- Boundaries regarding the scale of application

As proposed in the methodology, three different scales are used in the study; intervention scale, the city scale, and the regional scale. The intervention scale covers the deployment of technology along a defined transition period and for the interventions identified in section 4.3.3 'Identification of the potential technologies and interventions'. The city scale, on the other hand, can be understood as an aggregation of districts. For the analysis six districts of Donostia-San Sebastián are evaluated in detail, covering more than the 40% of the city's building stock. The districts included in the analysis are Amara, Cortazar, Antiguo, Gros, Txomin Enea, and Aldezaharra. Finally, the regional scale of the study corresponds to the Basque Country.

- Boundaries regarding the city areas

The concept of an energy transition scenario for cities is wide enough to generate discussion. The purpose of the study is the reduction of the energy demand and GHG emissions of Donostia-San Sebastián while increasing the use of renewable energy sources by developing and implementing energy technologies and trying to maximise the socioeconomic impact created in the city and in the region.

In this context, several sectors can be considered in the city assessment. However, given the focus of the study, the main object of interest corresponds to the energy supply and demand of the city's building sector. Therefore, energy aspects related to mobility, industry, and the primary sector are outside the scope. Furthermore, in Donostia-San Sebastián, as occurs in most European cities (Ecofys, 2012), the quantity of residential and office buildings is the most relevant factor in the total building stock. Hence, in this study, energy generation distribution and consumption by residential and office buildings are considered.

- Boundaries regarding the dimensions and type of impacts considered

The following table describes the dimensions considered for the analysis. Moreover, the scales and type of impacts that are included in each of the dimensions of the sustainability are described.

Table 12. Impacts considered for each of the three dimensions and for each of the three scales of the study.

	Environmental dimension		**Economic dimension**			**Social dimension**		
	Direct	Indirect	Direct	Indirect	Induced	Direct	Indirect	Induced
Intervention	x	x	x	x				
City	x	x	x	x		x	x	
Region			x	x	x	x	x	x

4.3. Analysis of the city by evaluating the most relevant districts and identification of the potential technologies and interventions

4.3.1. Area of study

The area of study comprises six districts covering more than the 40% of the city's building stock. As is presented in the urban plan, the city has 6105ha that has the following land uses: 1190ha for residential use, with an average density of 70 dwelling per hectare, 164ha for industrial use, 203ha for tertiary use, 140ha for community equipment, 238ha for communication infrastructures, 88ha of open space and 4081ha making up non-urban areas.

This study considers the districts of Amara, Cortazar (Centro), Antiguo-Ondarreta, Gros, Aldezaharra (Parte vieja) and Txomin Enea. The sum of these districts encompasses the most relevant areas of the city in terms of building stock and population. Moreover, it also provides a proper context for the simultaneous evaluation of different areas of the city with very diverse characteristics.

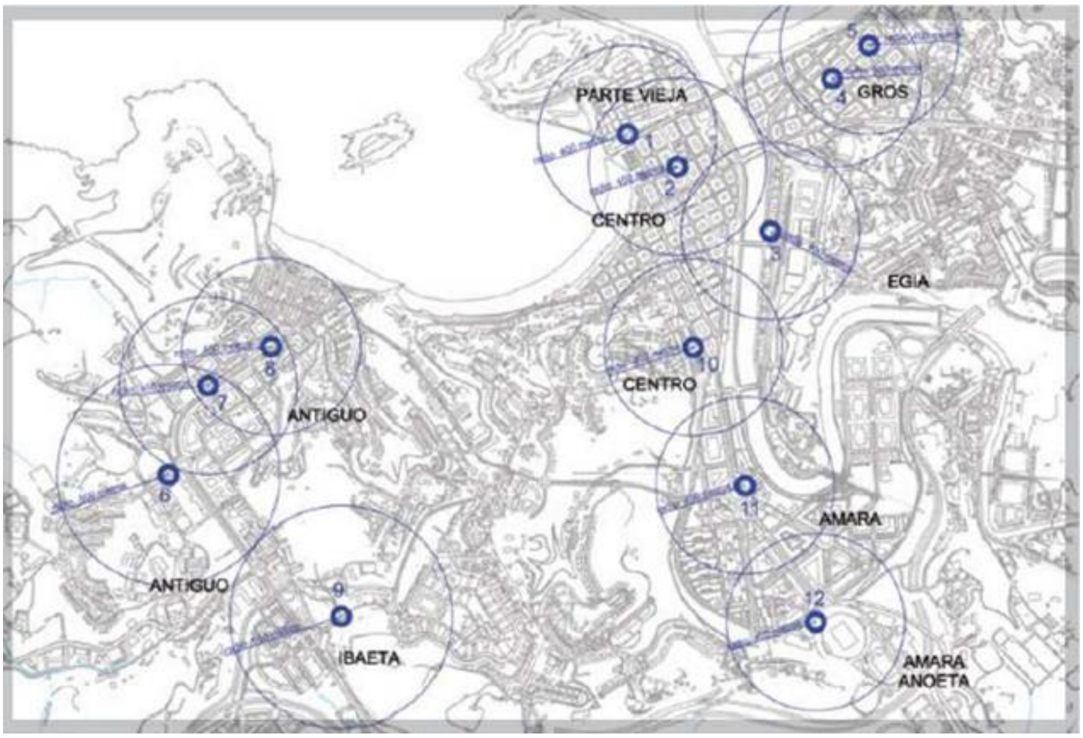

Figure 42. Map of Donostia-San Sebastián.

The **district of Amara,** with an area of 132ha is one of the most relevant districts for the city's residential development. After the enlargement of Amara district was approved in the first general urban plan of Donostia-San Sebastián in 1962, the district increased in density and currently has 9929 dwellings. In addition, with an increase in population size of 1.34% in the last year, Amara continues consolidating as the main district of the city, currently having a population of 29179 (16% of the population of the city's population).

The **districts of Cortazar and Aldezaharra,** with 6215 and 1813 dwellings respectively, and with a total area of 116ha, constitute the old town and the city centre. In the 1990s, this area was the focus of a refurbishment plan. Nowadays, the district has 21947 inhabitants (11.8% of the population of the city) and is the city's main commercial area with 1075 establishments. This district also has the most hostelries.

The district of **Antiguo-Ondarreta**, with an area of 116ha, is one of the districts that has experienced the most change. Some decades ago, it was a residential area with many low-rise building blocks and single-family houses. However, in the 1990s, saw a lot of residential growth and today has 3291 dwellings and 14740 inhabitants (7.9% of the city's population).

The **district of Gros,** constituting an area of around 44ha is one of the most chaotic examples of Donostia-San Sebastián's urbanisation. The district has changed from having very irregular building blocks and a maze of streets saturated by a mix of uses on its ground floors (commercial, garages, and small industries) to having many new residential buildings. The high building density and the wide commercial offering are the main characteristics of the district, which today has 7821 dwellings and 18804 inhabitants (10.1% of the population of the city).

Finally, the **district of Txomin Enea**, covering an area of 11.6ha is a residential one with a mix of several blocks of buildings built in the 1950s that require refurbishment, some industrial buildings, and a few modern buildings. This district is not very relevant in terms of the current building density and inhabitants.

However, it will change significantly in the coming years considering that most of the existing buildings will be refurbished or replaced and that the building of more than 1300 new ones is projected. The development planned for this area close to the River Urumea is focused on restoring the natural environment and replacing the current degraded landscape with the planned residential areas and new sports and cultural facilities. Another interesting characteristic of the district is the planned district heating system that will provide heating and domestic hot water to the entire neighbourhood.

Figure 43. The new residential district of Txomin Enea.

Table 13 shows the main socioeconomic characteristics of the districts evaluated in the study, including demography, employment, economic activity, and income.

Table 13. Socioeconomic characteristics of the most relevant districts studied for Donostia-San Sebastián. Adapted from: Barómetro de Economía Urbana 2015 (Fomento San Sebastián, 2015).

	Amara	Antiguo-Ondarreta	Cortazar & Aldezaharra	Gros	Donostia
DEMOGRAPHY (2015)					
Total population	29,719	14,740	21,947	18,804	186,062
Men	13,624	6,866	9,790	8,447	87,541
Women	16,095	7,874	12,157	10,357	98,521
Foreign population	2,266	798	1,986	1,545	12,263
Population <18	4,522	2,280	2,672	2,210	28,541
Population 18 - 29	3,263	1,691	2,385	2,112	20,851
Population 30 - 64	15,009	7,165	10,447	9,132	94,134
Population >64	6,925	3,604	6,443	5,350	42,536
EMPLOYMENT (2015)					
Unemployment	1,470	605	931	838	9,668
Unemployment rate	10,8	9,1	9,7	10	11,2
ECONOMIC ACTIVITY (2015)					
Commerce	2,255	1,400	4,483	2,414	18,870
% dedicated to services	90%	88%	94%	93%	87%
Persons employed	7,033	5,813	17,337	6,544	88,237
INCOME (2013)					
Average household disposable income	38,417	44,928	40,748	37,949	37,805
Average personal disposable income	18,955	21,918	20,891	18,778	18,313

4.3.2. Energy characterisation of the area of study

Each district is evaluated more in detail in this section, which aims to define the baseline situation of the city. The focus of the baseline is paid in the energy issues of the existing buildings and the energy generation and distribution systems. Considering the lack of specific data on the energy demands and consumption patterns of the area of study, it has been necessary to follow all the stages proposed by the methodology. What follows is an explanation of the main characteristics considered in each stage of the energy characterisation methodology described in section 3.4.1 of Chapter 3.

Stage I: Data gathering:

Table 14 shows the most relevant characteristics of the six districts covered in the study. Data available in the geographic information systems (GIS) (Visor GeoEuskadi, 2017) and the city's cadaster (Cadaster of Gipuzkoa, 2017) have been used to define the characteristics of buildings, such as the area, the use, the age, and the recent refurbishment actions undertaken.

Existing energy efficiency certificates have been also gathered from the regional database (Departamento del Desarrollo Económico y Competitividad del Gobierno Vasco, 2017). This database provides the actual energy efficiency level of each building. Interviews with local authority technicians have been conducted to infer the type of energy generation systems and their energy sources when these are not directly available.

In the case of the district of Txomin Enea, the largest share of the buildings corresponds to new developments that will be carried in the coming years, and, therefore, information on these has been gathered from the Special Urban Plan defined for the district and the viability analysis of the planned district heating system for the area.

Further details of the data gathering process are available in section 6.6.1 of the Appendix.

Table 14. District characteristics obtained from public databases and from the municipality of Donostia-San Sebastián.

	Amara	Cortazar	Antiguo	Gros	Txomin Enea	Alde-zaharra
Residential Buildings (1000 m^2)	885	1.100	599	988	151	239
Office Buildings (1000 m^2)	126	141	26	6	3,5	-
Age of Buildings (%) (<1960; 1960-1980;1980-2000; >2000)	59;41;0;0	94;5;0;1	8;16;22;14	42;44;12;3	7;0;0;93*	100;0;0;0
Existing energy certificates (Nº)	65	34	70	19	0	21
Existing energy certificates grades (%D%E%F%G)	12;66;8;14	9;62;3;26	26;50;1;23	16;47;16;21	n/a	10;48;10;33
Nº of refurbishment interventions	67	36	21	103	10 planned	37
Nº of central heating systems %NG;%OtherLF;	44 83;17	25 87;13	42 90;10	17 67;33	0 n/a	13 77;23
Nº Cooling systems	25	73	24	31	n/a	14
Heating system type:%C%I%P%W*	41;49;9;1	14;62;21;2	21;74;4;0	23;53;22;1	DH*	2;49;46;3

**Note:* In Txomin Enea district, the 93% of the area is related to future planned buildings for residential buildings and the 100% for the office buildings. A district heating (DH) network is planned for the new and refurbished buildings. Heating system type: Central/Individual/punctual/Without.

Stage II: Energy performance assessment.

In this stage, the energy performance of all the residential and office buildings of the districts evaluated has been defined. For those buildings without an energy performance certificate, the procedure defined within stage II of the methodology has been followed, taking into account the information gathered for each building in stage I, as summarised per district in Table 1. The next figure shows the percentage of the considered built areas within each district and the performance level assigned, which varies between grade C and grade G.

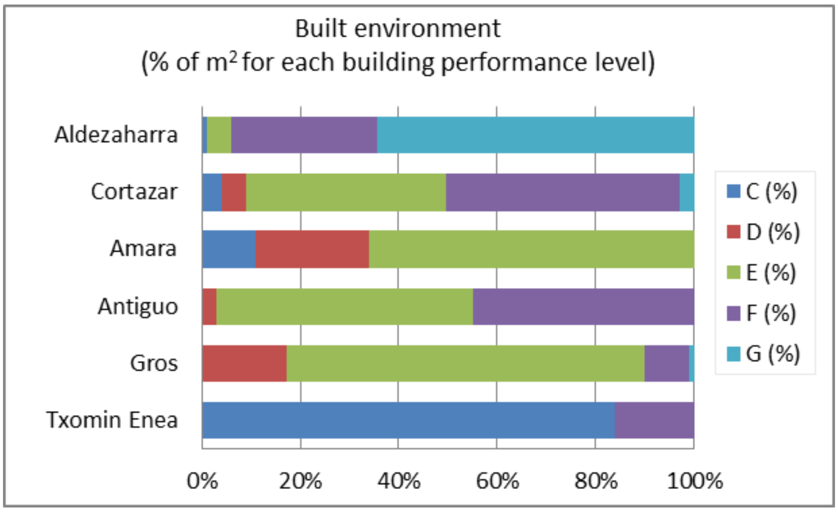

Figure 44. Energy performance levels in the analysed districts as a proportion of the built area with grades (C to G for existing buildings).

Stage III: Reference building definition and modelling:

A total of 10 reference buildings have been defined (five for residential use and five for office use) according to different characteristics and energy efficiency levels in order to cover the majority of the existing building stock of the city for those building typologies. Validation of the energy demands of each reference building has been undertaken according to the specifications of the Spanish regulation on the energy certification of buildings and the Technical Building Code. The resulting heating and cooling energy demands of the defined reference buildings are shown in Table 15. DHW demand is common for all the residential buildings, 13.2 kWh/(m^{2}year), and is considered zero for office buildings. Electricity consumption is 45.4 kWh/(m^{2}year) for residential buildings and 78 kWh/(m^{2}year) for office buildings.

Table 15. Energy demand per energy end-use in residential and office buildings for each energy performance level (grades A to G).

	A	B	C	D	E	F	G
Residential heating (kWh/m^{2}year)	12.6	19.9	31.1	56.5	100.0	120.1	130.6
Office heating (kWh/m^{2}year)	10.0	9.5	14.9	20.7	26.1	32.4	40.2
Office cooling (kWh/m^{2}year)	13.0	14.2	22.3	31.1	39.2	48.6	60.3

The reference buildings have been modelled in the energy analysis, Design Builder Software which is based on the calculations of EnergyPlus. This software calculates on an hourly and sub-hourly basis the heating and cooling loads necessary to maintain internal temperatures as well as other building energy end uses (hot water, appliances).

Further details about the reference building models are available in section 6.1.2 of the Appendix.

Stage IV: Profiling energy use of urban building stock:

Following the use of equation 1 of the methodology for each of the building's energy end uses, hourly demand profiles for each residential and office building within the evaluated districts of the city have been completed. The sum of all the hourly energy demands represents the hourly energy demand of the selected city area. The annual energy demands of the six districts are described according to building use and fuel type in Table 17. Further details about the energy profiles of the building stock are available in the section 6.1.3.

Stage V: Model validation:

In this stage, the district energy demand profiles calculated in previous stages have been complemented by the data gathered in Stage I (Table 14) regarding the type of heating system and the type of fuel consumed. The type of heating system for buildings with unavailable data in Table 14 has been defined according to the distribution of fuels described in Table 16 for each district.

These distributions have been adapted from the province's actual data for the characteristics of each district. The performance of the systems, when unavailable, has been inferred from system energy performance data from the Spanish regulation of energy certification of the existing buildings. Combining demand profiles with system performance characteristics and data allows for the calculation of the hourly energy consumption profiles of the evaluated districts. In the case of Donostia-San Sebastián, only the electricity and natural gas consumed in the residential sector, as shown in Table 16, are used for the validation.

Total district electricity consumption of 128,803.4 MWh/year and natural gas consumption of 209,435.9 MWh/year obtained in the model can be compared with actual measured values in the city. City values are adjusted taking into account the proportion of buildings analysed in relation to the total number of city buildings and issues such as the proportion of unoccupied buildings. For this validation stage, in the case of the district of Txomin Enea only the existing buildings' energy consumption has been considered.

Table 16. Top-down (province and city) data used for the validation of the model.

Heating system type (Province data)*	(%Elec.)	(%NG)	(%OtherLF)	(%Biom.)	
Central	0%	83%	17%	0%	
Individual	9%	78%	8%	5%	
Punctual	100%	0%	0%	0%	
Energy carrier of the heating system & Nº of Buildings	**(%Elec.)**	**(%NG)**	**(%OtherLF)**	**(%Biom.)**	**Number of Buildings**
Donostia	29%	61%	7%	3%	88.207
Aldezaharra	52%	41%	7%	0%	3.332
Cortazar	28%	62%	7%	3%	8.988
Amara	14%	73%	11%	3%	11.639
Antiguo	11%	76%	9%	4%	3.856
Gros	27%	62%	8%	3%	9.581
Txomin Enea	-	35%	-	65%	156 exist. 1.469 new
Unoccupied Buildings* 16%					

Residential sector		Energy Consumption		Energy Demand
	City*	Districts (Proportion of buildings)	Districts (modeled)	Districts (modeled)
Electricity (GWh)	243.4	105.6	128.8	127.5
Natural Gas (GWh)	376.3	136.1	209.4	149.3

Note: The heating system type distribution of this table corresponds to the province level and is adapted later to the city and district levels. The energy consumptions of the city are actual data provided by the energy distribution companies. Actual data (non-adapted) are marked with an asterisk '*' in the table.

<u>Stage VI. Simultaneity effect:</u>

In this stage, simultaneity factors are applied to each type of building (residential and offices) for each energy end-use (heating, DHW, and electricity for lighting and appliances). The simultaneity factor for the residential heating and DHW energy demands have been obtained following the equations proposed by (Tol & Svendsen, 2011) as shown in the Equation 21, where Q_{SHD} is the individual heat demand for each consumer, Q_{SHD} is the heat load for space heating, and $Q_{DHWL(N)}$ is the heat load for domestic hot water. The simultaneity factor used for electricity is that proposed by the national ministry of industry for the provision of capacity for a low voltage electricity supply (Spanish National Ministry of Industry, 2003). For office buildings, the same factors as in the case of residential buildings have been used for heating and hot water use. A factor of 1 has been considered for electricity use in office buildings (no simultaneity effect considered), as proposed by the national Ministry of Industry.

$$Q_{SHL(N)} = \left(0.62 + 0.38/CC_{(N)}\right) x\ CC_{(N)} x\ Q_{SHD}$$

$$Q_{DHWL(N)} = 1.19\ x\ CC_{(N)} + CC_{(N)}^{0.5} + 0.3$$

Equation 21

As a result of the evaluation of simultaneity, the hourly demand profiles calculated in the previous stages are adjusted and the peak loads for the different energy end uses are reduced. This step can serve for studying district and city level peak loads and for providing an input for the design of energy systems. It has to be noted that all of these factors depend on the number of buildings of the same type that are evaluated together.

In this study, the simultaneity factor has been calculated taking into account the buildings within all analysed districts. When using simultaneity factors for other purposes, such as the dimensioning of energy systems for specific city areas, the simultaneity factors should be adapted to the corresponding number of buildings.

The results obtained from the modelling of six districts in Donostia-San Sebastián, including new building developments at Txomin Enea district, allow for the calculating the energy demand of the districts by building typology, by different energy end use, and by fuel type, as shown in Table 17. The main consumption of the districts corresponds to natural gas and electricity use, with other types of fuels having lower usage values.

Table 17. Energy demand of the six districts by building typology, energy end use and fuel type.

Energy demand (GWh/year)					
	Heating	**DHW**	**Cooling**	**Electricity**	
Residential use	198.8	26.7	-	92.6	
Office use	5.2	-	6.5	13.7	
Use of fuel (GWh/year)					
	NG	**Electricity**	**Gas oil**	**Biomass**	**Other LF**
Residential and office use	222.6	152.8	33.3	2	2.1

The results also allow for the observation of hourly energy demand and hourly energy supply for each district and as a whole. Figure 45 shows the hourly profile of the heating energy demand in residential and office buildings for a typical winter week in all the evaluated districts.

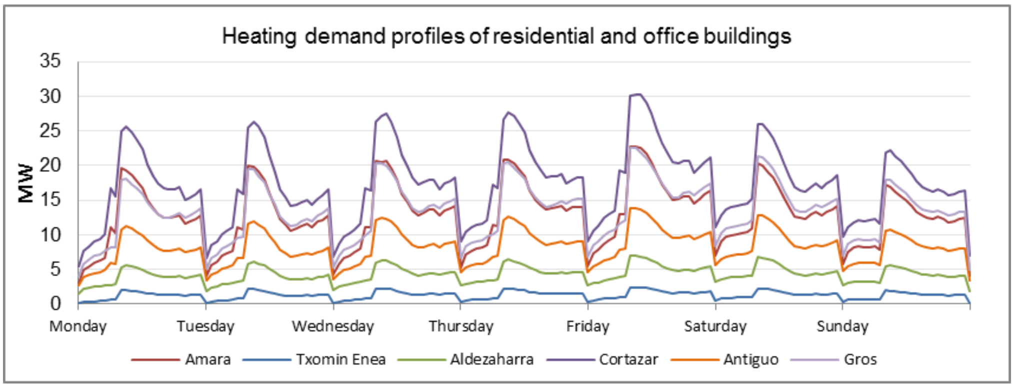

Figure 45. Heating demand loads of the residential and office buildings of the six districts for a typical winter week.

The validation of the model with real measurement results from the whole city shows a reasonable gap between simulated and real results for electricity use, and a larger difference between simulations and real data for natural gas use.

The factors of 0.82 for electricity consumption and of 0.65 for natural gas consumption are, however, in line with the results presented in other studies, such as that by (Majcen et al., 2015), which shows that there are considerable discrepancies between the normalised theoretical energy use calculated from building energy certificates, and actual heating consumption. In fact, this research shows that overestimations of building energy use are particularly relevant for the buildings with the worst energy certificate levels. Therefore, considering that in this case study, the building stock is mainly old buildings with a low energy performance, similar results for overestimating heating energy demand can be observed.

From another point of view, the case-study also demonstrates the relevance of considering the simultaneity effect for the determination of the peak load demand at district and city scales. While there is plenty of research on the importance of this simultaneity effect on electricity generation and distribution systems, examples are not so common on the simultaneity of heating demands. This case study demonstrates the importance that this factor could have for the optimisation of heating systems, especially for the distributed generation at the district scale.

Figure 46 shows the heating peak loads of each district with and without the simultaneity effect. The results show that a maximum reduction in the peak loads of between 36.9% and 38% could be achieved depending on the characteristics of the district in terms of the number of buildings and the proportion in the mix of buildings of different typology and uses. The figure also shows that if all districts shared the same energy generation system, overall peak loads could be reduced up to 46.9% because simultaneity factors decrease peak loads as the number of buildings increases.

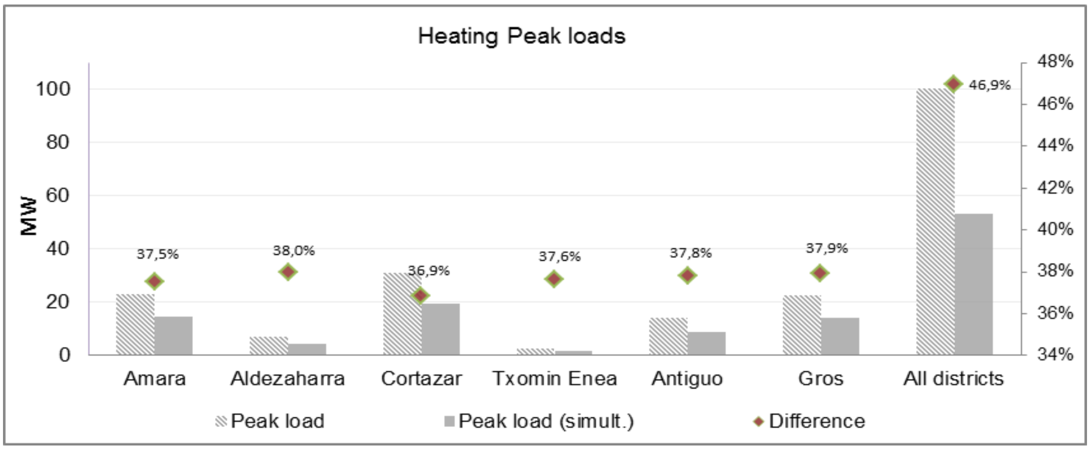

Figure 46. Heating peak loads and their percentage of reduction considering the effect of the simultaneity, for each of the six districts evaluated and for all the districts considered as a whole system.

Figure 47 shows in detail the daily energy peak loads of heating, cooling, and domestic hot water for the total area covered by the six districts considering and not considering the simultaneity effects, and a reduction in peak loads for heating of 46.9% can be clearly observed.

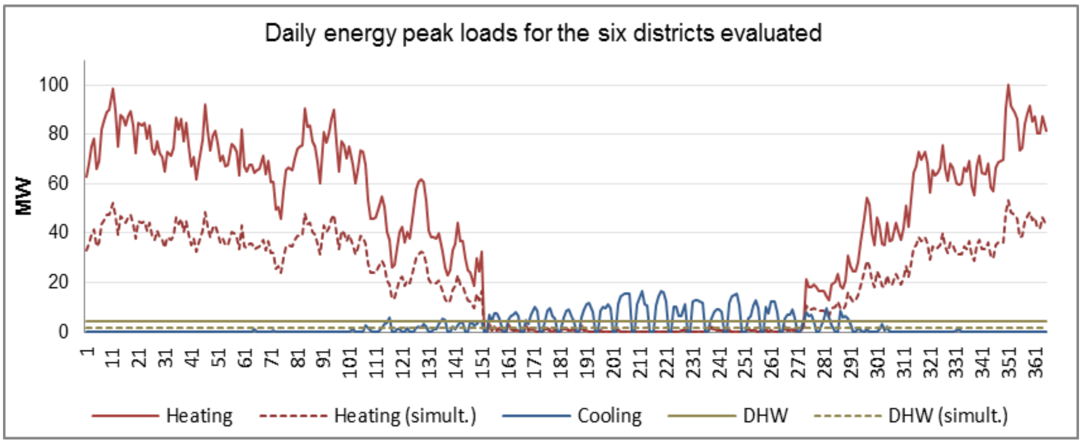

Figure 47. Daily energy peak loads of heating, cooling, and domestic hot water of the six districts considering and not considering the simultaneity effects.

However, considering the aim of the characterisation, the hourly energy demand of the six districts is the main output of this part of the analysis. Figure 48 shows the total energy demand per use for the total area covered by the districts evaluated for the city. This information and the specific hourly energy demand and consumption of each district are used as inputs for the analysis of the use stage of the sustainability assessment.

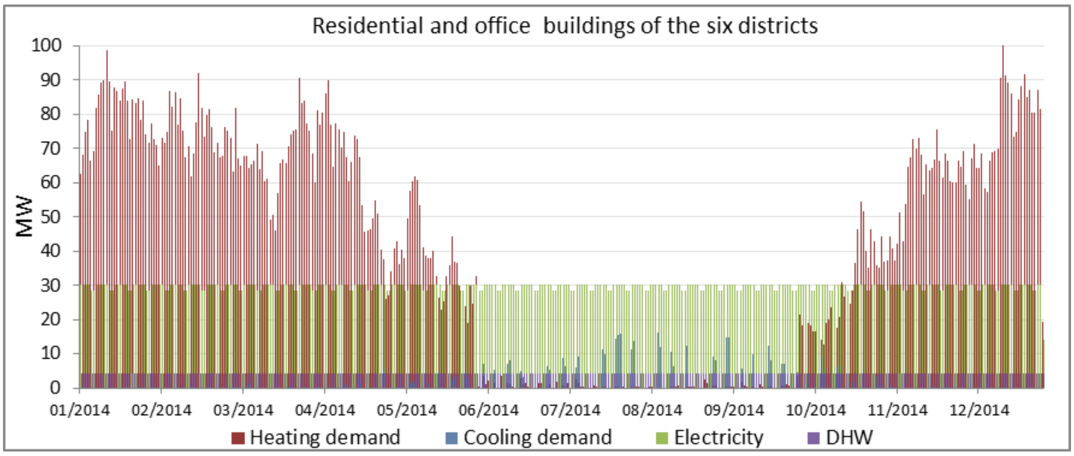

Figure 48. Residential and office buildings heating, cooling and domestic hot water energy demand and electricity consumption for the six districts evaluated.

Further detail with regard to the energy characterisation of the districts evaluated can be seen in section 6.1.3 of the Appendix.

4.3.3. Identification of the potential technologies and interventions

The general objective of the study is the identification of the most appropriate scenario for the transformation of the city towards a low carbon city; thus, the interventions that can help reduce environmental emissions need to be evaluated in principle. Moreover, the scope of the study limits the area of actuation of the energy generation, distribution, and consumption of the building sector of the city. Therefore, the potential interventions will pursue one of the next three objectives: reducing building energy demand, generating and supplying energy in a more efficient way, and increasing the share of the renewable energies in the energy consumption of buildings. Finally, considering that the scope of the study is not limited to the building scale and that the district and city scales are included, interventions such as district-scale energy generation and supply systems are included.

That the validation of the methodology aims to demonstrate the suitability of the methodology for the comparison of interventions and scenarios has to be taken into account. Therefore, the promotion of specific technologies or solutions is completely outside of the scope of the study. Moreover, due to the resource limitations, a reduced set of interventions has been selected for the case of Donostia-San Sebastián. From the broad variety of possible interventions, the selection has been made taking into account the technologies identified in the city's Sustainable Energy Action Plan (SEAP of Donostia, 2011) as it is considered a key document on which the covenant signatory is based and also in considering the priorities set for the energy axis of the Smart City Plan (SC Donostia-San Sebastián, 2015). The technologies described below seek to cover the next three categories: district scale efficient and renewable energy generation and distribution technologies, building scale efficient and renewable energy generation technologies, and passive building interventions.

i) District scale energy generation and distribution technologies
• District heating with combined heat and power, gas-fired (DHCHPNG) • District heating with combined heat and power, wood chips fired (DHCHPB) • District heating with biomass and natural gas boilers (DHNGB) • Central Solar Heating Plants with Seasonal Storage and natural gas boilers (CSHPNG) • Central Solar Heating Plants with Seasonal Storage and biomass boilers (CSHPB)

ii) Building scale energy technologies/interventions
• Natural gas individual heating boilers (INGB) • Natural gas central heating boilers (CNGB) • Biomass central heating boilers (CBB) • Heat pumps (HP) • Solar thermal heating systems (ST) • Solar photovoltaic system (SPV) • Passive interventions for buildings (PIFB)

Figure 49. Interventions included in the study.

<u>Potential technologies and interventions for the study</u>

i) District scale energy generation and distribution technologies

These technologies provide very flexible solutions considering that they are allowed to use any fuel, including renewables, waste heat, and the application of combined heat and power. This aspect offers good opportunities for designing integrated solutions that contribute to the achievement simultaneously the goals of energy saving and the reduction of the environmental impacts.

With this aim, the interventions included in the study under this category, will be applied to the heating and domestic hot water demand of the residential and office buildings. Moreover, in the study, it is considered that the investment related to this type of interventions will be carried out by private companies or by the municipality.

Five different configurations are evaluated:

- District heating with combined heat and power, gas-fired

This solution provides the simultaneous generation of useful thermal heat and power from a single fuel, in this case from natural gas. The cogeneration unit has been defined in order to operate at close to full load most of the time. This configuration also includes natural gas-fired condensing boilers that are used to cover the peak loads of the district. The heat generated is supplied through the district heating network to buildings. Moreover, a storage tank is considered for decoupling the generation of heat and the demand. The electricity generated is used to cover the electricity consumption of the energy generation plant and the electricity surplus sold back into the grid.

For the economic analysis, a cogeneration unit natural gas fired with a reference cost between 700 and 800 €/kWe has been considered for the nominal electric capacity range of the study according to (ETRI, 2014). A cost of 60 €/KW applied to the natural gas boiler for district heating (Danish Energy Agency and Energinet.dk, 2012) has been considered. Finally, the remainder of the costs related to the distribution pipes, trench works, pumping, electric installation, building, substation and management system costs, they have been adapted directly from the economic memory of the projected district heating system for Donostia-San Sebastián (Fomento de San Sebastían, 2015).

- District heating with combined heat and power, wood-chip fired

This configuration is very similar to the previous one but in this case the cogeneration unit operates with wood-chips from forestry. The use of biomass as the heat source for cogeneration allows both the electricity and heat supply to be decarbonised. This configuration also includes natural gas-fired condensing boilers to cover the peak loads of the district's buildings and a heat storage water tank.

In this case, an initial investment cost of 2400 €/kWe was used for the biomass-fired cogeneration units (Obernberger & Thek, 2008). The remainder of the cost assumptions is the same as that of the previous configuration.

- District heating with biomass and natural gas boilers

Only thermal energy is supplied in this case. This solution consists of generating heat in a central generation plant that includes biomass and natural gas fired district heating boilers. Biomass boilers are designed to operate at close to full load most of the time in order to maintain their efficiency as high as possible. In this sense, biomass boilers cover almost 60% of the heating demand. District heating natural gas condensing boilers are included for the peak load hours and the heat storage water tank to decouple the generation and the demand.

In addition to the previously mentioned costs, an investment cost of 500 €/kW is set for the biomass boilers (Danish Energy Agency and Energinet.dk, 2012). The distribution of the CAPEX for all the generation system described so far have been taken according to the database (CYPE). This database provides the price (and the costs breakdown including the cost of subcomponents, installation works, etc.) of all the construction components in Spain including energy generation systems.

- Central Solar Heating Plants with Seasonal Storage and natural gas boilers

This configuration allows heat production for a district heating system from solar radiation. This type of system can produce year-round thermal energy, and with the help of large heat storage systems can achieve significant solar fractions with respect to the district's heating and domestic hot water demand. Four seasonal storage concepts have been successfully demonstrated. In this case, the entire system was defined in order to have a solar fraction near to 40%. However, part of the demand needed to be supplied by an additional generation, covered in this case by district-heating natural gas boilers.

In addition to the aforementioned cost of systems for the supply side, the cost considered for the solar thermal plant varies depending on the dimensions of the total solar field covered. For the study, the curve provided in (EINSTEIN project. D5.5, 2015) has been used. In the same way, the cost per cubic metre of the thermal energy storage solutions varies depending on the type and dimension of the tank. The next figure shows the curves considered in each case.

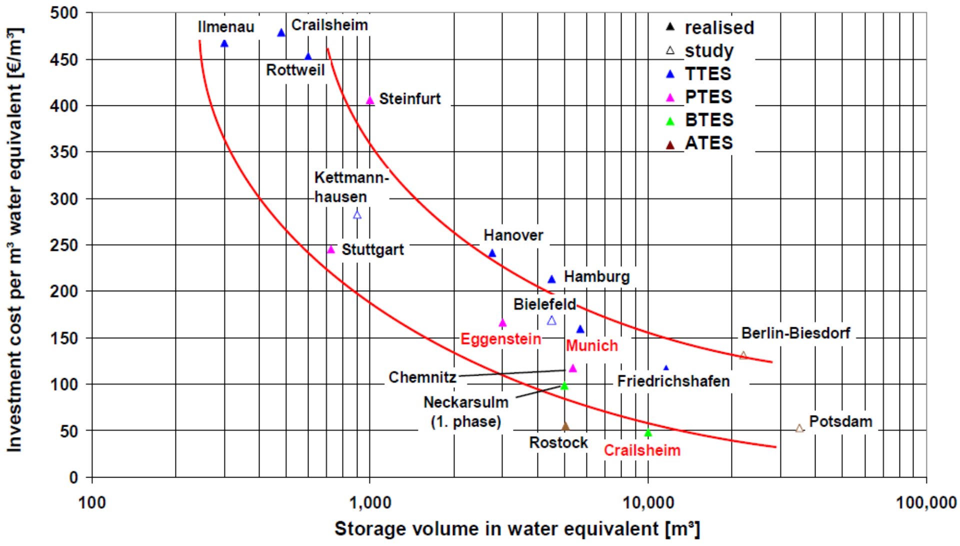

Figure 50. Specific investment cost for STES (Mangold & Schmidt, 2000).

The investment cost of the rest of the equipment has been considered in an integrated way in an increasing factor of 25% with respect to the collector and STES costs (Guadalfajara et al., 2014).

The disaggregation considered for this extra cost is 7% for installation costs, 5% for the building and terrain cost, 10% for the design, project, and related costs, and 3% for the control system costs. The breakdown of the costs of the large-scale storage has been done according to (Mangold, 2017).

- Central Solar Heating Plants with Seasonal Storage and biomass boilers

This configuration is very similar to the previous one, but in this case, the boilers operate with wood-chips from forestry. Therefore, this configuration allows heat to be produced for a district heating system from solar radiation and biomass boilers which heat the water that is stored in the seasonal thermal energy storage system. The system is configured in order to have a solar fraction near to 40%.

ii) Building scale technologies/interventions

The study considers that the investment related to these types of interventions will be covered by citizens. The following three main intervention blocks come under this category.

- Heating boilers and heat pumps

The technologies defined under this category allow for the provision of very specific and oriented characteristics at the building level. Individual systems can be applied to the dwelling scale and central systems at the building scale. As in the case of the district scale interventions, the interventions included in the study under this category are oriented to the heating and domestic hot water demand of the residential and office buildings.

Four different technologies are evaluated. In the case of individual systems, natural gas-fired condensing efficient boilers and air-source heat pumps are included. The initial investment of the boiler adopted is 54 €/kW (market average price) and for the heat pump 500 €/kWe (Danish Energy Agency and Energinet.dk, 2012), with a respective operation and maintenance cost of 1.6% and 4% with regard to the initial investment cost (Ministerio de Fomento de España, 2013).

On the other hand, natural gas-fired condensing central heating boilers and biomass central heating boilers are evaluated. An initial investment cost of 250 €/kW has been adopted for biomass central heating boilers and 54 €/kW for the natural gas-fired boilers (Fomento de San Sebastían, 2015), with an operation and maintenance cost of 1.6%. The distribution of the CAPEX for all the generation systems described under this category has based on the database (CYPE).

- Solar thermal heating systems

For the study, solar thermal systems will act only on the domestic hot water demand of the residential buildings within the area selected. The cost of solar thermal collectors considered is 437 €/m^2, with a project cost of 10%, an annual operation and maintenance cost of 1.5%, and an installation cost of 7% with respect to the CAPEX (SDH, 2012). The distribution of the costs of the CAPEX of the solar system has been considered according to (IEA-ETSAP & IRENA, 2015).

- Solar photovoltaic system

Solar photovoltaic systems will be installed on the roofs of the residential and office buildings for renewable electricity generation. The photovoltaic solar panel cost adopted is 278.9 €/m^2 (Smestad, 2008) with an operation and maintenance cost of 0.5% of the CAPEX (International Energy Agency, 2008). The distribution of costs between the different components of the CAPEX is defined by (Eric et al., 2013).

- Passive interventions for buildings

In contrast with the previously described interventions, passive interventions are oriented to reduce the energy demand of buildings rather than to improve the energy efficiency of the systems. These measures will be critical in the following years in order to move towards the concepts of the Passive House or the Life Cycle Zero Energy Buildings (Hernandez & Kenny, 2010). In this study, the interventions will act only on the heating demand of the residential buildings by window replacement and by improving the thermal insulation of the building envelope. Within this intervention subcategory the combination of the following measures is used in order to decrease the heating energy demand of existing buildings in the area of study depending on their initial situation: Internal energy refurbishment (Basic/ Efficient/Advanced) and window replacement (Advanced) with an initial investment cost of 0.4 (€/(m^2·a), 0.45 (€/(m^2·a), 0.62 (€/(m^2·a) and 0.9 (€/(m^2·a) respectively. The installation costs and the maintenance costs of each measure are 0.13 (€/(m^2·a) and 0.1 (€/(m^2·a) for envelope refurbishment measures and 0.25 (€/(m^2·a) and 0.47 (€/(m^2·a) for window replacement measures respectively (Oregi, 2015).

Analysis of interventions

As described in Chapter 3, in order to select technologies, the first step of the multi-criteria analysis aims to evaluate each potential solution from a viability point of view. The technical specifications and the energy models used for the simulation of the use phase of all the interventions described in this section are detailed in section 6.2.1 of the Appendix.

For considering the life cycle perspective, the following indicators are evaluated: the Cumulative Net Present Cost (CNPC), the Dynamic Payback Period (DPP), the Cumulative Global Warming Potential Reduction (CGWPR), and the Cumulative Non Renewable Primary Energy Reduction (CN-RPER). The phases of the life cycle considered for each component of the interventions are A1-A3, A4-A5, B2, B4, and B6 for the economic analysis and A1-A3, B4 and B6 for the environmental analysis. The results are provided for the reference unit of kWh of Non Renewable Primary Energy savings during the life cycle of the intervention.

Regarding the economic and environmental characterisation of the interventions evaluated, Table 18 describes the main processes used and the lifetime for each intervention.

Additional information is provided in section 6.2.2 of the Appendix regarding the sub-processes of the district heating solutions case.

Table 18. Main processes used in the life cycle analysis.

System	Life time	Product / process	Source	Unit
Solar thermal system	30	Solar system, flat plate collector, multiple dwelling, hot water	Ecoinvent	Unit
Solar photovoltaic system	30	3kWp flat roof installation, single-Si, on roof	Ecoinvent	Unit
Individual natural gas boiler	20	Gas boiler 10 KW	Ecoinvent	Unit
Central natural gas boiler	20	Gas boiler 100 KW	Ecoinvent	Unit
Central biomass boiler	20	Furnace, pellets, 50kW	Ecoinvent	Unit
Heat pump	20	Heat pump 30kW	Ecoinvent	Unit
Building refurbishment	50	Internal energy refurbishment - Basic/ Efficient/Advanced	(Oregi, 2015)	m^2 of building
Building refurbishment	50	Window replacement - Advanced	(Oregi, 2015)	m^2 of building
District heating	50	Supply side, Trench-works, Principal pipes, Surface box, Tap, Pump, Service pipes, Components in buildings	(Oliver-Solà et al., 2009)	Quantity in the scenario
Large Storage	50	polystyrene, expandable, at plant; concrete block, at plant; Reinforcing steel; Chromium steel 18/8, hot rolled;PVC	(Raluy et al., 2014)	Quantity in the scenario

For the environmental impact analysis of the operational phase, the next factors recommended for each final energy source consumed in the building sector of Spain have been used (see Table 19).

Table 19. Global Warming Potential and total and Non-Renewable Primary Energy conversion factors (Ministerios de Industria, Energía y Turismo, 2016).

Energy source	GWP factor (kgCO2/kWh)	PE factor (MJ/kWh)	NRPE factor (MJ/kWh)
Electricity	0,357	8,6508	7,2252
Gasoil	0,311	4,2552	4,2444
Natural Gas	0,252	4,302	4,284
Biomass	0,02	4,068	0,306

i) Reference scenario

The comparison of technologies needs to be done using a common reference scenario. This scenario describes the baseline situation that will be replaced by each intervention evaluated. In this case, the scenario defined corresponds to the situations of the districts of Txomin Enea and Amara for the base year. This provides an appropriate context in which all the interventions can be evaluated. The detailed analysis of each district was provided in the previous section of the article. However, the most relevant parameters of the baseline scenario for the intervention's dimensions are described here: Domestic hot water demand of 8.1GWh/year for solar thermal panels, heating and domestic hot water demand of 55.6GWh/year for the district heating and individual heating systems, and a heated area of 647,818 m^2 for refurbishment interventions in which 31% of the building energy demand corresponds to building with an energy certification level of D, 67% corresponds to E and 2% corresponds to F. All the buildings are refurbished to a level of C.

Moreover, regarding the economic aspects of the reference scenario, the following energy prices (taxes included) defined in (Ministerio de Fomento de España, 2013) have been considered for households: 0.209 euro/kWh for electricity, 0.068 €/kWh for natural gas, 0.096 euro/kWh for gas oil and 0.046 for biomass. From the district heating operator point of view, the cost of energy consumption and the selling price have been defined by direct interviews with operators. An energy cost of 0.05 €/kWh for natural gas, 0.03 euro/kWh for biomass, and 0.133 €/kWh for electricity has been considered. Finally, a price of 0.011 €/kWh for the power generated for sale to the grid and a heat selling fixed price of €18 per dwelling and month and a variable price of 0.06 €/kWh have been defined.

The increase in the rate of the energy price for each fuel used is defined according to the definition of the scenarios of interventions for the transition.

ii) Results of the analysis

The results of the analysis of the potential interventions are presented in Table 20, which distinguishes the indicators selected. Although some of the interventions have a notable performance for individual indicators, it is difficult to affirm from the results that a specific intervention should be prioritised above the rest. The reason is that in many interventions, the good performances of some indicators are opposed by the bad performances of the rest of the indicators.

Table 20. Results of the indicators evaluated for each of the interventions.

	CNPC (€/RU)	DPP (years)	CGWPR (kGCO2eq./RU)	CNR-PER (kWh NR-PR/RU)
SPV	4.5E-02	1.3E+01	1.5E-01	8.8E-01
ST	3.1E-02	1.6E+01	2.1E-01	9.6E-01
PIFB	2.8E-02	2.5E+01	2.1E-01	9.8E-01
INGB	2.0E-02	6.0E+00	2.1E-01	9.4E-01
CNGB	7.0E-03	2.0E+00	2.2E-01	9.9E-01
CBB	1.1E-02	7.0E+00	2.1E-01	9.9E-01
HP	2.7E-02	1.8E+01	2.1E-01	9.7E-01
DHCHPNG	3.9E-01	1.7E+01	1.1E-01	8.1E-01
DHCHPB	2.8E-02	1.7E+01	2.1E-01	9.9E-01
DHNGB	4.7E-02	1.8E+01	2.5E-01	9.8E-01
CSHPNG	3.7E-02	2.1E+01	2.2E-01	9.1E-01
CSHPB	2.2E-02	2.6E+01	2.2E-01	9.5E-01

Moreover, the impact assessment results of many of the evaluated interventions vary depending on the context and boundary conditions defined. One of the clearer examples is the variability of the results depending on the thermal energy demand of the buildings in the area of study. Therefore, the deployment of interventions focused on reducing building energy demand will directly affect the results of many other interventions. This is the reason why each of the interventions needs to have its dimensions set and be designed for the specific operating conditions. Therefore, they have to be evaluated in the different scenarios in which they will be included.

Another consideration that needs to be taken into account is that not all the interventions are mutually exclusive. Their aim and application area can differ.

4.4. Definition of the potential transition scenarios of the city

This section aims to present the alternative energy transition scenarios, concentrating on reducing environmental emissions, decreasing the dependence on fossil fuels, and increasing the socioeconomic development of the city and the region. The background analysis for the scenario development relies on the city baseline evaluation and on interviews with the municipality. The resulting 68 scenarios have different future energy generation mixes and investment choices for the transformation of Donostia-San Sebastián. These scenarios form the input for the multi-criteria analysis of the following section.

The definition of scenarios presented in this section has been carried out considering the effect of several barriers that can limit the implementation level of each intervention. Table 21 shows the relation between the potential barriers evaluated and the interventions that are potentially affected. Further details of the specific information gathered for the analysis of the potential barriers are provided in section 6.6.1 of the Appendix.

Table 21. Relation between the potential barriers that can affect the implementation level of the interventions and interventions potentially affected.

Districts characteristic evaluated		Intervention affected
Building density of the district	→	District heating based interventions
Useful area available in building roofs	→	Solar thermal and photovoltaic systems
Heritage conservation grade of buildings	→	Building refurbishment and solar thermal and photovoltaic systems
Existence of central heating systems	→	Heating/DHW systems for buildings
Recently replaced energy generation system	→	Heating/DHW systems for buildings
Building stock with high energy demand	→	Building refurbishment
Buildings refurbished recently	→	Building refurbishment

This section also includes a description of the main four parameters considered for defining scenarios as well as their evolution during the transition period.

<u>Energy Price escalators</u>

In terms of the reference scenario of the case study, the projections of energy price are adopted from the EU Energy, Transport and GHG Emissions Trends to 2050 as described in Chapter 3.

Discount rate

Based on (EC, 2009), for long-term planning, a discount rate of 4% has been considered. Moreover, discount rates of 3% and 5% have been adopted for the sensitivity analysis of the results.

Energy technology cost trends

As is common in this type of study, where a long-term scenario definition is necessary, it is assumed that technology costs (in real terms) will decrease in the future. Figure 51 shows the considered cost reduction curves in the case study. The lifetime defined for the interventions is 50 years and the transition period considered covers the period from 2017 to 2067. Therefore, it has been assumed that the CAPEX costs remain constant after 2050.

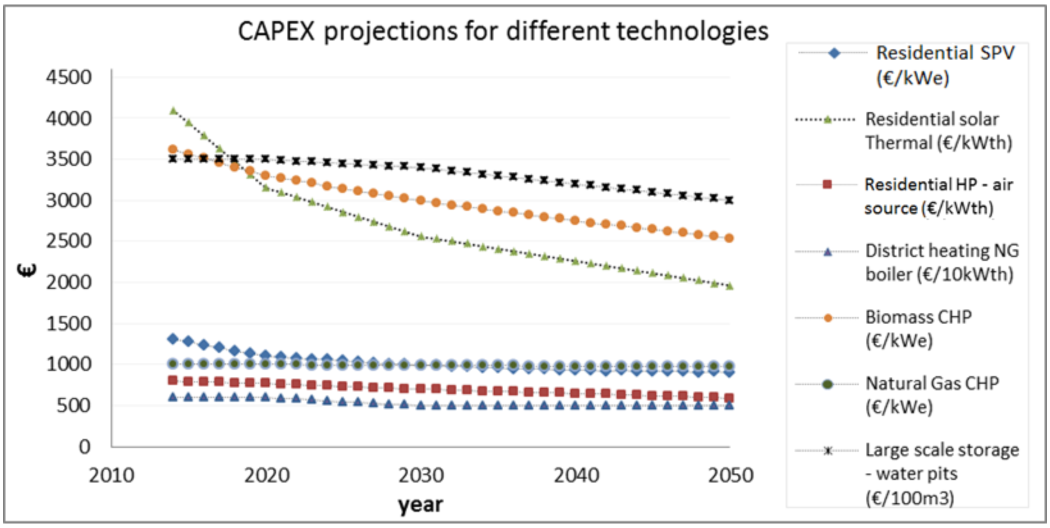

Figure 51. CAPEX projections for different technologies for the time frame 2013 to 2050. Based on (ETRI, 2014) and (Danish Energy Agency & Energinet.dk, 2012).

In the case of individual and central boilers and building refurbishment related interventions, no relevant cost reduction has been considered due to the current maturity level of the technology and the lack of reliable projections. Based on the data provided in this figure the annual cost reduction rate is defined for the transition scenario.

Annual implementation rate of the interventions

The implementation rate of the interventions in the city during the defined transition period will affect the results in several ways. The timing of the implementation of technologies will influence aspects such as the investment moments along the period, the final cash flow, the moment in which the CO_2 emission reduction target was achieved, etcetera. Here, the implementation rates defined for the transition period of 2017 to 2067 of the study are presented. Nevertheless, these implementation rates could be modified in other new sets of alternative scenarios.

As proposed by (Saheb, 2016), an annual implementation rate of nearly 2% has been set for building refurbishment interventions. The hypothesis that boiler replacement and the installation of solar thermal and solar photovoltaic systems follow the same rate is used in the study. In the case of these interventions, the initial investment moment is considered the same as the year of each individual implementation.

For district heating-based interventions, three different rates have been defined for both the connection of the buildings to the network and for the investments. These cases correspond to the three hypotheses considered for the deployment grade of district heating solutions that define in the same way the three main blocks of interventions.

- Rate 1: A connection rate to the district heating networks of 9% (percentage of building energy demand) is set for the case in which only one district is connected. Therefore, based on an existing viability analysis of the district heating in Donostia-San Sebastián, it is assumed that in 11 years all these buildings will be connecting to the network gradually. Moreover, it is considered that the total amount of the investment is made in the beginning of this period.
- Rate 2: A connection rate to the district heating networks of 4% (percentage of building demand) is set for the case in which two districts are connected. All the buildings will be connecting gradually over 24 years. Here, the CAPEX costs are divided into two main parts. The first part corresponds to the 70% of the total investment and it is spent during the first period of 10 years. The remainder of the investment is considered at the beginning of the second period.
- Rate 3: A connection rate to the district heating networks of 3% (percentages of building demand) is set for the case in which three districts are connected. The buildings within the area selected will be connecting gradually over 33 years. As in the previous case, here the CAPEX costs are also divided into the same two main parts.

<u>Definition of the scenario for the analysis</u>

Several transition scenarios are evaluated for the city. Each scenario describes the way in which the different interventions are deployed along the different districts. There are several simple rules that have been followed in order to define whether there is a possibility for the combination of interventions within the same district. For example, no individual boilers, central boilers, or solar thermal systems for DHW will be implemented in districts where district heating interventions are implemented. The building refurbishment and solar photovoltaic systems are evaluated for all the districts (taking into account the possible heritage limitations), and the sum of the roof areas used by the solar thermal systems and the solar photovoltaic systems for buildings cannot exceed the defined maximum area.

Considering the high number of scenarios defined, the following nomenclature structure is used for their identification, 'X'X'X'X'. The first term, **'X'**X'X'X' corresponds to the main groups of scenarios defined depending on the coverage area of the district heating-based interventions. Here, number '1' means that the district heating intervention will affect only the district of Txomin Enea, where the city has already planned the implementation of a district heating network. The number '2' means that the district heating interventions will expand towards a second district thus, the districts of Txomin Enea and Amara are included in this case. Finally, the number '3' means that the district of Txomin Enea, Amara and Cortazar will be covered by this type of intervention. Based on the definition of these three main groups, Table 22 summarises the application area of the different interventions for each scenario group.

Table 22. Main characteristics of the three main blocks in the configuration of scenarios.

	Intervention	Amara	Cortazar	Antiguo	Gros	Txomin Enea	Alde-zaharra
Scenario group 1	Residential solar PV	x	x	x	x	x	x
	Residential ST	x	x	x	x		x
	Building refurbishment	x	x	x	x	x	x
	Individual/central heating and DHW systems	x	x	x	x		x
	DH based interventions					x	
Scenario group 2	Residential solar PV	x	x	x	x	x	x
	Residential ST		x	x	x		x
	Building refurbishment	x	x	x	x	x	x
	Individual/central heating and DHW systems		x	x	x		x
	DH based interventions	x				x	
Scenario group 3	Residential solar PV	x	x	x	x	x	x
	Residential ST			x	x		x
	Building refurbishment	x	x	x	x	x	x
	Individual/central heating and DHW systems			x	x		x
	DH based interventions	x	x			x	

The second term 'X**'X'**X'X', corresponds to the typology or configuration adopted for the district heating-based interventions. Here, 'A' corresponds to a (DHCHPNG), 'B' to a (DHCHPB), 'C' to a (DHNGB), 'D' to a (CSHPNG), and 'E' to a (CSHPB) configuration.

The third term 'X'X**'X'**X', corresponds to the configuration and deployment level of each of the following interventions defined for building scale: the individual natural gas boilers, central natural gas boilers, central biomass boilers, and the heat pumps. Here, four main groups of scenarios have been defined depending on the fuel and systems prioritized.

The number ‘0’, corresponds to a scenario where a compromise solution has been adopted in the fuels used, but the use of biomass resource is prioritised where possible for new systems. Table 23 shows that the 90% (% in energy demand) of the existing individual boilers will be replaced by new condensing natural gas boilers and the 10% by new central heating boilers of biomass. Of the 100% of the existing central heating boilers, natural gas-fired ones will be replaced by new biomass central heating ones. Existing gas oil-fired (and other fossil fuel-fired) individual boilers will be replaced by new natural gas condensing individual boilers. All the existing gas oil-fired central heating boilers will be replaced by biomass central heating boilers and the 100% of the electricity-based heating and DHW systems will be replaced by heat pumps.

Table 23. Main characteristics of the three configurations used in the definition of scenarios regarding the replacement of heating and domestic hot water demand systems.

New technology		Replaced Natural Gas fired boilers		Replaced Gasoil fired boilers		Replaced Electric systems	Replaced Other fuels systems
		Individual	Central	Individual	Central		
Scenario group ‘X’X’0’X’	Individual heating boilers, NG	90%	0%	100%	0%	0%	90%
	Central heating boilers, NG	0%	0%	0%	0%	0%	0%
	Central heating boilers, Biom	10%	100%	0%	100%	0%	10%
	Air source HP	0%	0%	0%	0%	100%	0%
Scenario group ‘X’X’1’X’	Individual heating boilers, NG	100%	0%	100%	0%	100%	100%
	Central heating boilers, NG	0%	100%	0%	100%	0%	0%
	Central heating boilers, Biom	0%	0%	0%	0%	0%	0%
	Air source HP	0%	0%	0%	0%	0%	0%
Scenario group ‘X’X’2’X’	Individual heating boilers, NG	0%	0%	0%	0%	0%	0%
	Central heating boilers, NG	0%	0%	0%	0%	0%	0%
	Central heating boilers, Biom	10%	100%	0%	100%	0%	0%
	Air source HP	90%	0%	100%	0%	100%	100%
Scenario group ‘X’X’3’X’	Individual heating boilers, NG	45%	0%	0%	0%	0%	45%
	Central heating boilers, NG	0%	0%	0%	0%	0%	0%
	Central heating boilers, Biom	10%	100%	0%	100%	0%	10%
	Air source HP	45%	0%	100%	0%	100%	45%

Note: Percentage of demand replaced by the new technology depending on the existing system type.

In the same way, the number ‘1’, corresponds to a scenario in which the use of the natural gas resource is prioritised and the number ‘2’ to a scenario in which the use of the biomass resource is prioritized as shown in Table 23. Finally, the number ‘3’ corresponds to a scenario in which the use of the biomass resource and the heat pumps is prioritised when possible.

The last term 'X'X'X'**X'** is only applied in the case of those scenarios that, according to the results of the analysis of the interventions, will potentially achieve very favourable results in terms of CO_2 emission reduction. This term is related to the proportion in which the available roof space for solar thermal system installation is shared between the solar thermal and the solar photovoltaic systems.

In the case where no parameter is used for this last term, the proportions defined for the reference scenarios are maintained. However, if the term 'a' is added, it means that the space occupied by the solar thermal systems is used to increase the amount of solar photovoltaic systems.

Following this terminology and through all the combination of interventions 68 transition scenarios are defined for the city. Table 24 shows the main characteristics of the scenarios that have been grouped for the occasion.

Table 24. Main common parameters defined for the scenarios. Scenarios are presented in groups depending on their common characteristics.

Scenario groups	**DH systems**			**Individual and central systems**	**Solar systems**	
	Demand (GWh)	**ST in CSHPSS (10^3m^2)**	**DH pipe length (km)**	**Demand (GWh)**	**SPV (10^3m^2)**	**ST (10^3m^2)**
1(ABC)(0123)	5.2	-	2.0	216.5	250.0	34.0
1(EF)(0123)	5.2	5.5	2.0	216.5	250.0	34.0
1(ABC)2a	5.2	-	2.0	216.5	284.0	-
2(ABC)(0123)	55.6	-	14.0	166.3	250.0	25.0
2(EF)(0123)	55.6	38.0	14.0	166.3	250.0	25.0
2(ABC)2a	55.6	-	14.0	166.3	275.0	-
3(ABC)(0123)	122.3	-	25.0	100.3	250.0	15.2
3(EF)(0123)	122.3	77.0	31.0	100.3	250.0	15.2
3(ABC)2a	122.3	-	25.0	100.3	265.2	-

That all the scenarios have the same general characteristics regarding the refurbishment interventions has to be taken into account, considering that refurbishment will be always applied for all the districts.

The total refurbished residential building area is 2.5 million of square metres. The energy demand covered by the area of buildings to be refurbished is broken down as follows: 15% of the demand corresponds to buildings with an energy demand level of ‘D’ according to the values defined, the 57% corresponds to ‘E’, the 24% to ‘F’ and the final 4% to ‘G’.

4.5. Multi-criteria impact assessment of alternative energy transition scenarios of cities

4.5.1. Goal

This impact assessment study aims at evaluating for the three dimensions of the sustainability the impact that the potential energy transition scenarios will have in the city and the region. The results will be used as the main criteria for the prioritisation stage of the methodology.

4.5.2. Reference unit

The main function of an energy transition scenario is to transform the energy matrix of the city during the defined transition period in such a way that the performance of the city is maximised. In this case, the criteria to measure the performance of the city are established by the selected indicators. The reference unit selected for the evaluation of all the impacts and all the scales of the energy transition scenarios is '*the energy transition scenario itself over the period of 50 years'*.

The transition period has been set at 50 years, based on the longer reference service life of the interventions that will compound the scenarios.

4.5.3. System boundaries

The system boundary determines the processes that are taken into account for the object of assessment, which, in this case, covers various dimensions and scales. Table 25 shows the stages of the life cycle considered in each dimension and scale.

Table 25. Stages of the life cycle considered for each of the scales in each dimension.

	A0	A1-A3	A4-A5	B2	B4	B6
Environmental						
Intervention scale		X			X	X
City scale		X			X	X
Economic						
Intervention scale	X	X	X	X	X	X
City scale	X	X	X	X	X	X
Regional scale	X	X	X		X	
Social						
City scale	X	X	X	X	X	X
Regional scale	X	X	X		X	

In the environmental analysis the phases A4-A5 and B2 have not been included since their contribution to the total impacts is not very relevant (as discussed in Chapter 3). In the social and economic dimensions at the regional scale, the only stage considered in the use stage is the replacement of components. Finally, the end-of-life stage has not been considered in the study for any of the dimensions due to the lack of reliable data for many of the interventions evaluated.

4.5.4. Environmental, economic, and social impact assessment

Impact Indicators

Based on the impact categories and indicators proposed in the developed methodology, the indicators that have been included in the LCA, LCC and the macroeconomic and social study are described here.

For Donostia-San Sebastián, nine indicators have been selected for the multi-criteria impact assessment. The socioeconomic assessment at the city scale has been carried out with the following indicators:

- Cumulative Net Present Value (CNPV) in M€/RU
- Dynamic Payback Period (DPP) in years
- Cumulative Net Present Cost-Social (CNPC-S) in M€/RU
- Cumulative Net Present Cost of Public/Private Companies (CNPC-PPC) in M€/RU

The environmental/energetic assessment at the city scale has been carried out through the evaluation of the next three impact indicators:

- Cumulative Global Warming Potential Reduction (CGWPR) in kgCO_2eq/RU
- Cumulative Non Renewable Primary Energy Reduction (CN-RPER) in kWh of NR-PE/RU
- Cumulative distributed renewable and local energy generation (CDRLEG) in kWh/RU

The indicator (CDRLEG) in this case represents the sum of three indicators proposed in the methodology related to the cumulative distributed renewable and low carbon heat and electricity in the city.

For the macroeconomic and social assessment at the regional scale, the next two indicators are evaluated:

- Regional Gross Domestic Product (RGDP) in M€/RU
- Regional Employment (RE) in No. of jobs/RU

Life cycle assessment at city scale

The environmental and economic impacts associated with the energy transition scenarios of the city for the different stages of the life cycle and the calculation of the selected indicators, have been done according to the steps and equations described in section 3.6.5 of Chapter 3.

As proposed in Figure 25 of Chapter 3, the new yearly energy demands and consumption by the city during the period covered by the transition scenario, have been calculated with the same methodology proposed for the baseline analysis described in section 4.3.2 *Energy characterisation of the area of study,* replacing progressively the existing technologies and buildings characteristics defined by the new interventions. New interventions have been evaluated through the energy and techno-economic simulations described in section 4.3.3 *Identification of the potential technologies and interventions.*

Regional macroeconomic and social impact assessment of the energy transition scenarios of the city

This part of the analysis aims at evaluating the cumulative impacts over the 50-year period, associated with the deployment of the interventions of the energy transition scenarios for Donostia-San Sebastián, in the macroeconomic and social development of the Basque Country.

As proposed in the methodology, for this study an existing and flexible Extended Input-Output model has been used, the MIOCIM model (Kratena, 2015). The tool offers different types of analysis. For this study, the direct, indirect and induced impacts are evaluated. In this case it is supposed that an increased labour demand would match a higher labour supply and that the public budget restrictions do not need to be balanced.

The impact assessment has been carried out with the last year of data available of the input-output tables for the Basque Country. Specifically, the supply and demand tables of the Basque Country for 2014 have been used. These tables are the main inputs for the MIOCIM model and are available at (Eustat, 2017). The tables are provided in a classification of 88 sectors and 105 commodities expressed in basic prices and in thousands of euro.

Supply and demand tables include the basic information required to construct the MIOCIM model. This information includes the Domestic intermediate demand, the Imported intermediate demand, the Domestic final demand, the Imported final demand, the Value added per output of each sector, and the distribution of the Employment and the wages by sector. Moreover, the market shares matrix (with the contribution of each industry to the product output) and the technical coefficients matrix (which reflects the direct effects of change in the final demand for a certain commodity) are obtained by the model. A marginal propensity of consumption of 0.6 has been used for the calculations.

Another aspect that needs to be considered is that MIOCIM model works with basic prices but the Basque Country IO tables do not provide information related to the margins of commerce and transport that are needed to transform the costs from purchase prices to basic prices. Here, the margins of the Spanish economy for 2013 have been used. These are available in the national input-output tables (INE, 2016).

Further details regarding the input data and parameters used in the model are available in section 6.4.1 of the Appendix.

Finally, the main input for the IO model considering the purpose of the study is the exogenous demand vectors, called 'shocks'. These vectors will be the main way to provoke a change in the regional model. The following sections describe in detail the composition of the shocks for the interventions and for each energy transition scenario of the city.

- Composition of the shock of interventions for the scenario composition

As explained in the methodology, the shocks are exogenous demand vectors that correspond to investments carried out during the life cycle of the scenarios. The LCC analysis of the interventions and scenarios provides the main information that is needed for their composition. Therefore, for the macroeconomic and social assessment, the same parameters used for the LCC study are used. The parameters include, the discount rate, the energy price escalators, the technology cost evolution, and the implementation rate of the interventions as described above.

Table 26 shows as an example the composition of the shock for the solar thermal technology case. The first step is to consider the cost break-down of the solar thermal systems. In the case of the technology in the example, the break-down of the main components of the initial investment has been made according to the specifications of (IEA-ETSAP & IRENA, 2015).

As the aim is to evaluate the impact of the deployment of this technology during the entire transition period, the cost that is considered for the composition of the shock is all the costs that will occur during the following 50 years due to the yearly newly installed systems and due to the replacement of components. All the costs expressed in purchase prices and discounted to the present. Therefore, the output of the LCC assessment of the technology is used, but considering only the stages A0, A1-A3, A4-A5, and B4. Table 26 shows the break-down of the solar thermal technology components, the assigning of the corresponding commodity in the classification of the Basque Country, the factors used for the transformation of the purchase prices to basic prices (BP/PP), and the import shares.

Finally, the cumulative discounted costs of the intervention in purchase prices ($CDCI^{PP}$) are expressed in euros, divided by the reference unit defined for the interventions.

The assigning of the corresponding commodities from the 105 goods of the Basque Country, to each of the cost components of the intervention has been done according to the NACE code used for the statistical classification of economic activities in the European Community (Eurostat, 2008).

Table 26. Breakdown of the cumulative discounted costs for solar thermal intervention implemented in the transition scenario and the main characteristics used for the composition of the corresponding shock.

Breakdown of components	Stage of the LC	Corresponding Commodity	$CDCI^{PP}$ (€/MWh NR-PE savings)	BP/PP factor	Import share
Project costs	A0	Nº 83	0.82	88%	0%
Solar Collector	A1-A3, B4	Nº 61	3.07	88%	0%
Structure components	A1-A3, B4	Nº 40	1.96	66%	56%
Hydraulic Connections	A1-A3, B4	Nº 44	0.28	60%	64%
Automatic purger	A1-A3, B4	Nº 44	0.28	60%	64%
Security valve	A1-A3, B4	Nº 44	0.19	60%	64%
Storage	A1-A3, B4	Nº 40	1.40	66%	56%
Antifreeze	A1-A3, B4	Nº 26	0.09	65%	74%
Ball Valve	A1-A3, B4	Nº 44	0.09	60%	64%
Tubes	A1-A3, B4	Nº 61	0.93	88%	0%
Insulation	A1-A3, B4	Nº 9	0.74	81%	56%
Heat exchanger	A1-A3, B4	Nº 44	0.28	60%	64%
Installation	A4-A5	Nº 53	0.57	88%	0%

The final composition of the shock is achieved by following the steps described in the methodology. Therefore, the costs in purchase prices are transformed into basic prices and then the import share is applied in order to achieve the final Domestic Cumulative Discounted vector of the intervention.

Following this criteria, the shocks of the interventions that will be included in the study are presented in Table 27. The interventions are presented according to the classification defined in Figure 49. Each of the scenarios that are defined for Donostia-San Sebastián will be formed with different combinations of these interventions that will be implemented in each scenario with different intensities.

Table 27. Cost components breakdown by commodities for the shocks of different interventions, in (€/MWh NR-PE savings).

	SPV	ST	PIFB	INGB	CNGB	CBB	HP	DH-CHPNG	DH-CHPB	DH-NGB	CSHP-NG	CSHP-B
Commodity Classif.	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
Nº 9	0.00	0.26	0.00	0.00	0.00	0.00	0.00	1.31	0.12	0.22	0.16	0.09
Nº 26	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nº 28	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Nº 29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nº 30	0.00	0.00	1.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nº 31	0.00	0.00	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.02
Nº 32	0.00	0.00	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.02
Nº 36	0.00	0.00	0.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nº 40	0.28	0.96	0.00	2.03	0.69	0.94	2.39	9.09	1.58	1.55	0.35	1.61
Nº 42	0.44	0.00	0.00	0.02	0.02	0.03	0.01	1.79	0.17	0.15	0.06	0.03
Nº 44	0.00	0.24	0.00	0.001	0.00	0.02	0.002	1.28	0.12	0.21	0.15	0.08
Nº 53	1.71	0.57	0.00	0.24	0.05	0.10	0.00	1.10	0.14	0.17	0.81	0.44
Nº 59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.80	0.25	0.43	0.66	0.36
Nº 61	0.00	3.51	3.98	0.00	0.00	0.00	0.02	6.27	0.59	1.03	9.36	5.11
Nº 63	0.85	0.38	1.08	0.39	0.14	0.20	0.46	4.15	0.52	0.64	0.62	0.60
Nº 64	2.43	1.09	3.11	1.13	0.39	0.58	1.31	11.92	1.51	1.83	1.78	1.72
Nº 70	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.07
Nº 83	1.40	0.82	0.00	0.13	0.05	0.21	0.33	1.57	0.20	0.24	1.16	0.63

The results show that the most relevant costs that contribute to the definition of the shocks of interventions are concentrated in 18 commodity categories within the classification of the Basque Country. Figure 52 shows in a more visual way the relevance of each commodity classification in the composition of the shock of each intervention.

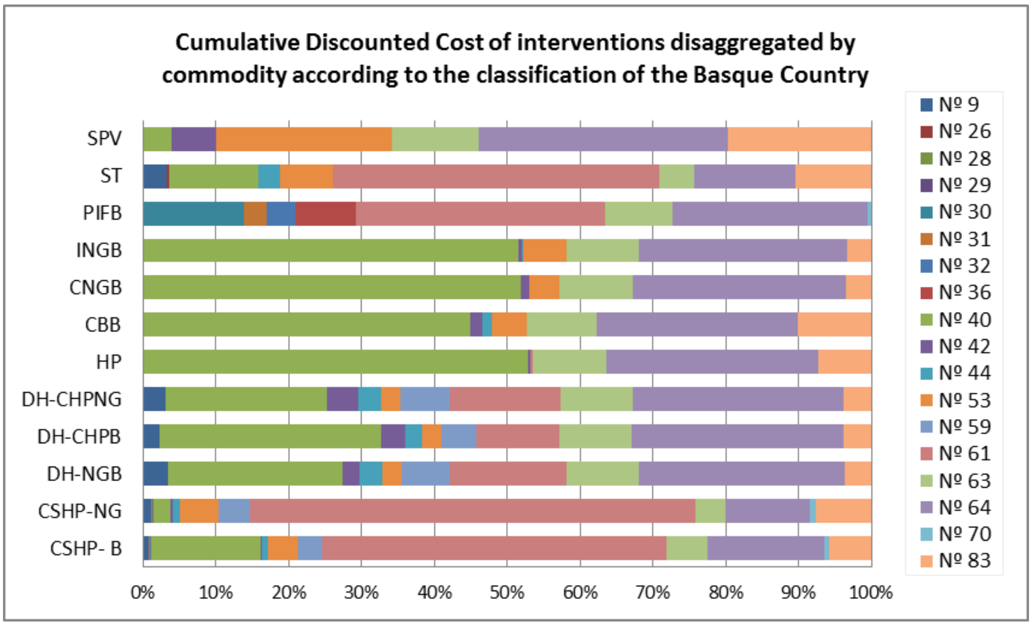

Figure 52. Proportions of the costs components by commodities in the classification of the Basque Country for the shocks of different interventions.

Following the same methodology but referring to the reference unit defined for the transition scenario comparison and extending the analysis from the individual interventions to the energy transition scenarios of Donostia-San Sebastián for a period of 50 years, the shock corresponding to each of the 68 scenarios is evaluated.

Figure 53 shows the composition of the shocks of the alternative scenarios defined for Donostia-San Sebastián, disaggregated by commodity according to the classification of the Basque Country. Differences of up to 27% are seen between the scenarios defined. These are considerable differences taking into account that there are interventions such as the building refurbishment and the solar photovoltaic systems that are included in all the scenarios in order to maximise the obtained emission reduction at the end of the transition period.

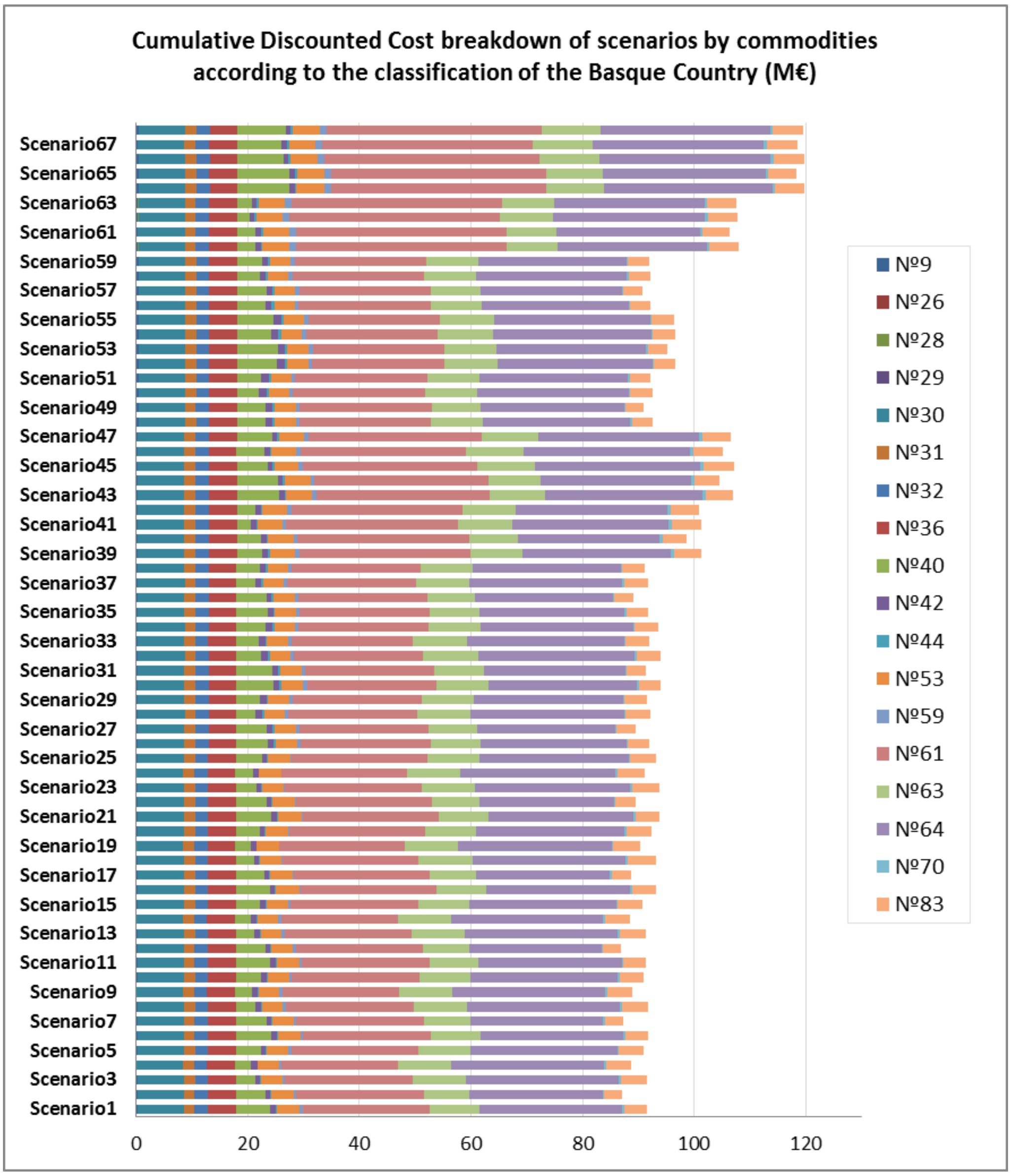

Figure 53. Cumulative Discounted Cost breakdown of scenarios for Donostia-San Sebastián. Breakdown by commodity according to the classification of the Basque Country in millions of euro.

Results of the energy transition scenarios

With regard to the alternative energy transition scenarios, the figures presented in the following pages show the performance of each scenario for each of the evaluated impact indicators. The results are presented directly in this section with no treatment. Hence, no weighting has been applied for any dimension or impact category. These results are used in the following section for the prioritisation phase.

- CNPV impact indicator

Figure 54 shows the result of the cumulative net present value of the alternative energy transition scenarios defined for Donostia-San Sebastián at the end of the period of the transition scenario, which is 2067. Three main clusters can be identified in Figure 54, corresponding to the three main scenario categories defined depending on the proportion between the individual and central heating and DHW systems and the district heating-based solutions. The results show a better performance for the indicators in the case of scenarios with district heating-based interventions. This aspect is directly linked to the different business models associated with each type of intervention. In the case of district heating solutions, the performance of these indicators depends on the designed fixed and variable selling price of the heat, the water heating, and the electricity (in the case of solutions based on cogeneration). Those prices have been designed in this study in such a way that a compromise solution is achieved between the owner/operator and the citizen, but the results are more profitable for the DH owner and the operator. In any case, the relevant variability of the results can be appreciated, with differences of up to 69% between the most extreme scenarios.

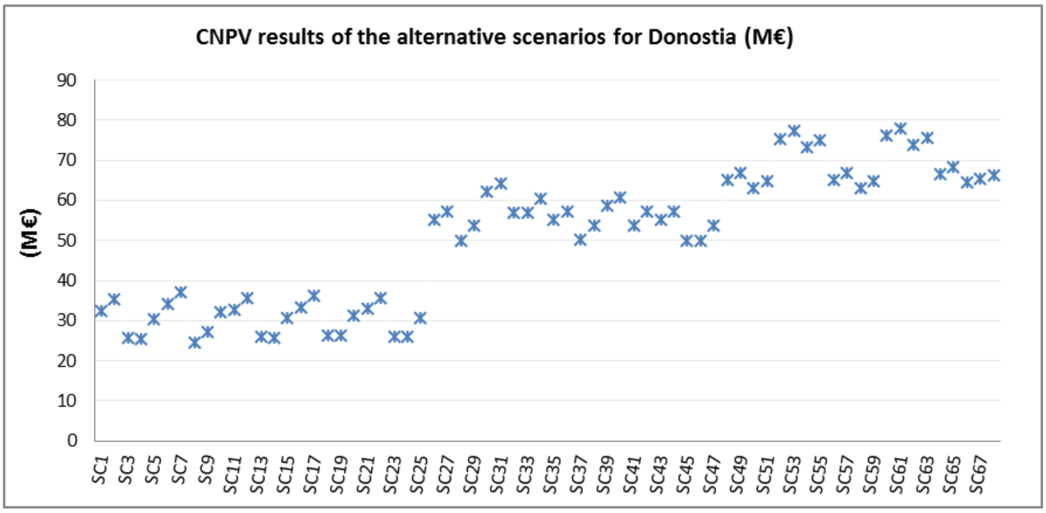

Figure 54 Results of the impact indicator of CNPV for the alternative scenarios for Donostia-San Sebastián in the period 2017-2067.

The application of the methodology allows for greater evaluation of the evolution of the CNPV for each scenario and the contribution of each intervention that compounds it during the transition period. This can be seen in Figure 55, where, as an example, the case of scenario 2.E.1 is presented.

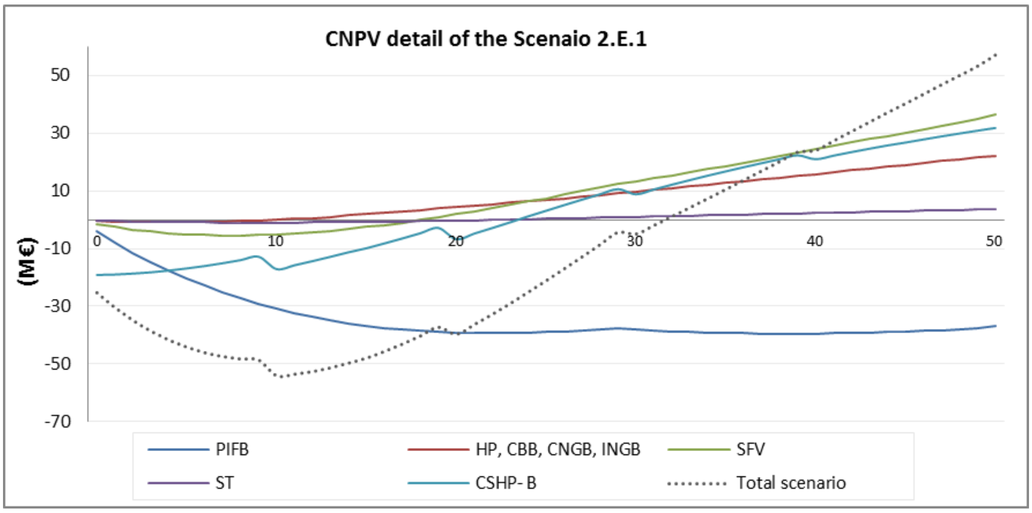

Figure 55. Evolution of the CNPV of scenario 2.E.1 for the city of Donostia-San Sebastián, during the 50 years of the transition period.

- DPP impact indicator

The results of the impact indicator of DPP show that all the scenarios defined for the city in the specified conditions are returned economically within the period of the 50 years. This is evident since the results of the CNPV for all scenarios are positive at the end of the period. This means that although some interventions such as building refurbishment can show (if we analyse them individually) negative values for the CNPV at the end of the transition period, those values are compensated by other technologies, such as the district heating, solar systems, and boilers, as shown in Figure 55. The payback period of the scenarios evaluated shows a variability of up to 29% for a range of 29 to 41 years.

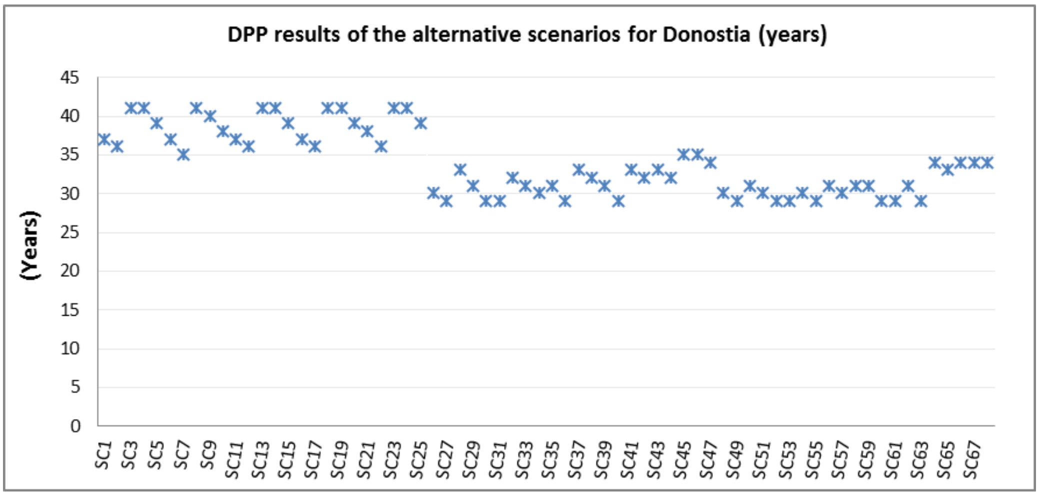

Figure 56. Results of the impact indicator of DPP for the alternative scenarios for Donostia-San Sebastián.

Moreover, it can be said that, as occurs with the impact indicator of the CNPV, scenarios that incorporate interventions based on natural gas, such as individual and central heating boilers and district heating interventions with natural gas-fired boilers, show the best performance in this impact category. Therefore, the results with the worst performance are linked to those scenarios that incorporate a bigger share of biomass resource and the heat pump-related interventions.

- CNPC-S impact indicator

This impact indicator is the one that shows the lowest variability of results, with values of around 6%. Although the differences between scenarios are not very high, a similar clustering of results is appreciated. The main reason for the similarity of results is that the costs from the point of view of the citizens are highly dependent on the costs related to solar photovoltaic and especially, to the refurbishment interventions, both of them included with the same intensity in all the scenarios. Moreover, as mentioned before the fixed and variable costs of the heat and the DHW consumed by the citizens have been set in the case of interventions based on district heating solutions, considering that similar final costs, as with the solutions with boilers, should be achieved.

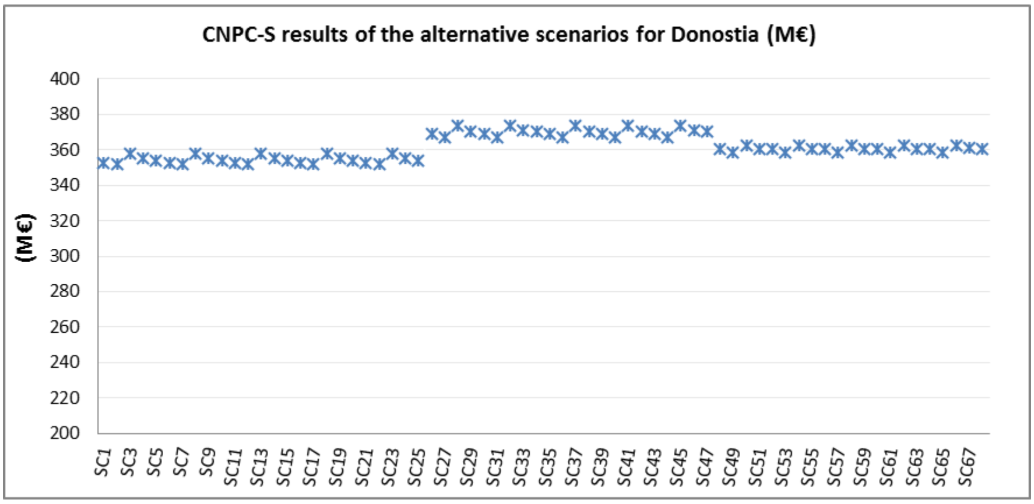

Figure 57. Results of the impact indicator of CNPC-S for the alternative scenarios for Donostia-San Sebastián in the period 2017-2067.

- CNPC-PPC impact indicator

The results in relation to the impact indicator of CNPC-PPC are directly linked to the investments that public or private companies have to make during the transition period. Here, the initial investments, as well as the costs associated with the replacement of components and systems during the entire life cycle of the scenarios, are taken into account. In Figure 58 it can be seen that the aggrupation of scenarios does not correspond exactly to the results of previous impact indicators. Here, the line between the three main groups of scenarios in crossed in the case of some scenarios. The scenarios that show this singular feature are the ones that incorporate the deployment of interventions related to the Central Solar Heating Plants with Seasonal Storage for both natural gas boilers and for biomass boilers. The high costs associated with these interventions influence the results. Differences in the results of up to 96% can be seen between extreme scenarios.

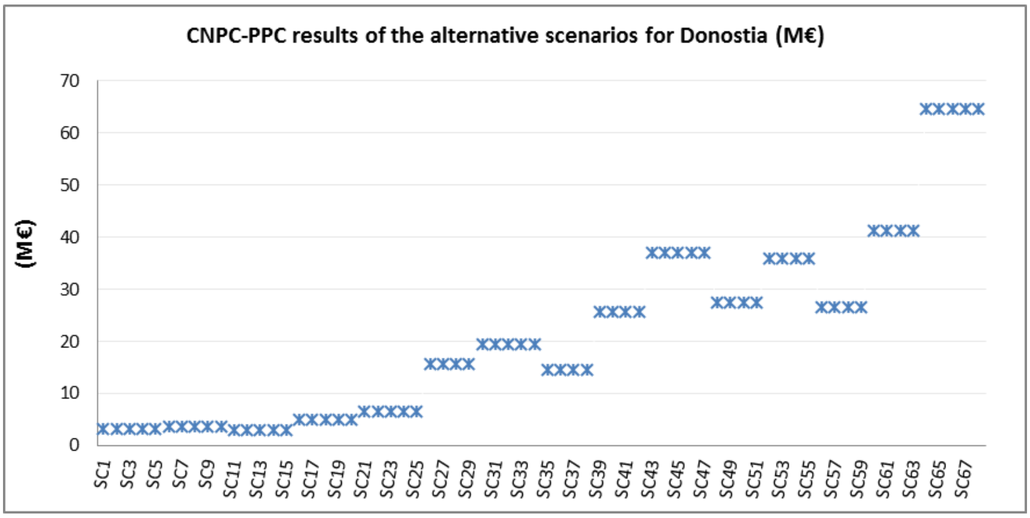

Figure 58. Results of the impact indicator of CNPC-PPC for the alternative scenarios for Donostia-San Sebastián in the period 2017-2067.

- CGWPR impact indicator

The results of this impact category do not correspond to the same distribution and clustering of the previously evaluated indicators. Here, the distribution corresponds mainly to the proportion of fuels of each scenario. Important variations can be seen in Figure 59 with differences of up to 75% arising.

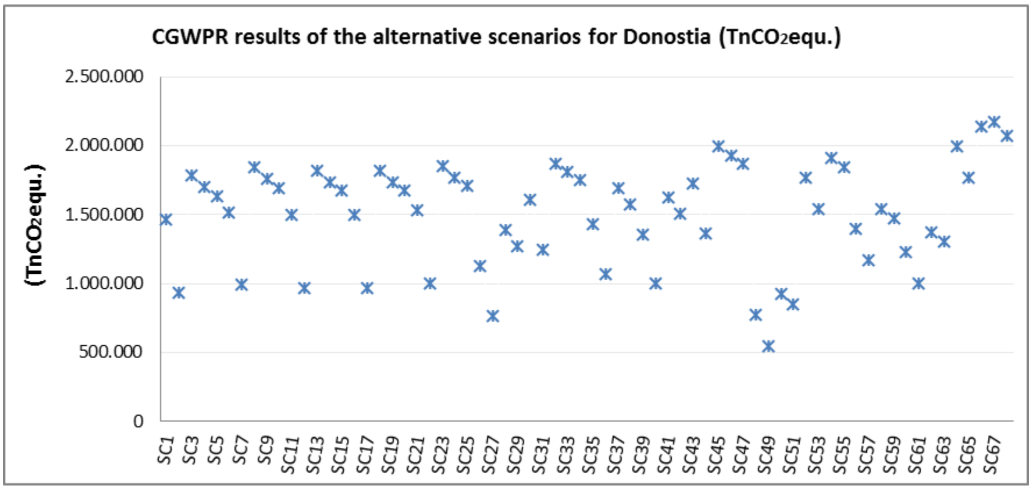

Figure 59. Results of the impact indicator of CNPC-PPC for the alternative scenarios for Donostia-San Sebastián in the period 2017-2067.

This is reflected in the CO_2 emission reductions obtained in the city at the end of the period according to each scenario. The results show that CO_2 equivalent emission savings in the city vary from 40% to 80% with respect to the values of the year 2007, which is the reference year used by the city for defining the targets.

Following the same example, Figure 60 shows the evolution of the life cycle emission reductions in the city during the transition period, distinguishing the contribution of each of the interventions to the overall results of scenario 2.E.1. The relevance of the interventions of refurbishment and the Central Solar Heating Plants with Seasonal Storage and biomass boilers can be seen in this case.

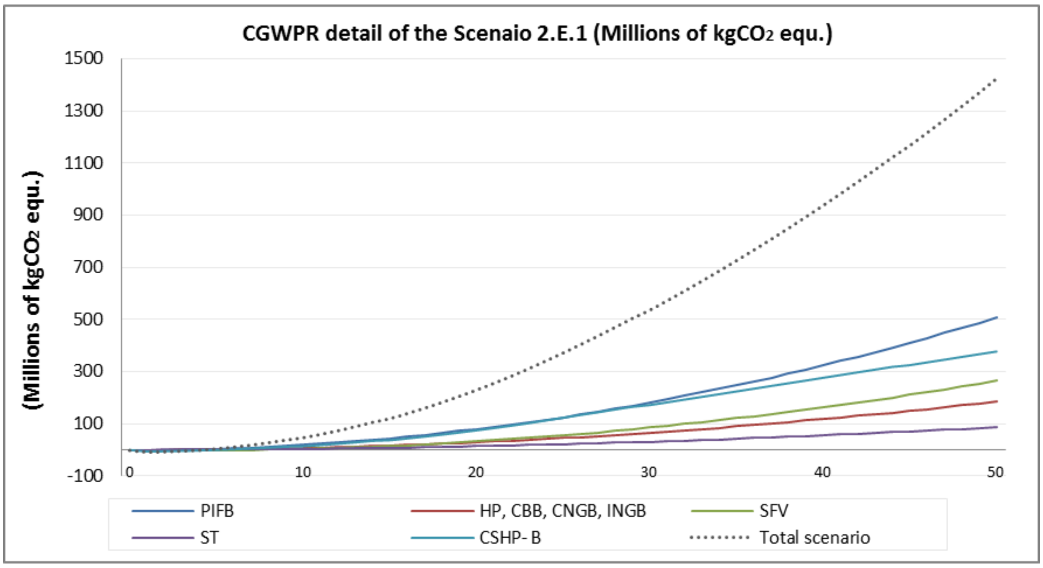

Figure 60. Evolution of the CGWPR for scenario 2.E.1 for the city of Donostia-San Sebastián, during the 50 years of the transition period.

That the emissions savings are negative at the beginning of the transition period due to the emissions related to other stages of the life cycle apart from the use stage has to be taken into account. In fact, those negative emissions occur throughout the transition period, but they are rapidly compensated by the savings gained in the use stage.

Figure 61 shows that the transition scenario starts saving CO_2 emissions in the city after the fourth year. Moreover, it can be seen that the life cycle environmental emissions of all the interventions occur more gradually than in the case of the district heating intervention. The reason is that all the interventions are implemented gradually in the different areas of the city. However, although the district heating intervention is also connected gradually to the city dwellings, it requires a significant amount of equipment and systems to be installed from the first year of operation.

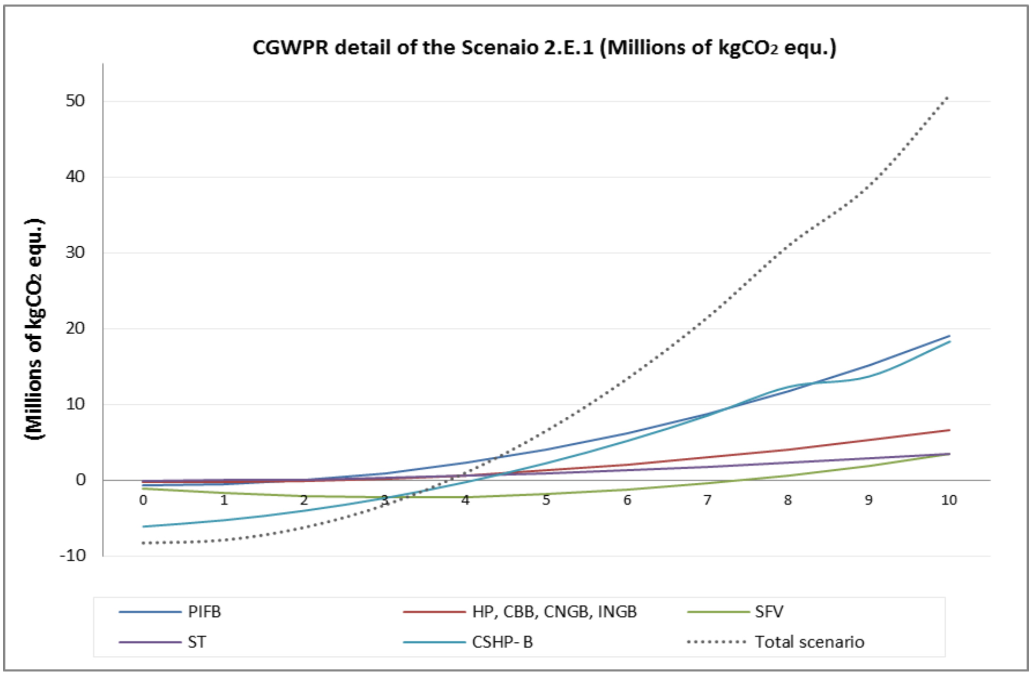

Figure 61. Evolution of the CGWPR for scenario 2.E.1 for the city of Donostia-San Sebastián, during the first 10 years of the transition period.

- CNR-PER impact indicator

The results of the impact indicator of CNR-PER of the scenarios evaluated correspond to a very similar distribution observed in the case of the CGWPR indicator. This is in line with the expected results taking into account that this indicator considers only the non-renewable part of the primary energy consumption.

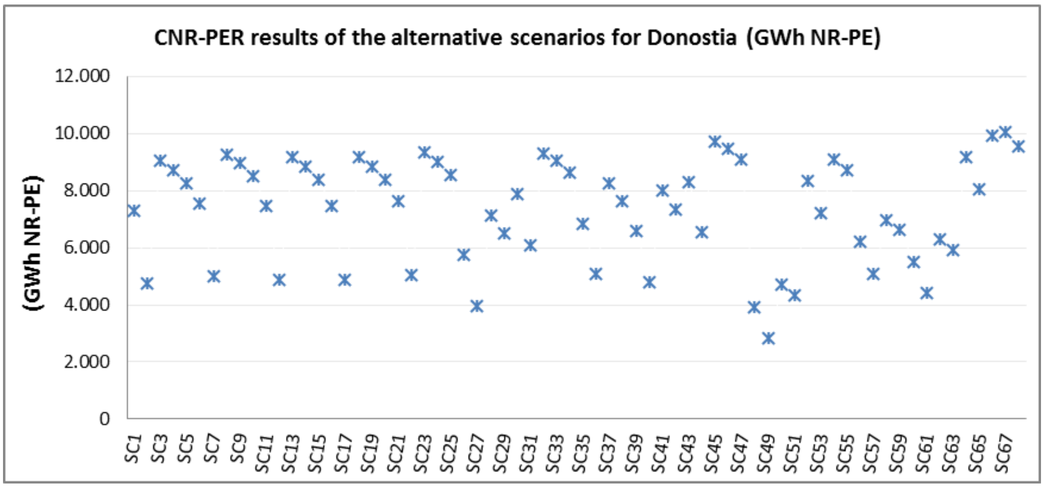

Figure 62. Results of the impact indicator of CNR-PER for the alternative scenarios for Donostia-San Sebastián in the period 2017-2067.

The distribution would be very different in the case of evaluating the total primary energy reduction mainly for the scenarios with high shares of the biomass resource that is linked to the high renewable primary energy consumption. However, the methodology does not penalise the use of renewable primary energy.

Variations of up to 72% can be seen between the most different scenarios. The variability is slightly lower than in the case of the CGWPR indicator.

- CDRLEG impact indicator

For the CDRLEG impact indicator, the scenarios evaluated have several similarities to the results obtained for CGWPR and CNR-PER indicators, but with some singularities that allow for expanding the analysis by taking into account another point of view. Here, the energy produced within the city boundaries (both the renewable and the low carbon) can be observed for each scenario. The results presented in Figure 63 allow for identifying the potential of the use of the biomass resource as well as the potential linked to the district energy networks to integrate renewable and low carbon energy sources. Variations up to 66% can be seen between the scenarios.

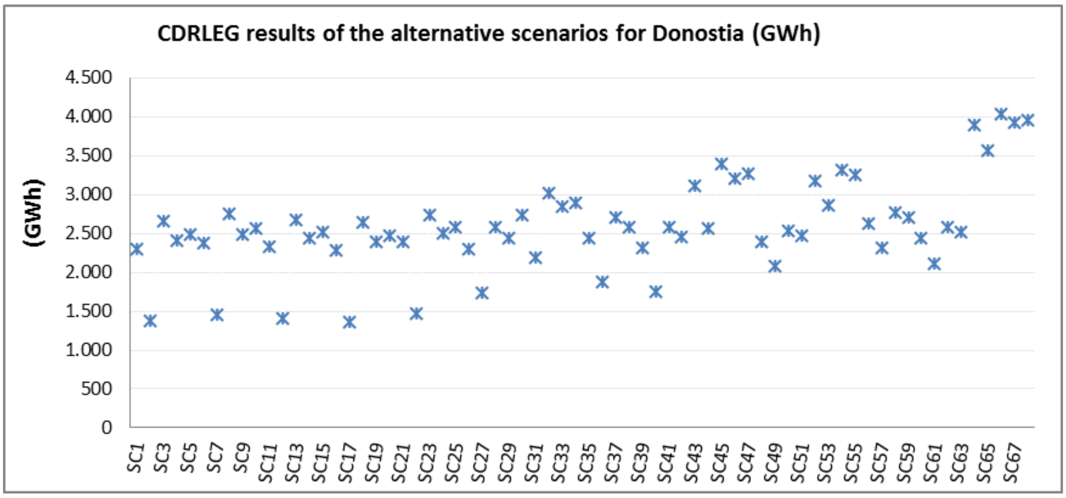

Figure 63. Results of the impact indicator of CDRLEG for the alternative scenarios for Donostia-San Sebastián in the period 2017-2067.

- RGDP impact indicator

The induced impacts in the GDP of the Basque Country accumulated over the 50-year period of city transition scenarios are presented in Figure 64 for each potential scenario. The results show differences between the scenarios of up to 28%.

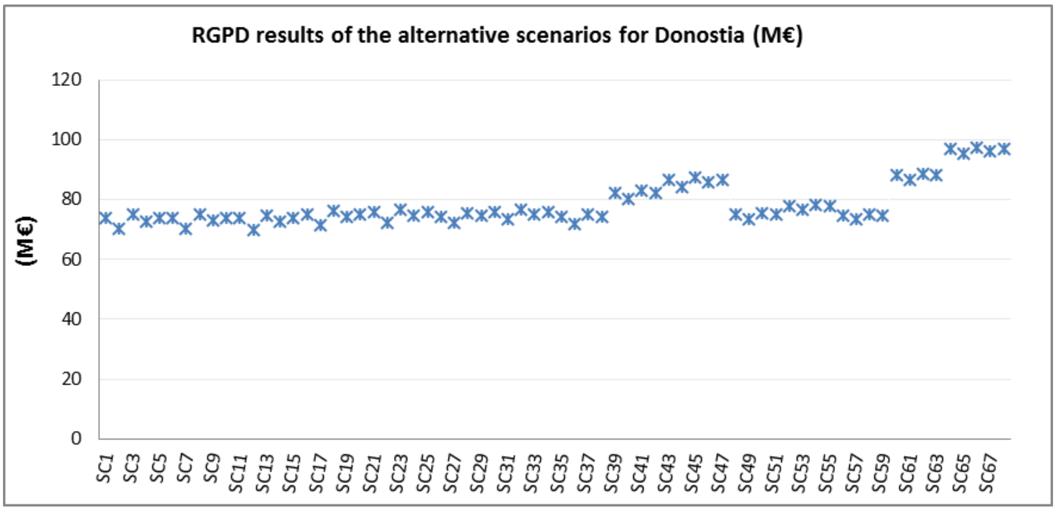

Figure 64. Results of the impact indicator of RGDP at the regional scale, for the alternative scenarios for Donostia-San Sebastián in the period 2017-2067.

There are two main reasons for the variability of the results at the regional scale between the scenarios. The first one is related to the potential associated with each technology to induce the economic activity in the region as presented in Figure 65. These technologies are integrated according to different proportions in each scenario, defining the final multiplier of each scenario.

The potential of each intervention to generate impacts at the regional scale is evaluated more in detail here with the multipliers. The multipliers are the factors that are usually used for understanding the potential of an action to generate a reaction, in this case, the reaction due to the indirect and induced effects created in the economy of the Basque Country. These multipliers are provided in a particular way in this study. The multipliers take as a reference value the cumulative discounted cost of the intervention in purchase prices in spite of the cumulative domestic and discounted costs of the intervention in basic prices, namely, the cost incurred in the interventions without considering whether these are local or not and expressed in purchase prices. As a result, the local induced impact generated in the region is considered. The objective is to reflect the proportion of the generated effects in the region depending on the total investments made in the case of each intervention.

The results show that there are relevant differences between the potential to generate an impact in the region by each intervention, of up to 46%. For example, significant differences are observed when evaluating the refurbishment intervention and the solar photovoltaic intervention. The main reason for these differences, in addition to the fact that each technology shows a different proportion of costs of commodities (which will affect sectors with different values added), is that in the case of photovoltaic systems, the main CAPEX cost corresponds to the solar collectors that are not produced locally, whereas most of the costs associated with the refurbishment can be provided locally.

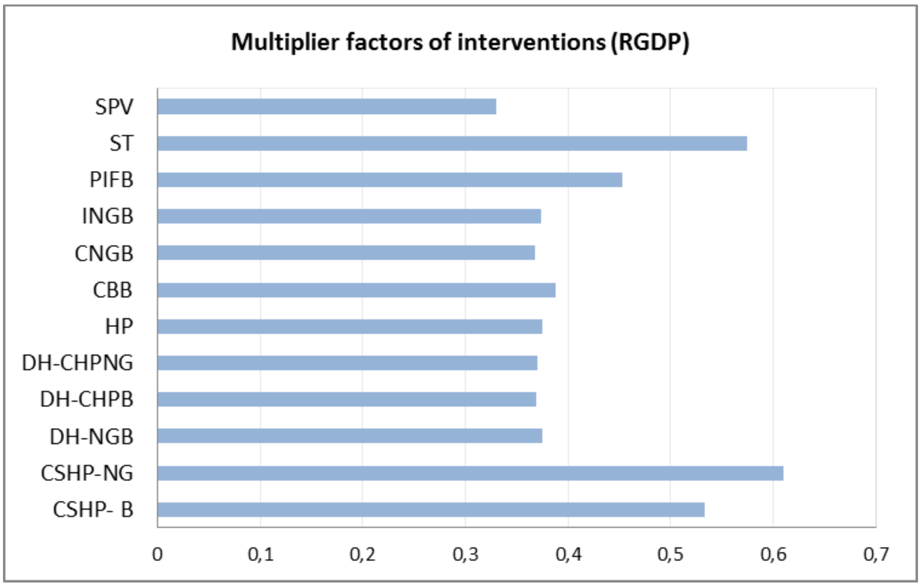

Figure 65. Multiplier factors of the interventions for the RGDP.

The second reason for the variability of the results between the energy transition scenarios is related to the total investment of each scenario. This aspect has a big influence on the results. Due to the selected reference unit for scenario comparisons, the results depend on the total investments carried out during the life cycle of each scenario.

Finally, as a contextualisation it is important to note that the induced impact in the GDP of the Basque Country by the city transition scenarios is close to the 0.16% of the regional GDP and close to 1.7% of the GDP of Donostia-San Sebastián. Therefore, these indicators are interesting mainly for the strategic vision and to understand the potential of the impact generated due to the replication of interventions in other areas of the city or in other cities of the region.

- RE impact indicator

The induced impact in the regional employment by the evaluated scenarios follows the same tendency as in the case of the RGDP indicator. However, the variability range of the results is slightly lower in this case, at up to 27%.

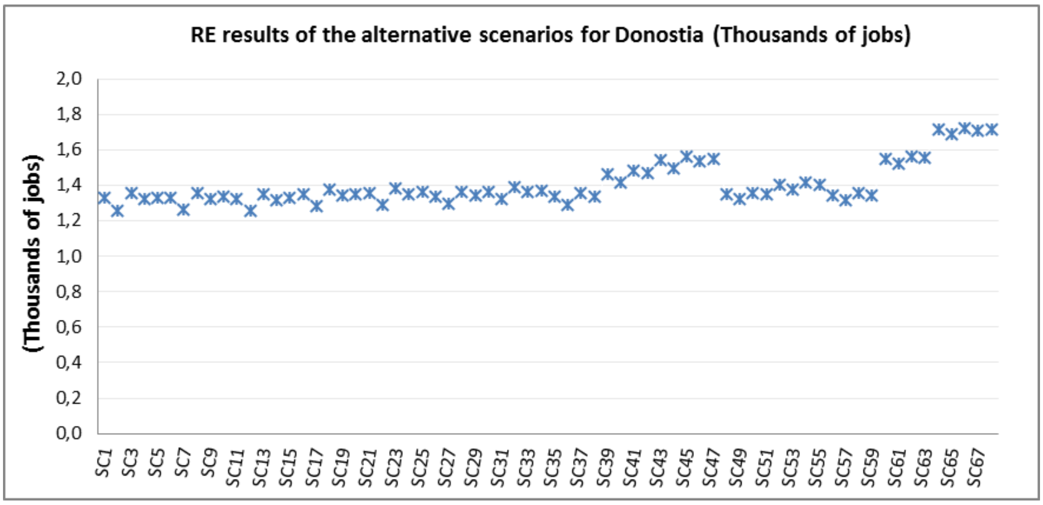

Figure 66. Results of the impact indicator of RHDI at the regional scale for the alternative scenarios for Donostia-San Sebastián in the period 2017-2067.

As in the case of the RGDP, the multipliers of the RE are shown in Figure 67. The results show that there are relevant differences between the potential to generate an employment impact in the region by each intervention. More precisely, differences of up to 40% are achieved.

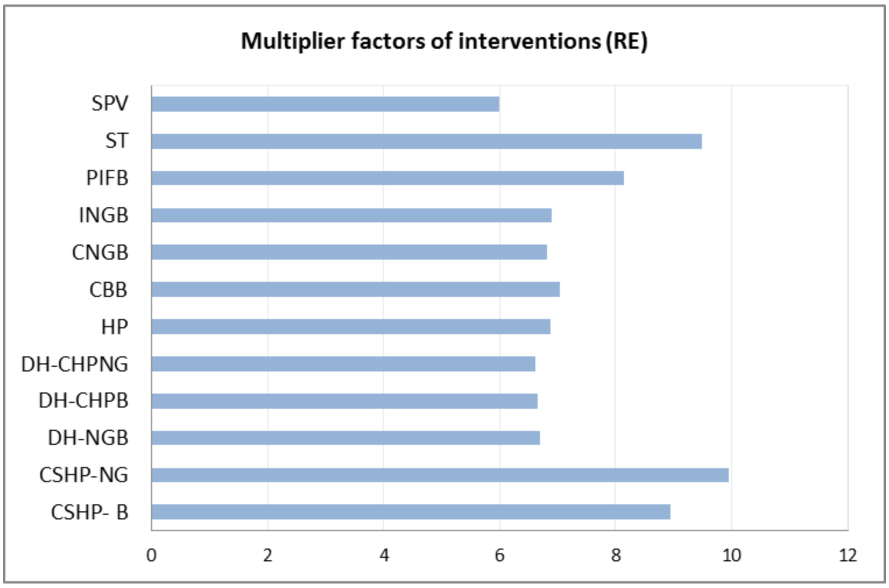

Figure 67. Multiplier factors of the interventions for the RE (jobs/M euro).

Not many studies have evaluated the direct, indirect, and induced employment impacts associated with the technologies. For example, in the case of the solar photovoltaic systems, the results obtained in this study show that 11.2 jobs/MW are created considering the direct, indirect and induced effects in the regional economy. These results are in line with data available in literature for this technology that vary from 4.3 jobs/MW, as evaluated by (Cameron & Van Der Zwaan, 2015), which considers only the direct, and indirect effects or cases such as the studies by (IDAE, 2005) and (Llera et al., 2013), which show values of 25 and 27.8 jobs/MW respectively. These latter studies are based on a given scenario for the growth of various renewable technologies in the first case and on the value chain approach with surveys in the second case. That these values are higher because they refer to a national economy and not to a regional economy has to be taken into account.

All the values of the figures included in this section of results are provided in tables in section 6.4.2 of the Appendix.

4.6. Prioritisation of energy transition scenarios

In order to make the decision of prioritising a specific energy transition scenario for Donostia-San Sebastián, including all of these conflicting criteria (defined by the selected impact indicators), a multi-criteria decision-making (MCDM) process has been followed. Based on the various existing methods, the Analytical Hierarchy Process (AHP) method has been followed to facilitate prioritisation process. In the assessment process, nine criteria corresponding to each of the indicators evaluated are considered. These criteria are classified into three main criteria, as shown in Table 28.

Table 28. Sub-criteria considered within the main criteria categories.

Economic	Environmental	Strategic (macroeconomic and social)
CNPV	CGWPR	RGPD
DPP	CNR-PER	RE
CNPC-S	CDRLEG	
CNPC-PPC		

The results of the impact indicators obtained for each scenario are used to develop the importance matrix of each scenario for the case of each of the criteria of the table. Before the importance weights of these criteria were rated and applied to the scenario values, the following results were observed (Figure 68). The relative performance of each scenario with respect to the others can be understood for each of the assessment criteria. This provides a visual first idea of the scenarios that are performing well in case all the criteria are weighted with the same importance.

However, as mentioned before, the CO_2 emission reductions obtained in the city at the end of the transition period by each scenario vary significantly. Therefore, considering that the main target of the city is to ensure good reduction levels of environmental emissions, this criterion is considered in the study as the main cutting rule.

In this case the cutting rule has been set at a minimum of 74% of CO_2 equivalent of emission savings with respect to the values of 2007. This will help to discard a high number of scenarios before the final prioritisation. In the case of other cities, for which the main purpose of the study is to ensure a minimum level of other criteria, this would be used for the assessment.

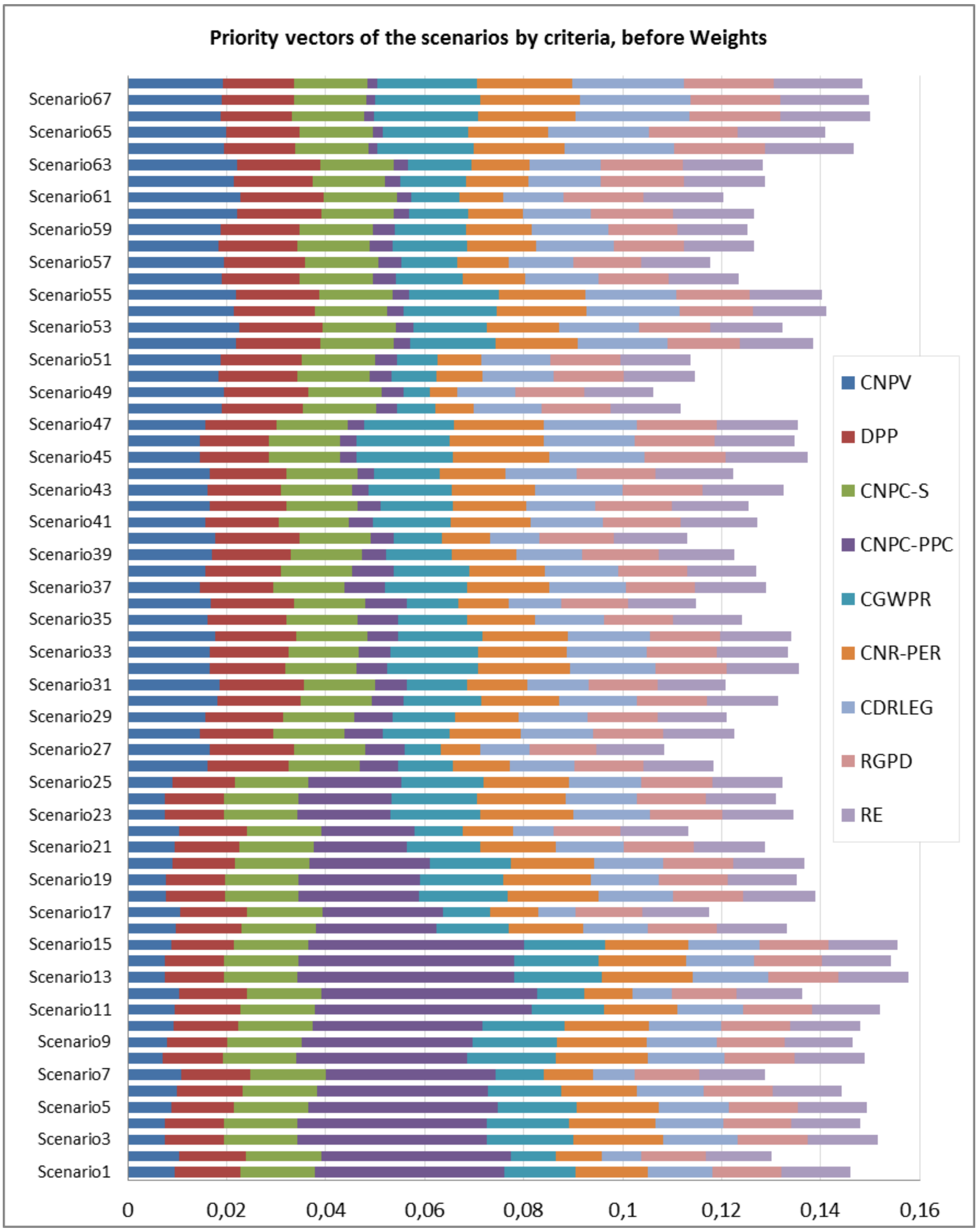

Figure 68. Priority vectors of the scenarios by criteria, before being weighted.

Figure 69 shows that the cutting rule that has been set is very restrictive and limits in an important way the number of potential city energy transition scenarios. Only 12 scenarios from the 68 evaluated pass the defined limit. It is important to note that there are several scenarios that would probably have a better global performance than some of those 12 scenarios;

however, these are not considered as valid. It is evident that the establishment of the value of the cutting rule will influence the results.

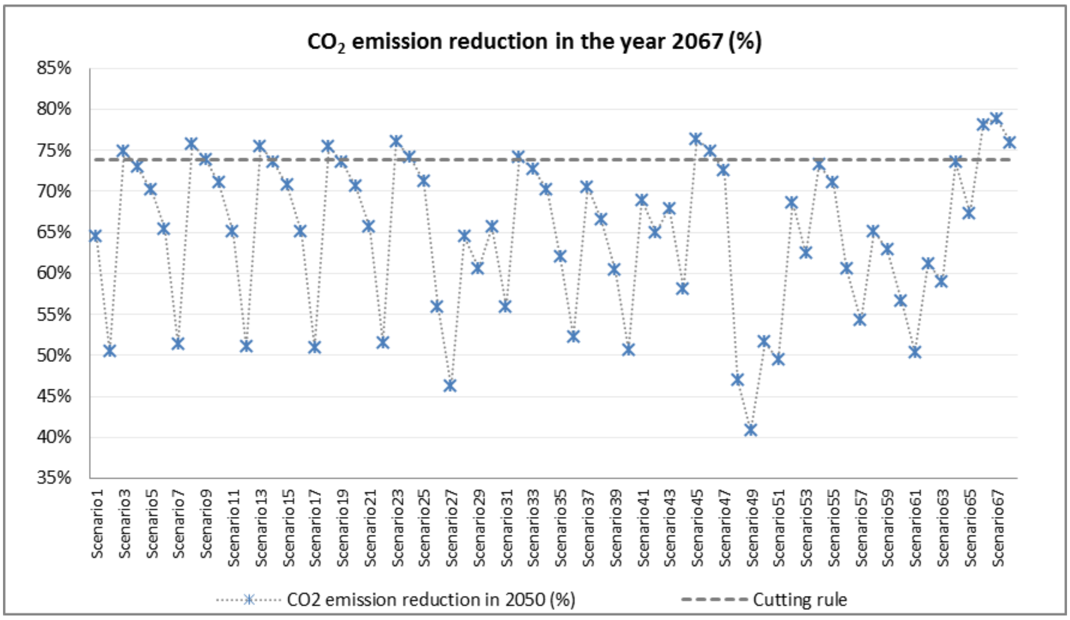

Figure 69. Application of the CO_2 emission reduction cutting rule to the 68 scenarios.

The importance weights of these nine sub-criteria are shown in Table 29. The relative importance of the sub-criterion within its respective main criterion and the final weights with respect to the nine sub-criteria are included in the table. In terms of the study, the weights considered have been defined according to the opinion of a reduced group of experts in the field of energy planning.

Table 29. Relative importance weights of each sub-criterion with respect to its corresponding main criterion and the final importance weights of each sub-criterion of the assessment.

Economic (40%)			Environmental (40%)			Strategic (20%) (macro-economic and social)		
	Relative	Final		Relative	Final		Relative	Final
CNPV	30%	12%	**CGWPR**	40%	16%	**RGPD**	50%	10%
DPP	15%	6%	**CNR-PER**	40%	16%	**RE**	50%	10%
CNPC-S	30%	12%	**CDRLEG**	20%	8%			
CNPC-PPC	25%	10%						

The weighted results of the scenarios are shown in Figure 70. The final score of each scenario can be seen with their respective contribution to the CO_2 emission reduction of the city by the end of the transition period and with the share of the CNPC-PPC with respect to the total CNPC.

This last rate is provided as additional information to reflect that each scenario is linked to different business models and, therefore, some of them will require greater company investment instead of individual investment from citizens.

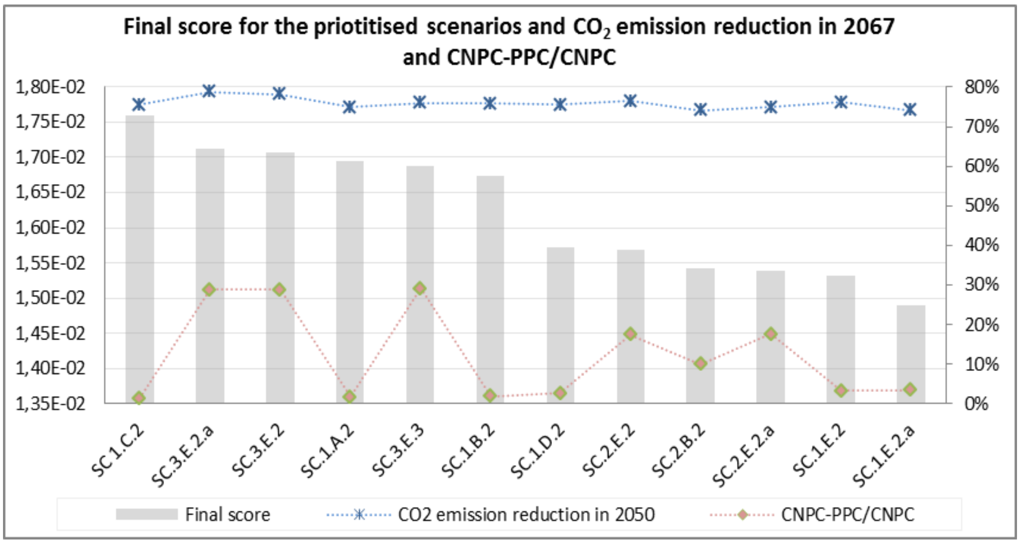

Figure 70. Final score for the prioritised scenarios' CO_2 emission reduction in 2067 and the share of the CNPC-PPC with respect to the total CNPC.

The results show that with the weights considered, the prioritised scenario is SC.1.C.2 followed by other scenarios, such as the SC.3.E.2.a.

The entire multi-criteria prioritisation process is considered the more subjective part of the study. Therefore, two alternative weights are evaluated here in order to understand the influence of a change in the weighting criteria. In the first alternative prioritisation weightings, the environmental criteria have more relevance at 60% and the economic criteria decrease their relevance to 20%.

Table 30. Results of the scenarios prioritised for the alternative weights.

Alternative 1		Alternative 2	
Scenario	**Result**	**Scenario**	**Result**
SC.3.E.2.a	1,88E-02	SC.1.C.2	1,80E-02
SC.3.E.2	1,87E-02	SC.1.A.2	1,71E-02
SC.3.E.3	1,84E-02	SC.1.B.2	1,66E-02
SC.2.E.2	1,73E-02	SC.3.E.2.a	1,55E-02
SC.1.C.2	1,72E-02	SC.3.E.2	1,54E-02
SC.1.B.2	1,69E-02	SC.3.E.3	1,54E-02
SC.2.E.2.a	1,68E-02	SC.1.D.2	1,52E-02
SC.1.A.2	1,68E-02	SC.2.B.2	1,44E-02
SC.2.B.2	1,64E-02	SC.1.E.2	1,44E-02
SC.1.D.2	1,63E-02	SC.1.E.2.a	1,42E-02
SC.1.E.2	1,63E-02	SC.2.E.2	1,41E-02
SC.1.E.2.a	1,57E-02	SC.2.E.2.a	1,39E-02

In the second alternative, the economic criteria increase their relevance to 60% and the environmental criteria decrease to 20%.

From the results shown in Table 30, it can be appreciated that the order of prioritisation of the 12 scenarios in each alternative, differs from the initial result. Scenario SC.3.E.2.a had the higher score in the case of the first alternative. In the second alternative, it can be seen that although the same scenario SC.1.C.2 is in the first position as in the case of the initial assessment, the order of the rest of scenarios is changed.

4.7. Sensitivity analysis

This last stage of the methodology focuses on making an evaluation of the sensitivity of results with respect to the main parameters and the hypothesis considered in the study. The aim of this analysis is to increase the understanding of the relationships between the main input and output variables in the model. Therefore, this section includes variations in six influential factors in order to estimate the lower and upper bounds for the impact indicators evaluated.

The sensitivity analysis was carried out for three different scenarios in order to understand the influence of these parameters in different situations. One scenario was selected for each of the three main groups of scenarios according to the classification defined. The selection of the scenario in each group was done according to the final results, following the order of the prioritisation. The scenarios evaluated were: SC.1.C.2, SC.2.E.2 and SC.3.E.2.a.

4.7.1. Shadow price on CO_2 emissions

If the effect of the shadow price on CO_2 emissions is considered over the 50 years of a scenario, in the case of the prioritised scenario (SC.1.C.2) the economic indicators improve as shown in Figure 71.

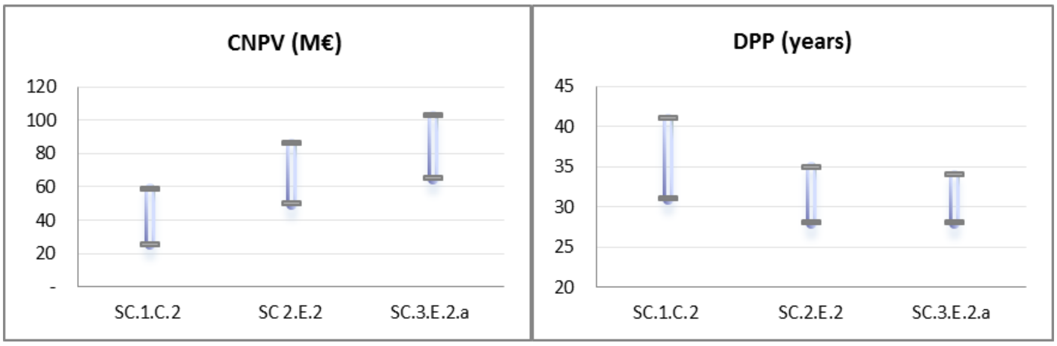

Figure 71. Sensitivity analysis results for the impact indicators of the three scenarios, due to consideration of the shadow price on CO_2 emissions.

The results show that a variation between 58% and 129% can be reached in the case of the CNPV indicator depending on the scenarios. This is directly linked to the impact indicator of CGWPR. In the case of the DPP indicator, variations between 18% and 24% are observed. For the assessment, that the CO_2 emission price will increase in the following decades has been considered. The base price and its tendency during the period of the scenario have been examined according to the values proposed by (Ministerio de Fomento de España, 2013). For the last years of the period (2050-2067), the same price as for the period from 2045 to 2050 has been taken.

Table 31. CO_2 emission cost in constant euros in 2012 considered for the assessment. Adapted from: (Ministerio de Fomento de España, 2013).

Year	CO_2 emissions cost (€/ton)
2012-2020	18.6
2021-2025	22.5
2026-2030	40.5
2031-2035	56.3
2036-2040	58.5
2040-2045	57.4
2046-2050	56.3
2050-2067	56.3

4.7.2. Marginal propensity of consumption

The marginal propensity of consumption provides an idea of the share from the saving of households that is reinvested in the economy. This is a parameter that is difficult to set by consensus and, therefore, a variation of 25% of the reference value has been applied for the sensitivity analysis.

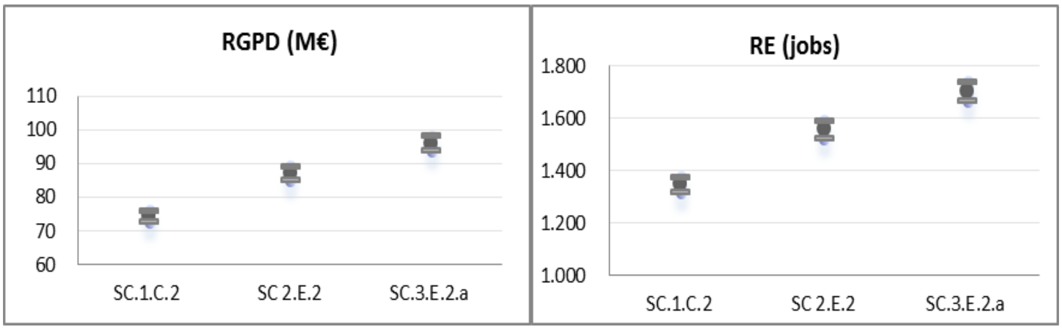

Figure 72. Sensitivity analysis results for the impact indicators of the three scenarios due to a variation in the marginal propensity of consumption.

The results show that a similar tendency is followed by the two regional impact indicators in the three evaluated scenarios, with variations of between 2% and 2.2%.

4.7.3. Energy price increase rate

Energy price is usually considered to be the major component of future cost uncertainty. Considering that a relatively moderate increase rate has been used in the study, for the sensitivity analysis, the annual increase rate of each fuel has been increased and decreased by 50%.

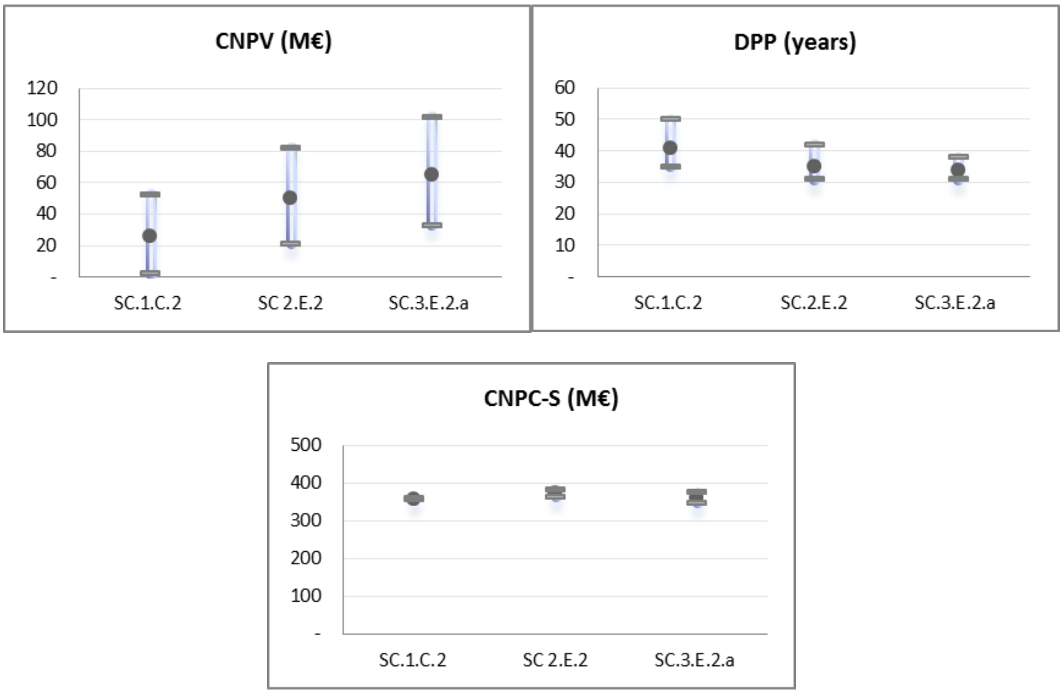

Figure 73. Sensitivity analysis results for the impact indicators of the three scenarios due to a variation of the energy price increase rate.

The CNPV impact indicator is the indicator that most significantly reacts to a variation of this parameter, with changes of between 56% and 104% depending on the scenario evaluated. DPP also varies notably by between 12% and 22%.

It can be also seen for those indicators that scenarios with higher shares of district heating-based interventions are less sensitive to a change in the energy price. The reason is that the return for the owner and the operator of the plant is based on a system of tariffs designed with a central role for fixed costs for the houses connected to it. Finally, it can be seen that the CNPC-S indicator shows a lower variation of 0.5% and 4.2%.

4.7.4. Discount rate

Two new values have been considered for the discount rate in order to evaluate the sensitivity of the results of the three scenarios for this parameter. Within the reference value of 4, a discount rate of 3 and 5 has been considered. The following group of figures shows the results of the analysis for each of the impact indicators that are influenced.

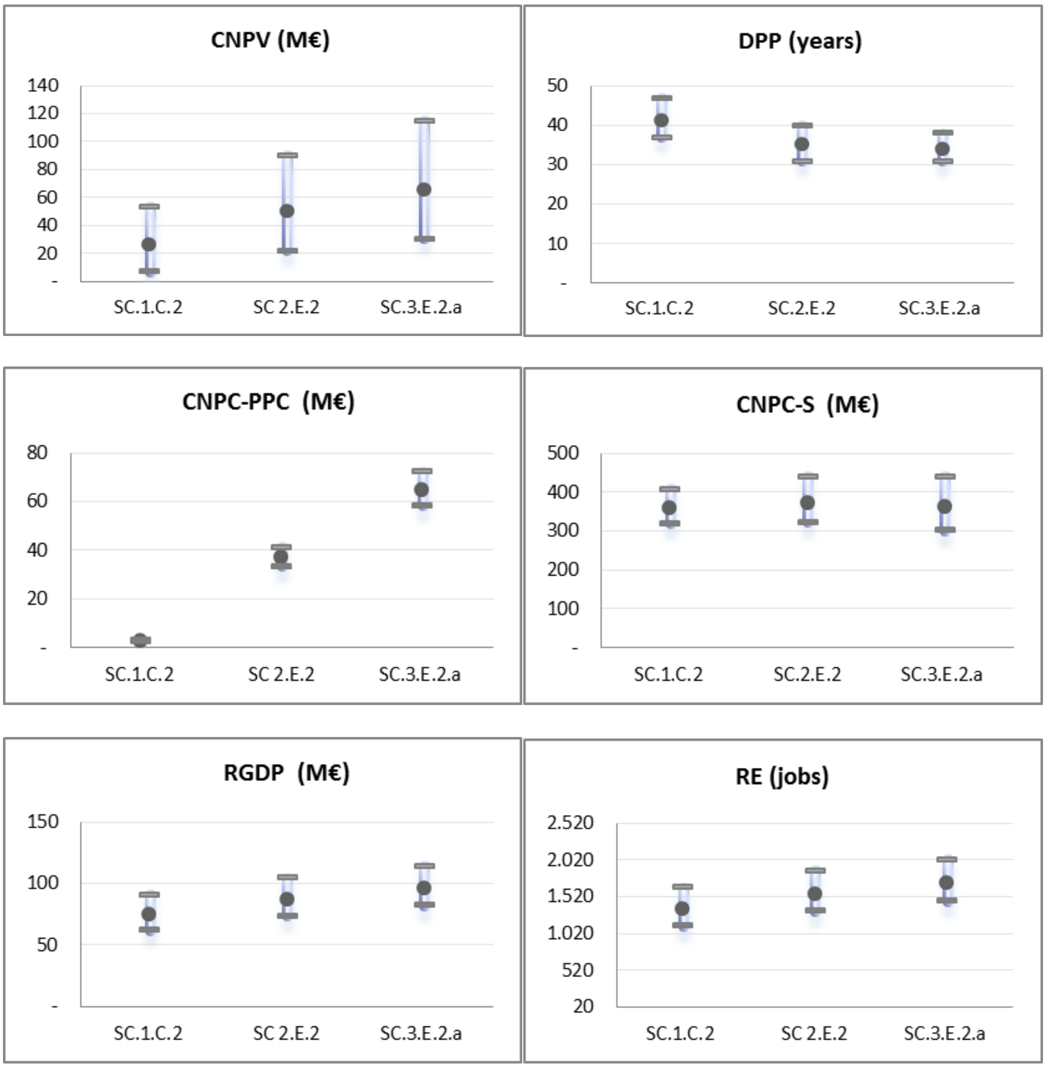

Figure 74. Sensitivity analysis results for the impact indicators of the three scenarios, due to a variation in the discount rate.

The results show that CNPV is the most sensitive impact indicator with variation between 77% and 109% with respect to the reference, depending on the scenario evaluated. The two macroeconomic and social indicators show a very similar reaction, with variations between 19% and 22%. The DPP has a variation of between 12% and 15%, CNPC-S variations of between 14% and 22% and, finally, the CNPC-PPC indicator shows the minimum sensitivity to this parameter, with values between 9% and 12%.

4.7.5. Annual implementation rate of the interventions

The annual implementation rate of the interventions included in the scenarios is an aspect that is susceptible to suffering variations when defining the transition scenarios. Changing the deployment rate of several interventions in the city can, among other aspects, accelerate or decelerate the achievement of the targets.

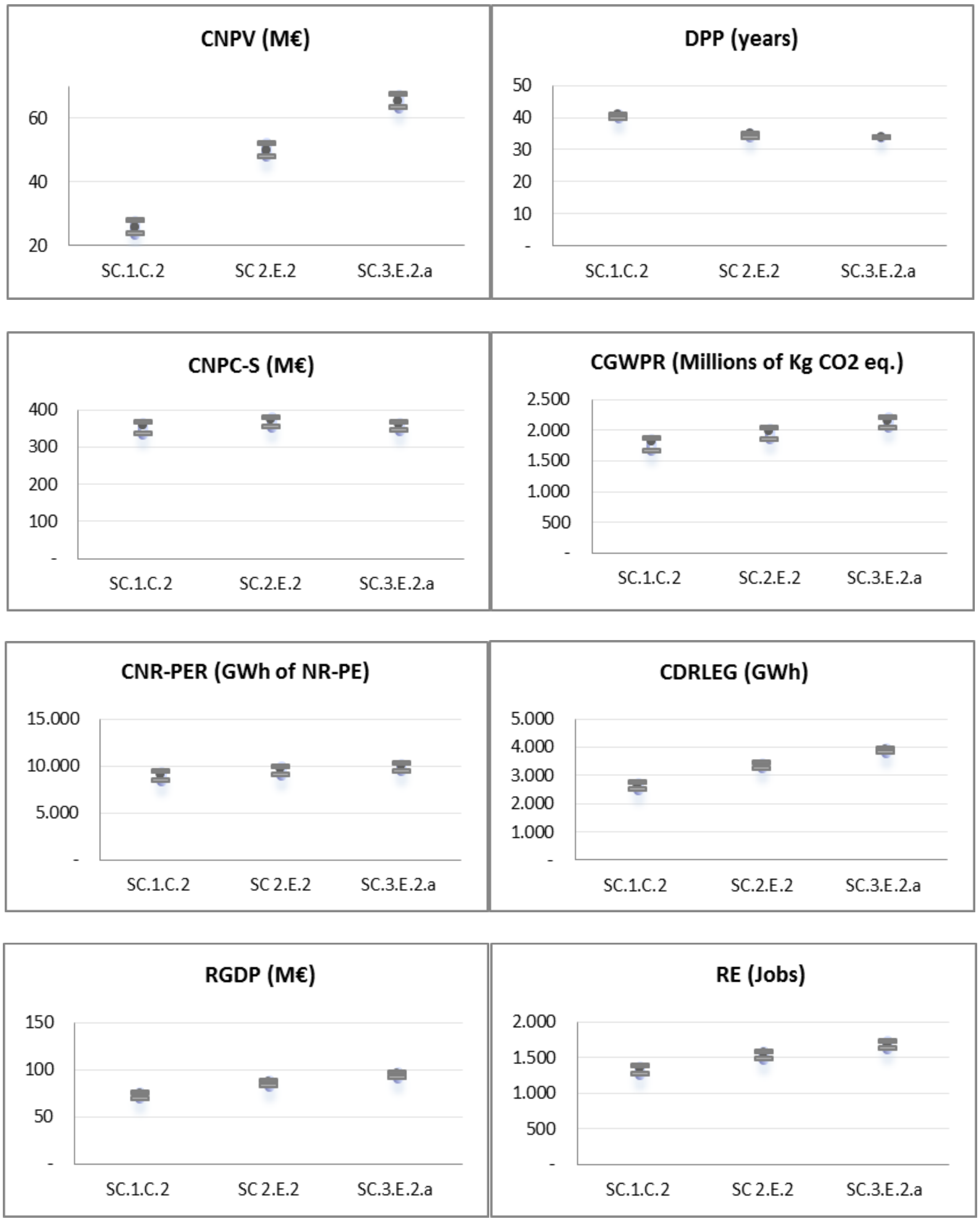

Figure 75. Sensitivity analysis results for the impact indicators of the three scenarios, due to a variation of the annual implementation rate in the interventions in the city.

Here, this parameter has been increased and decreased by 5% from the reference value. Figure 75 shows the results for each of the impact indicators that are influenced. It can be seen that among the economic impact indicators in this case energy and environmental impact indicators are also influenced. The results show that CNPV, CNPC-S, CGWPR, CDRLEG, and CNR-PER react in a similar way to the changes with variations with respect to the reference case of between 3% and 8%. It can be also seen that the first scenario is more sensitive for all the impact indicators in relation to this parameter. As in the previous case, the two regional impact indicators follow a similar evolution, with a variation of between 4.5% and 6.3%. Finally, the DPP indicator shows a minimum sensitivity to this parameter, with variations of between 0% and 3%.

4.7.6. CAPEX price increase

The initial cost of the interventions is another parameter that has been defined for the study and that can vary depending on aspects such as the country where it is purchased and installed.

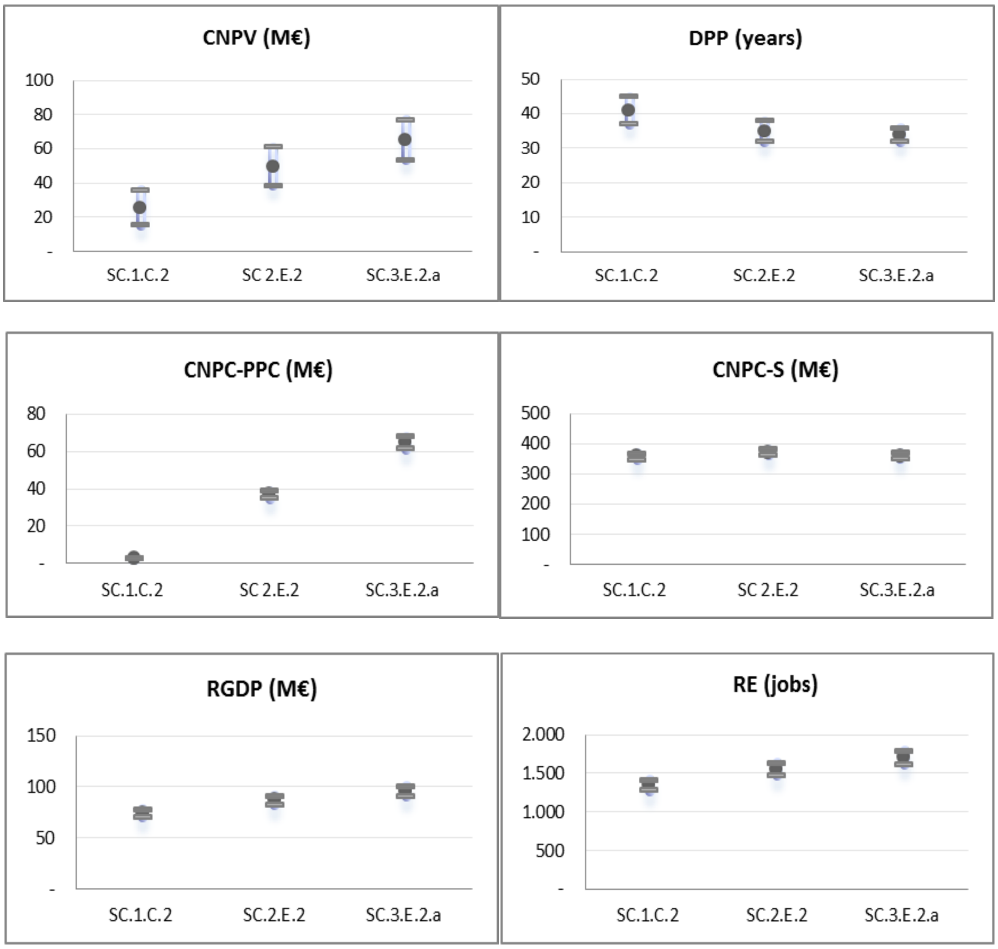

Figure 76. Sensitivity analysis results for the impact indicators of the three scenarios, due to a variation of the CAPEX costs of interventions.

Therefore, the CAPEX costs of the interventions implemented in each scenario have been increased and decreased by 5% with respect to the considered values.

As could be expected, the impact indicator with the higher sensitivity level is the CNPC with variations of between 18% and 40%, followed by the DPP indicator with values of between 6% and 11%. Finally, regional impact indicators and the CNPC-PPC indicator show a similar response to the variation in the CAPEX costs with values from 5% to 5.3%.

4.7.7. Energy technology cost trends

The energy technology cost reduction for the period of the study has been increased and decreased by 5% with respect to the reference value. The cost reduction rate will influence the economic impact indicator results of the three scenarios.

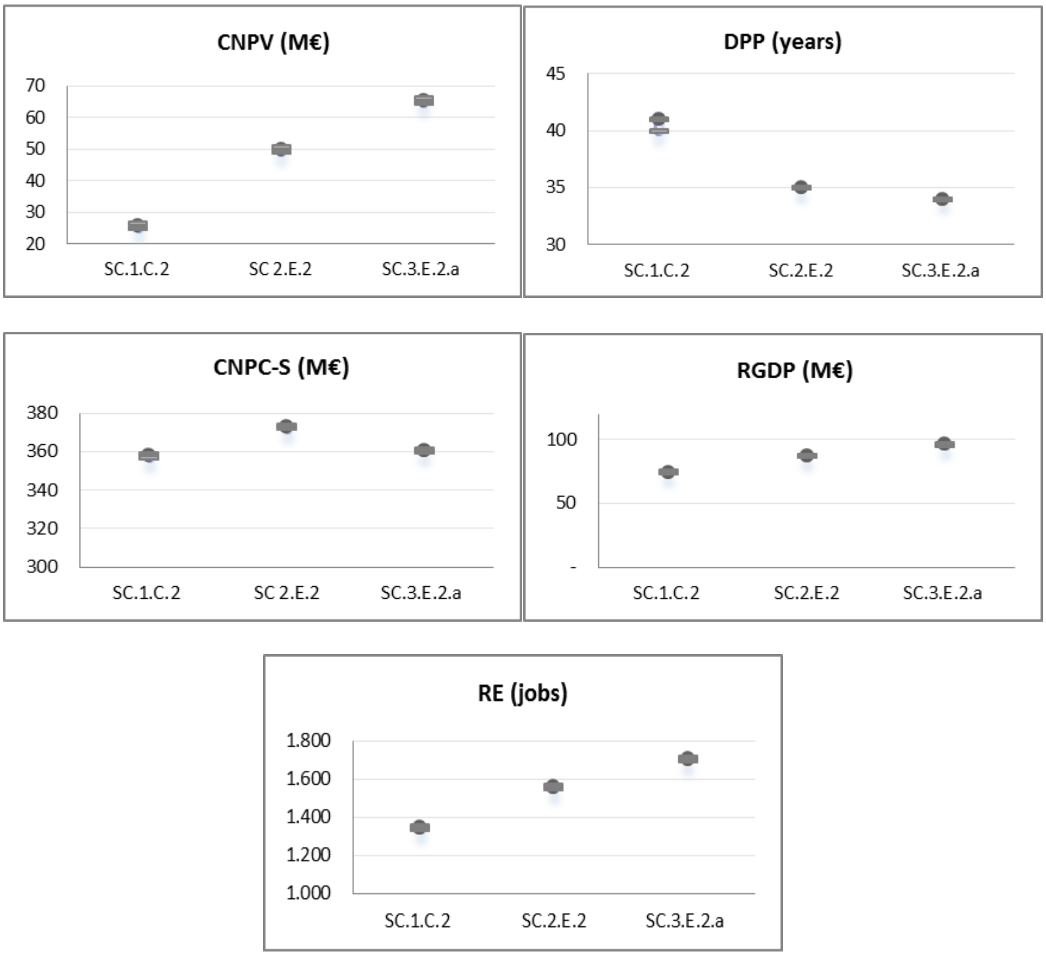

Figure 77. Sensitivity analysis results for the impact indicators of the three scenarios, due to a variation of the cost reduction rate of the interventions.

It has to be considered that the reference technology cost reduction trend considered has been conservative, due to the long-term period of the transition scenario and the lack of reliable data for all the technologies involved in the scenarios. The results of the sensitivity analysis show that variations of up to 3% are achieved in the case of the CNPV and the DPP indicators. The remainder of the impact indicators evaluated shows a lower sensitivity, with values of between 0.2% and 0.4%.

The values of the figures and the specific percentages of the variations for each scenario and indicator are provided in section 6.4.3 of the Appendix.

4.8. Further analysis of the results

4.8.1. Sectoral macroeconomic effects

A more detailed analysis of the macroeconomic effects allows an understanding to be gained of the distribution of the indirect and induced impacts in the different sectors of the economy. Table 32 shows for scenario SC.1.C.2, the disaggregation of the results obtained for the RGDP indicator.

The results are provided for the main sectors affected in terms of the indirect and the induced impacts created. It is observed that although the shock affects directly only some few commodities and sectors, the created indirect and induced impacts affect almost all the sectors of the economic activity.

The results are provided as percentages of variation of the value added by sector. Glass industry, concrete, the lime and gypsum industry, the metal construction sector, non-metallic construction sectors, commerce, the construction sector, repair and installation, and engineering and architectural services are the sectors with the most relevant impacts. Other sectors, such as the electricity sector, electrical equipment, transport activities, and the telecommunication sectors are also considerably affected.

A comparison between the indirect impacts and the induced impacts shows that aggregated induced impacts are 10% higher than the indirect impacts in cases where a marginal propensity of consumption (m) of 0.6 is considered and up to 22% higher for a marginal propensity of consumption of 0.8. These values vary for each of the sector. In terms of the employment impact, these values are 9% and 19% respectively. This reflects the relevance of evaluating not only the indirect impacts but also the induced impacts for the comparison of scenarios.

Moreover, it can be seen that although some sectors are not affected by the indirect effects, show a variation when the induced effects are considered. This is the case for sectors such as other personal services and household activities, among others.

Table 32. Indirect and induced effects (in %) by sector associated with the implementation of the transition scenario SC.1.C.2. Induced impacts are provided for two different marginal propensity of consumption (m) values.

	Indirect	Induced (m=0.6)	Induced (m=0.8)
Sector 1	0.03%	0.05%	0.06%
Sector 2	0.03%	0.03%	0.04%
Sector 4	0.38%	0.38%	0.38%
Sector 5	0.01%	0.03%	0.05%
Sector 8	0.01%	0.03%	0.04%
Sector 13	0.06%	0.06%	0.06%
Sector 15	0.07%	0.08%	0.08%
Sector 17	0.05%	0.05%	0.05%
Sector 22	2.73%	2.73%	2.73%
Sector 23	1.73%	1.73%	1.73%
Sector 24	0.55%	0.55%	0.56%
Sector 28	0.51%	0.51%	0.51%
Sector 31	0.15%	0.16%	0.16%
Sector 32	0.07%	0.07%	0.08%
Sector 33	0.10%	0.10%	0.10%
Sector 34	0.07%	0.08%	0.08%
Sector 38	0.06%	0.06%	0.07%
Sector 42	0.29%	0.30%	0.30%
Sector 43	0.09%	0.10%	0.11%
Sector 44	0.06%	0.07%	0.07%
Sector 45	0.05%	0.06%	0.09%
Sector 46	0.03%	0.04%	0.06%
Sector 47	0.30%	0.30%	0.31%
Sector 48	0.03%	0.04%	0.08%
Sector 49	0.23%	0.24%	0.25%
Sector 50	0.62%	0.65%	0.68%
Sector 51	0.04%	0.06%	0.07%
Sector 52	0.02%	0.04%	0.07%
Sector 53	0.08%	0.09%	0.10%
Sector 54	0.09%	0.09%	0.10%
Sector 56	0.08%	0.09%	0.09%
Sector 57	0.13%	0.15%	0.17%
Sector 58	0.01%	0.04%	0.06%
Sector 59	0.04%	0.05%	0.06%
Sector 61	0.08%	0.10%	0.12%
Sector 62	0.05%	0.06%	0.06%
Sector 63	0.05%	0.06%	0.08%
Sector 64	0.05%	0.07%	0.09%
Sector 65	0.05%	0.07%	0.09%
Sector 66	0.03%	0.05%	0.09%
Sector 67	0.06%	0.07%	0.08%
Sector 68	0.27%	0.27%	0.27%
Sector 70	0.10%	0.10%	0.11%
Sector 71	0.07%	0.08%	0.09%
Sector 72	0.09%	0.10%	0.12%
Sector 73	0.12%	0.13%	0.14%
Sector 74	0.01%	0.04%	0.07%
Sector 75	0.08%	0.10%	0.11%
Sector 83	0.00%	0.03%	0.05%
Sector 84	0.02%	0.04%	0.06%
Sector 85	0.02%	0.05%	0.07%
Sector 86	0.05%	0.07%	0.08%
Sector 87	0.00%	0.03%	0.06%
Sector 88	0.00%	0.03%	0.06%

4.8.2. Influence of the local production in the macroeconomic effects

It is also interesting to understand the influence of the local production of the components of interventions. In this section, an analysis of the solar photovoltaic intervention is presented. The initial situation in which the solar collectors are only distributed locally but not produced is compared with the situation where the collectors are produced in the Basque Country. Table 33 shows the results obtained in the case of the solar photovoltaic systems implemented in scenario SC.1.C.2.

Table 33. Comparison of the induced impacts in the RGDP and in the RE for the solar photovoltaic systems (collectors only distributed vs, produced).

	Only distributed	Produced
RGDP	11,207,287.8	12,783,026.6
RE	203.5	226.1

A difference of 14% can be seen in the induced impacts created in the RGDP and a difference of 11% in the induced impacts in the RE. Differences are originated not only due to the increase of the economic activity in the main sector directly affected in the production of the collectors (sector 33), but also due to the increase originated in the production of the rest of sectors. Table 34 shows the differences created in the increase of the impact in each sector in the new situation with respect to the results obtained in the initial situation. The main variations are observed in the sectors related to the glass industry, informatics and electronic products, mechanical engineering, other non-metallic industries, and the production of non-ferrous metals.

This type of disaggregated information can be used as comparative criteria to understand which sectors will be mainly affected due to the implementation of interventions and scenarios. Moreover, the information obtained can be used as criteria for strategic decision-making by municipalities and regional governments, which will have to decide in the coming years how and where to focus efforts and investments.

Table 34. Increments (%) of the induced effects in the RGDP originated in each sector, in a situation where solar collectors are produced locally with respect of the case in which they are only distributed locally.

	Variation		Variation
Sector 1	5%	**Sector 45**	21%
Sector 2	8%	**Sector 46**	16%
Sector 3	14%	**Sector 47**	10%
Sector 4	22%	**Sector 48**	11%
Sector 5	11%	**Sector 49**	4%
Sector 6	9%	**Sector 50**	1%
Sector 7	11%	**Sector 51**	18%
Sector 8	9%	**Sector 52**	16%
Sector 9	6%	**Sector 53**	15%
Sector 10	12%	**Sector 54**	24%
Sector 11	0%	**Sector 55**	14%
Sector 12	10%	**Sector 56**	12%
Sector 13	7%	**Sector 57**	6%
Sector 14	9%	**Sector 58**	14%
Sector 15	5%	**Sector 59**	9%
Sector 16	11%	**Sector 60**	6%
Sector 17	23%	**Sector 61**	8%
Sector 18	17%	**Sector 62**	8%
Sector 19	12%	**Sector 63**	14%
Sector 20	6%	**Sector 64**	13%
Sector 21	29%	**Sector 65**	10%
Sector 22	96%	**Sector 66**	10%
Sector 23	11%	**Sector 67**	18%
Sector 24	36%	**Sector 68**	1%
Sector 25	20%	**Sector 69**	2%
Sector 26	30%	**Sector 70**	10%
Sector 27	26%	**Sector 71**	14%
Sector 28	22%	**Sector 72**	12%
Sector 29	5%	**Sector 73**	29%
Sector 30	34%	**Sector 74**	14%
Sector 31	2%	**Sector 75**	12%
Sector 32	34%	**Sector 76**	11%
Sector 33	257%	**Sector 77**	16%
Sector 34	3%	**Sector 78**	16%
Sector 35	4%	**Sector 79**	14%
Sector 36	2%	**Sector 80**	14%
Sector 37	3%	**Sector 81**	15%
Sector 38	1%	**Sector 82**	15%
Sector 39	2%	**Sector 83**	14%
Sector 40	6%	**Sector 84**	11%
Sector 41	10%	**Sector 85**	14%
Sector 42	1%	**Sector 86**	18%
Sector 43	18%	**Sector 87**	14%
Sector 44	11%	**Sector 88**	15%

4.8.3. Life Cycle Analysis of the transition scenarios

The following tables show the results of the life cycle environmental impact assessment of the evaluated scenarios for the CGWPR and CNR-PER impact indicators.

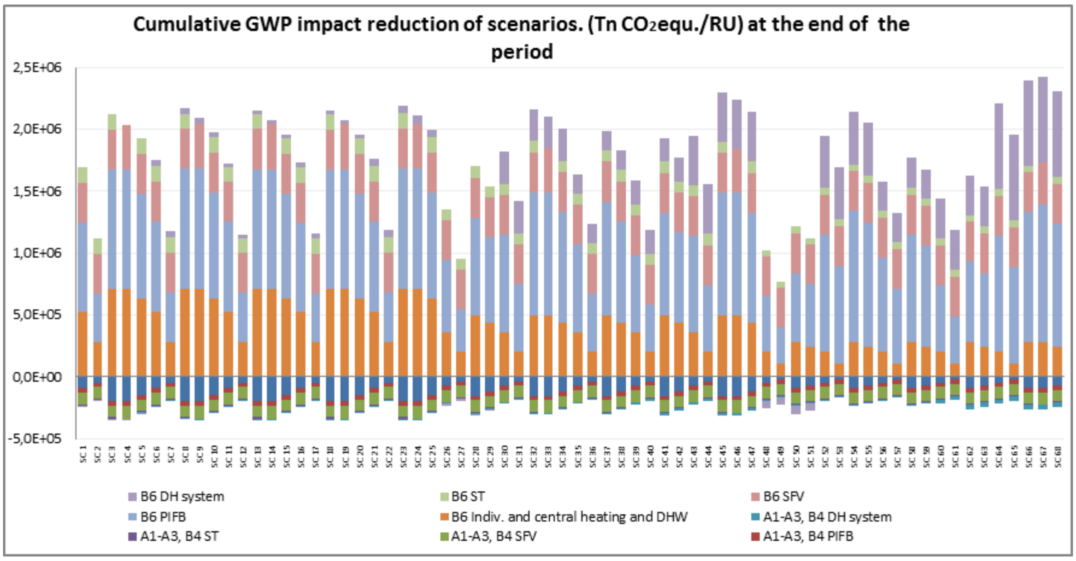

Figure 78. Cumulative GWP impact reduction of the scenarios at the end of the transition period in (Tn CO_2 equi./RU).

The resuts are disaggregated by the interventions included in each scenario, distinguishing between the impacts of the operational phase and the rest of the phases of the life cycle that have been considered. The values of the tables are included in section 6.5 of the Appendix.

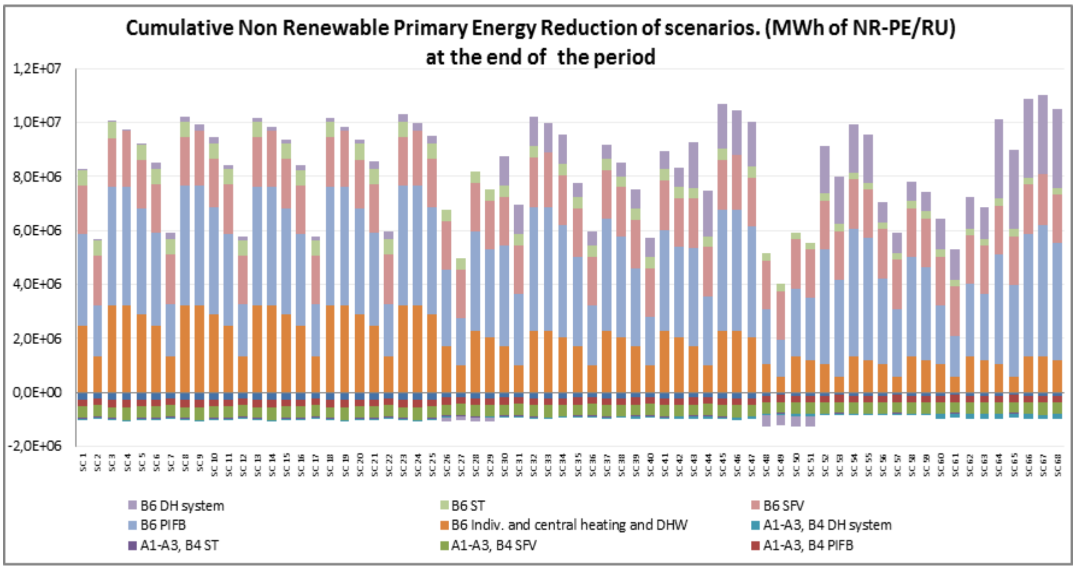

Figure 79. Cumulative Non Renewable Primary Energy Reduction of scenarios. (MWh of NR-PE/RU savings at the end of the period).

The results show that although the impacts of the rest of the phases of the life cycle are rapidly compensated during the first few years of the energy transition period, the emissions are relevant and vary considerably depending on the scenario prioritised. Moreover, it can be seen that the two indicators follow a similar tendency.

Finally, it is observed that in the case study, refurbishment interventions show the most favourable ratio between the emission saving of the operational phase and the emissions that ocurred in the rest of the phases. The solar thermal technology is in second position followed by a combination of individual and central heating and DHW systems, different district heating solutions, and the solar photovoltaic systems.

CHAPTER 5

Main conclusions and future work

5. Chapter 5: Main conclusions and future work

5.1. Summary of conclusions

The awareness of municipalities about the need of transforming the way in which cities consume and generate energy is increasing. However, the planning process is still complex due to the lack of consensus on the way to assess and prioritise different alternatives under a holistic framework. This thesis has developed a methodology for evaluating and prioritising alternative energy transition scenarios that seek to transform energy generation, distribution, and consumption of the building sector of cities.

The research hypothesis has been proven with the developed methodology. The supply chain analysis of interventions has demonstrated to be effective for combining the energy modelling and the adapted life cycle impact assessment methodologies with other methods used for macroeconomic impact assessment.

Besides, the applicability of the methodology developed has been proven with an example focused on the prioritisation of alternative energy transition scenarios for Donostia-San Sebastián from 2017 to 2067. Here, the methodology has served to compare the impacts associated with 68 scenarios defined for the transformation of the city to a low carbon future. The results show a good sensitivity of the methodology for reflecting differences even for the comparison of scenarios with a similar combination of interventions.

The usefulness and applicability of the results are manifold. The application of the methodology in the context of the energy planning of cities will provide quantitative criteria for each of the dimensions and the scales evaluated. As is described in section 5.1.4, the results will be useful for supporting many difficult decisions that need to be taken in our cities in the future.

Further discussion and specific conclusions are presented in the next sections following the phase structure of the developed methodology. The conclusions are focused mainly on those phases where the methodological contribution has been most relevant.

5.1.1. Conclusions of Phase III. Analysis of the city by evaluating the most relevant districts and identification of the potential technologies and interventions

In the next few years increased efforts will be made for transforming the way that cities consume and produce energy. In a process where the fossil fuels consumed in cities will tend to decrease, alternative energy generation system will have to provide the flexibility and security of supply that traditional generation systems currently allow. This is a huge challenge that will have to be solved progressively by combining multiple solutions and approaches. Different solutions for the distributed renewable and low carbon energy generation, energy efficiency measures, the improvement of distribution networks, the optimisation of storage options, and many other smart solutions for cities will have to be integrated into their energy systems. In this context, a need for studying hourly energy data was identified within this thesis. The design and planning of the combination of all these measures require detailed data that, unfortunately nowadays, is not commonly available. The developed methodology enables the profiling of cities' building energy use, while ensuring that the developed data can be of use in the following steps of energy planning. In this sense, the developed energy profiles can serve as an input for energy planning tools that are used for matching the availability of resources with actual energy demands, and for prioritising alternative scenarios for a city energy system.

Moreover, the methodology identifies the main requisites in the data gathering process and the key parameters for the energy performance assessment of the buildings of a city. It is also pointed out how the lack of data on energy certificates of buildings makes difficult the immediate application of the first option of the methodology. In this case, the application of an alternative method for a city analysis based on the data available in the cadastre of the city combined with the modelling of reference buildings is demonstrated. The combination of a top-down approach and a bottom-up approach has proven to be adequate for validating the results of the model with actual data of the city. Finally, the methodology proposes an approximation of the use of simultaneity factors at the district or city scale.

The proposed methodology combined with the monitoring of city energy use and actual performance of the systems that are already implemented in our cities can help to generate the data needed for the next steps of the energy planning of cities.

The application of the methodology has been demonstrated through the case study in Chapter 4, where it has been shown that a reasonable approximation of the city building energy demand can be achieved. Results reveal that despite the improvements in the field of building energy modelling, aspects such as occupant behaviour still result in a considerable gap between the theoretical and the actual energy consumption.

The results obtained through using the methodology are applicable in many cases. For example, when designing district heating and cooling networks for cities, this type of studies combined with different heat storage options can help to optimise the selection and sizing of the generation systems for base and peak loads. It has been shown how the calculated detailed hourly energy demand and the base and peak loads depend on the coverage of the district heating system and the simultaneity factors. This analysis can help with the difficult decisions that commonly arise, for example, when deciding on the extension of district heating systems throughout cities. In such cases, important issues to analyse are the district network losses, which increase with network length and coverage, in relation to overall system efficiency and viability, which improve in the largest networks due to the economies of scale and the simultaneity factors.

The study can also be extended to consider scenarios for the expected reduction of the building energy demand in cities due to progressive building refurbishment to higher energy efficient standards. As the total building energy demand of districts and cities decreases, hourly energy profiles and peak loads, taking into account simultaneity, will be increasingly important for evaluating district energy generation systems and networks at different scales, and can provide key information for evaluating the viability of investments and business models of energy infrastructures.

5.1.2. Conclusions of Phase IV. Definition of the potential transition scenarios of the city

Energy transition scenarios serve as instruments for reflecting and planning the long-term energy strategy of the city evaluated. They include details on the progressive implementation of specific interventions in different areas of the city and in different moments of the transition period.

As is concluded in Chapter 2, in most cases, energy transition scenarios are defined for the entire city following a top-down approach. For this phase the methodology, has focused its efforts on describing a procedure for defining alternative energy transition scenarios for cities following a bottom-up approach and aggregating the implementation of interventions in each district. This approach has demonstrated to be effective for considering in each scenario not only the temporal aspects but also the distributional aspects within the city. More concretely, it allows considering the most relevant barriers associated to the implementation of interventions, which in many cases can be associated to specific areas of the city.

The model has distinguished between the evolution of energy prices and energy technology cost trends with respect to aspects, such as the implementation rate of interventions. The latter characteristic is incorporated in order to provide flexibility and accuracy in the definition of scenarios and to facilitate the disaggregation of results on a yearly basis. This aspect is interesting for evaluating in detail the key moments across the period in which the main investments need to be made. It also serves to develop a better understanding of the influence of the adoption of different business models and the speed with which the CO_2 emission reduction targets are reached. In contrast, the energy price and the technology cost trends are aspects that cannot be controlled and that incorporate many uncertainties in the results. Although fossil fuel and electricity price projections have been the focus of many studies, their costs are heavily influenced by many aspects, such as the market, CO_2 trading, and resource availability. In a similar way, technology costs trends incorporate many uncertainties to the model. Taking into account that there are many uncontrolled aspects affecting their learning curves, the existing projections should not be taken into account in the short-term. The need of further research in the field is stressed in this thesis in order to generate projections for many other technologies and energy related interventions, especially for those used at city scale, which are not considered traditionally.

As a general conclusion, the results have demonstrated that the definition of scenarios is an intermediate but critical step that needs to be assessed carefully. It needs to be done taking into account that in many cases, small variations in certain hypotheses can provoke significant variations in the long-term results. The sensitivity analysis shows that, this statement affects, in particular the parameters of the discount rate and the evolution of energy prices.

Finally, it can be seen that this part of the methodology could also be adapted and extended to city scenarios that incorporate the remainder of the sectors of cities, such as mobility, and industry. In this case, considering the potential interventions and the barriers associated with each sector are the main difference.

5.1.3. Conclusions of Phase V. Multi-criteria impact assessment of alternative energy transition scenarios for cities

The increasing necessity of new approaches for impact assessment in the context of energy planning is manifold. Linking energy modelling with holistic impact assessment methodologies in such a way that the long-term energy transition scenarios for cities can be designed and assessed will be one of the main challenges in the field.

In this regard, the flexibility of methods and tools for facilitating the connection to each other will be one of the most critical aspects of ensuring this holistic perspective. Unlike in the case of studies at the country level, many municipalities do not have the necessary resources for carrying very detailed analyses that cover all the relevant fields of their cities. The adaptation of detailed national models to their particular reality is out of reach of many cities. This is why this thesis stresses that the priority of this type of methodology should be to facilitate their applicability in order to reach as many cities as possible and maximise the global impact.

Taking this into account, this thesis identifies and tries to overcome the current difficulties linked to the multi-criteria and multi-scale impact assessment. Connecting energy modelling at various scales with the time variation of city transitions scenarios and different methodologies for impact assessment is the most critical step.

The analysis carried out traditionally for each scale considered in the methodology pursues different objectives. It has been demonstrated that the analysis at the project or intervention scale clearly responds to a viability point of view and that it provides useful information mainly for the investor. The methodologies and tools used in this case do not provide directly information for other type of analysis with a wider perspective. For the impact assessment of the energy transition scenarios of cities, the adaptation of existing methodologies to the scale, the temporal range and the purpose of the study has been necessary. Within this phase evaluating in an annual basis and considering simultaneously all the interventions that are active in each year of the transition scenario results essential. The most relevant adaptations in the framework of the life cycle assessment have been related to including explicitly the time axis and the capacity to incorporate both the simultaneous evaluation of interventions and the staggered implementation of new interventions across the transition period.

Impact assessment at the regional scale, on the other hand, responds to a more strategic point of view that is in general far from the analysis at the intervention scale. It is difficult to stablish relations between the multiple and very specific energy interventions to be implemented in different areas of a city with their macroeconomic regional effects. Nevertheless, from a strategic point of view, understanding the implementation potential of specific energy technologies in cities and their regional impact in the GDP increase, employment creation, and diversification of the industrial sectors has attracted the interest of policy makers. In this regard, the study has demonstrated that, the intervention supply chain approach adopted for creating an exogenous shock is useful for connecting the life cycle cost assessment at the intervention and city scale, with the macroeconomic modelling approach at the regional level. More precisely, it has been useful for maintaining the temporal dimension of each investment and cost across the methodologies.

The application of the methodology to the case study has proven that there are some difficulties with its immediate application. The first one is the current lack of information regarding the supply chain of energy-related interventions. Even in the case of technologies for which there is some information available, this data needs to be adapted to the reality of each region. Another difficulty is the lack of standardisation of IO tables with regard to the classification of commodities and sectors. Moreover, regional IO tables are not always available in many countries, although some methodologies exist for adapting country IO tables to the regional scale.

It has been also proven that the disaggregation of results achieved by using this approach serves to understand how the deployment of each intervention can help to potentiate specific subsectors of the economy. This will allow planning the contribution of cities to the enhancement of certain regional strategies.

The results provide the multipliers for each intervention applicable in the city. Those multipliers can be used for evaluating the direct, indirect, and induced impacts in regional GDP and employment. Differences between multipliers evidence the relevance of properly selecting energy technologies. Variations of between 40% and 46% have been observed in the potential of each technology or intervention to create economic activity and employment. Here, the relevance of ensuring local manufacturing and not only local distribution has been demonstrated.

The relevance of considering not only the indirect effects but also the induced effects is also observed. The results show an increase of between 9% and 22% in the impacts created when the induced impacts are also considered. Moreover, a more detailed analysis of the disaggregated results shows that there are several sectors in which the impacts can only be observed if the induced effects are evaluated.

The validation of the methodology also shows that although the impacts created in the region due to the deployment of city transition scenarios are significant, the main potential is linked with the evaluation of the replication of interventions in other areas of the city and in other cities of the region. This aspect goes in many cases beyond the particular interest of the city evaluated.

From another point of view, the results also provide a comparison of the life cycle environmental and economic impact assessment of the long-term transition scenarios for the city. Although the environmental emissions avoided in the operational stage compensate the emissions of the remainder stages of the life cycle, their effects are relevant throughout the entire transition period. In the economic dimension at the city scale, the results reveal aspects such as that, different scenarios can be favoured in the prioritisation phase depending on who is responsible of the investment. The defined indicators allow distinguishing the interests of the citizens from the point of view of the public and private companies. Linking the environmental and economic dimensions, it is observed that the consideration of the shadow costs of the CO_2 emissions in the medium and long-term can be decisive for the cost-effectiveness of some renewable energy technologies. Depending on the evolution of the costs associated with the environmental emissions, and with other externalities, the economic performance of the transition scenarios will be substantially influenced.

Finally, the benefits and the potential for obtaining the yearly evolution of the impact indicators are evidenced. For example, from the municipality point of view, it serves to manage the timing of investments, identify the optimum business models, and plan and manage cash flow.

From a wider perspective, it can be said that the developed multi-criteria and multi-scale impact assessment methodology provides a set of quantitative criteria that will be useful for supporting different decisions that will be critical for the development of our cities.

5.1.4. Conclusions of Phase VI. Prioritisation of energy transition scenarios

The prioritisation phase is one of the most decisive steps taken just before making the final decision. In this phase, the continuous interaction between the analyst and the decision maker becomes essential. Chapter 2 has shown that there are many methodologies that can be used for combining the quantitative results from the scenario modelling with the multiple qualitative criteria selected for the prioritisation. Both the selection of the criteria and their weighting are critical steps that will condition the results.

This thesis provides an example of the use of the analytical hierarchy process for the city energy planning, establishing links between the results of the impact assessment of the scenarios with the prioritisation criteria. The case study has shown that the results are heavily influenced by the weights assigned to the different criteria. It is observed also that the alternative three scenarios propose a different order for the selection of scenarios. Therefore, considering that this is the most subjective step of the global methodology, it is necessary to evaluate different alternatives in the sensitivity analysis.

It is also remarkable the potential of the cutting rules to limit the number of scenarios that will arrive to the prioritisation phase. Here, there needs to be consultation on the section focused on defining the objectives of the study in collaboration with the municipality concerned.

From a wider perspective, the usefulness of these types of processes that support decision-making in energy planning, which in many cases is guided by a political vision can be pointed out. Collaborative works between municipalities and technical experts can help to overcome the existing gap between the long-term planning horizons and the short-term vision of the interventions implemented in our cities.

5.2. Limitations and future works

The work of defining and evaluating energy transition scenarios for cities is far from complete. There are many directions for further exploration. Several simplifications were adopted in this thesis in order to overcome the current limitations in data availability. For example, in the consideration of the phases of the life cycle assessment, further research would facilitate the extension of the methodology, especially for the social dimension in both the intervention and in the city scales.

This is also applicable to the consideration of phases for the composition of the shock through the supply chain analysis. In this work, the effects in regional socioeconomic development due to the consideration of cumulative operational energy use and savings as well as the effects of the end-of-life stage have not been included. In this regard, further research related to consideration of the potential negative effects on the productivity and employment of energy producer sectors due to the energy savings obtained by the scenarios would be necessary. Full consideration of the operational phase would open up the possibility of considering other potential positive impacts related to the consumption of locally generated energy resources.

A better understanding of the influence of the end-of-life stage is necessary. This will help to understand also the potential of reusing residues generated by the interventions incorporated in the scenarios as resources for new products, as is proposed by the circular economy concept. Here, consideration of the use of other resources, such as critical materials or water, will become increasingly challenging in the coming years.

Improving methodologies and tools for the analysis of the building sector of cities would also be an interesting subject for research. Advances in 3D modelling which incorporates semantic information extracted from the city cadaster or from other databases would facilitate the application of the methodology developed in Chapter 3 for profiling city energy use. Moreover, extending the methodology to other sectors of the city ensuring the interactions between sectors would be also of interest.

Further exploration of the influence in the results due to the selection of new business models or the incorporation of new impact indicators are other directions that could be followed. For example, considering indicators such as the impact in household disposable income, and its disaggregation by different groups of rents in society, would allow an evaluation of how the generated increase in income is distributed across the different social classes.

APPENDIX

6. APPENDIX

6.1. Chapter 4. Section 4.3.2. Energy characterisation of the area of study

6.1.1. Main characteristics for district energy modelling

The data gathering process followed for the energy characterisation of the building stock of evaluated districts in the city is documented at the end of the Appendix in section 6.6.1. This section includes the maps of the districts, where the buildings evaluated are coded. Moreover, main characteristics of each building are detailed, including aspects, such as number of plants, total area, floor area, area of the façade, and age. Further information detailing whether these buildings have been the subject of any refurbishment measure, an estimation of useful roof space, the protection grade, and the existence of cooling system or central heating systems is also included.

6.1.2. Reference building energy demand

This section describes the process used for defining the reference buildings used for the baseline analysis of the districts. The limits of annual energy demand of each building energy performance level considered in the study have been calculated according to the specifications in (IDAE, 2015), where the following procedure is proposed for both residential buildings and for buildings with other uses. The analysis corresponds to the climatic zone of Donostia-San Sebastián, D1.

Residential buildings

The index C_1 is used for defining the limits of energy demand of new buildings with energy performance levels of A, B, and C limiting with D. On the other hand, the index C_2, is used for defining the limits of energy demand for existing buildings with energy performance levels of D, E, F, and G. These indexes are calculated with the following equations.

$$C_1 = \frac{R * \left({I_0}/{I_r}\right) - 1}{2 * (R - 1)} + 0.6$$

$$C_2 = \frac{R' * \left({I_0}/{I_s}\right) - 1}{2 * (R' - 1)} + 0.5$$

Equation 22

I_0 is the value of the indicator evaluated (energy demand in this case) of the objective building. I_r, corresponds to the average value of the indicator evaluated for new residential buildings, which in Donostia-San Sebastián is considered 46.9 kWh/m^2. I_s, corresponds to the average value of the indicator evaluated for existing residential buildings, which in the case of Donostia is considered 118.8 kWh/m^2. R is the ratio between I_r and the indicator corresponding to 10% percentil of new residential buildings. This value is 1.7 for Donsotia-San Sebastián. R' is the ratio between I_r and the indicator corresponding to 10% percentil of existing residential buildings. This value is 1.1 for Donsotia-San Sebastián. The limits of the indexes C1 and C2 are described in Table 35.

Table 35. Limits for the indexes C_1 and C_2 for each energy performance level of residential buildings.

Energy efficiency level	
A	C_1<0.15
B	0.15<C_1<0.50
C	0.50<C_1<1.00
D	1.00<C_1<1.75
E	1.75<C_1 <C_2<1.00
F	1.75<C_1 1.00<C_2<1.50
G	1.75<C_1 1.50<C_2

Following the same procedure, annual energy demands for heating and DHW of residential buildings are obtained for each reference building depending on their energy performance level, from A to G.

The reference building used for defining the hourly distribution of the energy demand for residential buildings with energy performance level of E, corresponds to the building shown in Figure 80, which corresponds to an existing building of the district of Amara in Donostia-San Sebastián. This building was previously modelled in detail and evaluated (Oregi et al., 2017). The building corresponds to a multi-family residential building constructed in 1963, and it is considered as a building with a high replicability potential in the city. The building consists of a commercial ground floor and nine residential floors, with a total net floor area of 9484 m^2 and a heated surface of 8574 m^2. The building is naturally ventilated and has a centralized natural gas heating system. Due to the climatic conditions in Donostia-San Sebastián, no cooling system is considered as necessary, and no renewable energy systems are installed. Each house has individual DHW systems with a variety of electricity-based hot water systems.

The model is also used for evaluating the energy consumption of residential buildings with regard to the ventilation, lighting, and appliances. The envelope of the building has the following characteristics: U-value of the façade 1.12 W/(m^2 K), U-values of the roof 2.34, U-values of the first floor of 1.79 and a U-value of the openings of 5.77 W/(m^2·K) for the glazing and 4.2 W/(m^2·K) for the frame. Further details related with the simulation parameters of the building are available in the reference provided.

Figure 80. Render of the residential building used in the case study. Building modelled in the Design Builder software (Oregi et al., 2017).

The remainder residential reference buildings follow the same simulation parameters, such as occupancy, schedules, and set-point temperatures considered in this building. However, the reference building corresponding to an energy performance level limiting between C and D, is equivalent to a building that follows strictly the minimum requirements of the Spanish Technical Building Code in this climatic zone.

Table 36 shows main characteristics of energy demand of all reference residential buildings. Electricity consumption, on the other hand, is common for all the energy performance levels, 45.4 kWh/(m^{2}year).

Table 36. Heating and DHW energy demand of the residential reference buildings used in the district energy model.

	A	B	C	D	E	F	G
Residential heating kWh/(m^{2}year)	12.6	19.9	31.1	56.5	100.0	120.1	130.6
DHW demand kWh/(m^{2}year)	13.2	13.2	13.2	13.2	13.2	13.2	13.2

Energy simulations carried out in the Design Builder software provide the hourly distributions shown in Figure 81, corresponding to heating energy demand of a typical winter week for each of the residential reference buildings considered in the study.

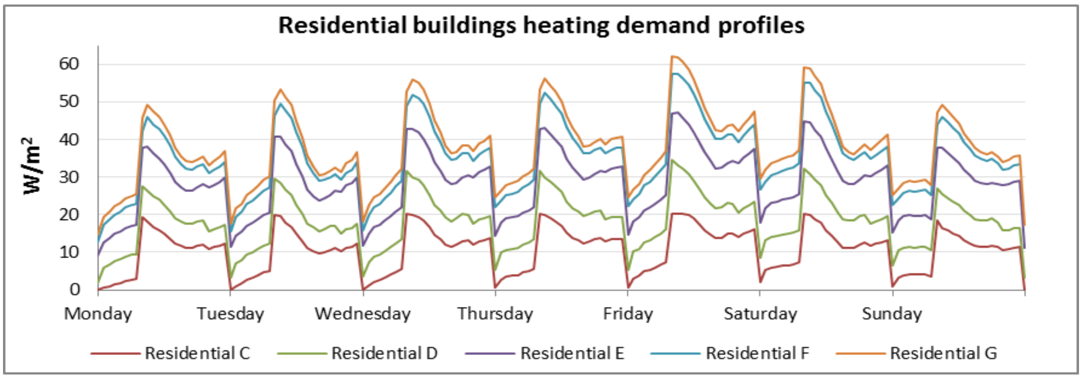

Figure 81. Hourly distribution of the heating energy demand for a typical winter week corresponding to each residential reference buildings.

<u>Office buildings</u>

For office reference buildings, the limits of energy demands (both for heating and cooling) between the energy performance levels are also defined according to the method defined in (IDAE, 2015), where the following equation is proposed.

$$C = \frac{I_o}{I_r}$$

Equation 23

Where, I_0 is the value of the indicator evaluated (energy demand) for the objective building. I_r is the average value of the indicator evaluated for new office buildings, which in the case of Donostia is considered 18kWh/m^2 for heating, and 27kWh/m^2 for cooling. The limits for the index C are described in Table 37.

Table 37. Limits of the index C for each energy performance level of the office buildings.

Energy efficiency level	
A	C<0.40
B	0.40<C<0.65
C	0.65<C<01.00
D	1.00<C<1.30
E	1.30<C<1.60
F	1.60<C<2.00
G	2.00<C

The reference building used for calculating the hourly distributions used in the study was modelled according to the specifications defined in (Ecolabel for Office Buildings, 2011). This project defines the reference office building as representative of the existing office buildings in

Europe. Following these specifications, the building was adapted to the climatic zone of Donostia-San Sebastián.

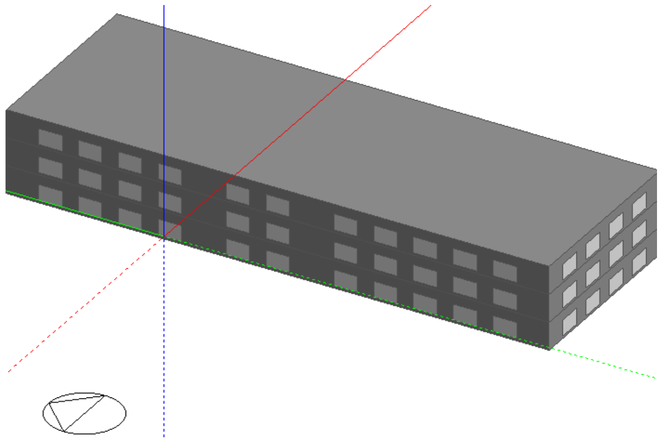

Figure 82. Render of the office building used in the case study. Building modelled in the Design Builder software.

This building has a total area of 4620 m^2 divided into three floors. The glazing area corresponds to 30% of the external wall. With regard to the construction materials, for a reference building with an energy efficiency level limiting between C and D, the following characteristics can be highlighted; insulated cavity wall with outer layer of brickwork and with concrete block as indoor layer with a U-value of 0.66 W/m^2 K, floor of insulated concrete, screed, and timber with a U-value of 0.49 W/m^2 K, roof of plasterboard, insulation and asphalt with a U-values of 0.38 W/m^2 K, and a wooden frame with double layer glazing with a U-values of 2.9 W/m^2 K.

The use, setting, and occupancy schedules and the lighting, heat gains, and temperature requirements are shown in the table below.

Table 38. Main characteristics of the office reference buildings.

Characteristics	
Occupancy Hours	7h to 19h
Occupancy days per year	260 days/year
Density of occupancy	0.11 person/m^2
Metabolic rate	120 W/person
Set point cooling	25 Celsius degrees
Set point heating	21 Celsius degrees
Equipment	12 W/m^2
Ventilation	10 W/m^2

The remainder office reference buildings follow the same simulation parameters, such as the occupancy, schedules, and set point temperatures considered in this building. Table 39 includes the energy demands of each reference office building. Electricity consumption is common for all energy performance levels, 91.6 kWh/(m^{2}year).

Table 39. Heating and cooling energy demand of the office reference buildings used in the district energy model.

	A	B	C	D	E	F	G
Office heating kWh/(m^{2}year)	10.0	9.5	14.9	20.7	26.1	32.4	40.2
Office cooling kWh/(m^{2}year)	13.0	14.2	22.3	31.1	39.2	48.6	60.3

Hourly distribution of heating energy demand and cooling energy demand for a typical winter week, and a typical summer week, corresponding to each of the defined office reference buildings are shown in Figure 83. All the curves illustrated are obtained from the results of the simulations of reference buildings in the Design Builder software.

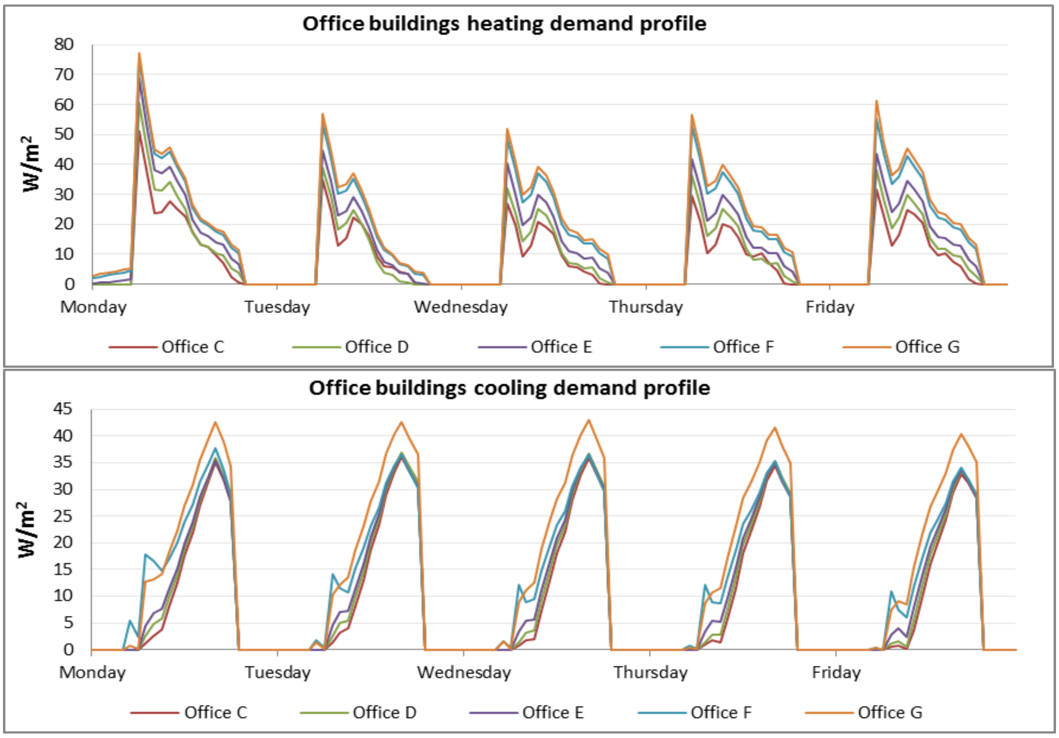

Figure 83. Heating demand loads of the reference office buildings for a typical winter week and cooling demand loads for office buildings in a summer typical week.

6.1.3. Energy characterisation of the districts evaluated

This section provides further information regarding the energy demands of the area evaluated in Donostia-San Sebastián. The main characteristics regarding the hourly distribution of energy demands of the six districts evaluated in the study are included here. Figure 84 shows daily peak loads for heating demand of residential and office buildings in each of the districts.

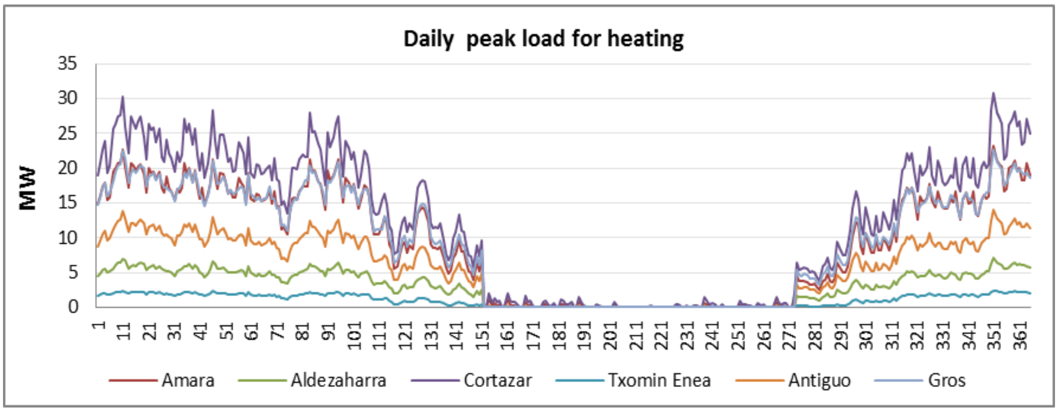

Figure 84. Daily peak loads of the heating demand of the residential and office buildings in each of the districts evaluated for the city.

These results provide useful information for dimensioning individual energy generation systems of buildings in the baseline situation, before building refurbishment. However, Figure 85 shows the daily peak loads for heating demand of residential and office buildings in each of the districts, considering the demand simultaneity. It can be seen how energy peak load reduction is significant in all the districts evaluated. In this case, the results are useful for dimensioning the energy generation and distribution systems at district scale for the baseline situation of the city.

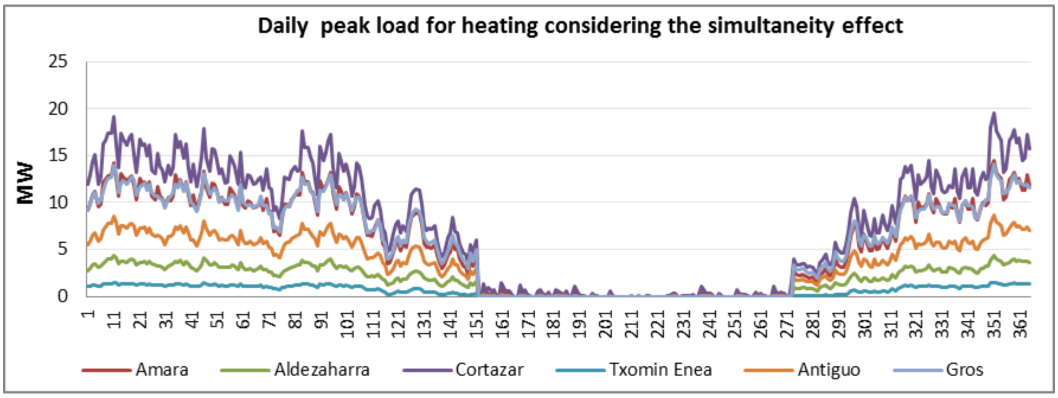

Figure 85. Daily peak loads of the heating demand of the residential and office buildings in each of the districts evaluated for the city taking into account the simultaneity effect.

Moreover, in the coming years, as the existing buildings are progressively refurbished energy peak loads will decrease. This aspect, combined with energy generation at district scale (or covering various districts), will result in even smaller energy peak loads.

Regarding cooling demand, Figure 86 shows the daily peak loads distinguishing the districts evaluated in the study. It can be seen that the cooling peak loads of the districts are lower than the heating peak loads. This is due to the relation between the number of residential and office buildings with heating demand, respect to the reduced number of office buildings of the districts.

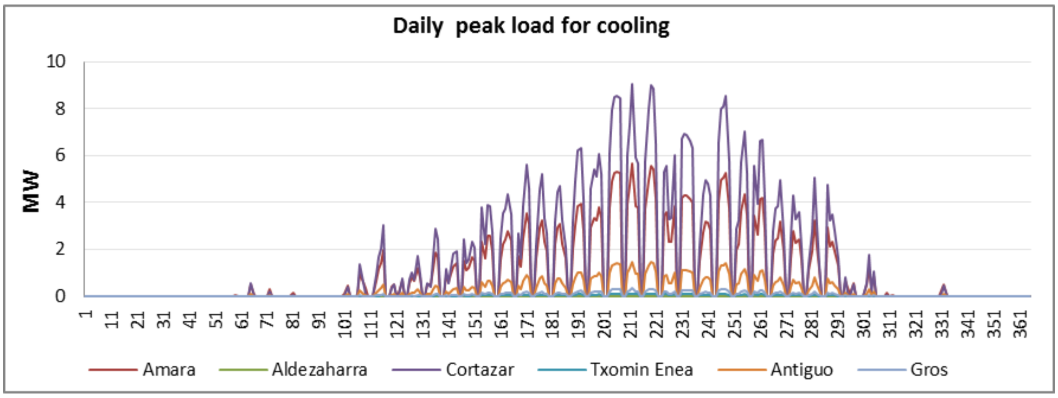

Figure 86. Daily peak loads of the cooling demand of the office buildings in each of the districts evaluated for the city.

Finally, the following two figures show the annual hourly demand of heating, cooling, and domestic hot water, as well as the electricity consumption of all the area evaluated in the case study. This represents the main input to the energy modelling.

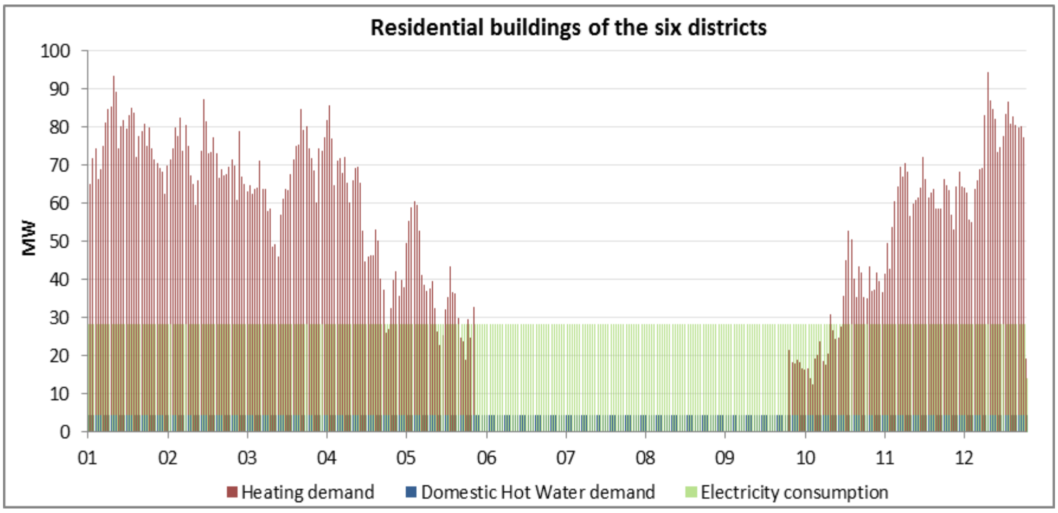

Figure 87. Hourly heating demand, DHW demand, and electricity use of the residential buildings included in the six districts evaluated.

Figure 87 shows the results for residential buildings, and Figure 88 shows the results for the office buildings studied. It can be seen how the difference between heating energy demand and cooling energy demand is much greater than the previously described difference in energy peak loads.

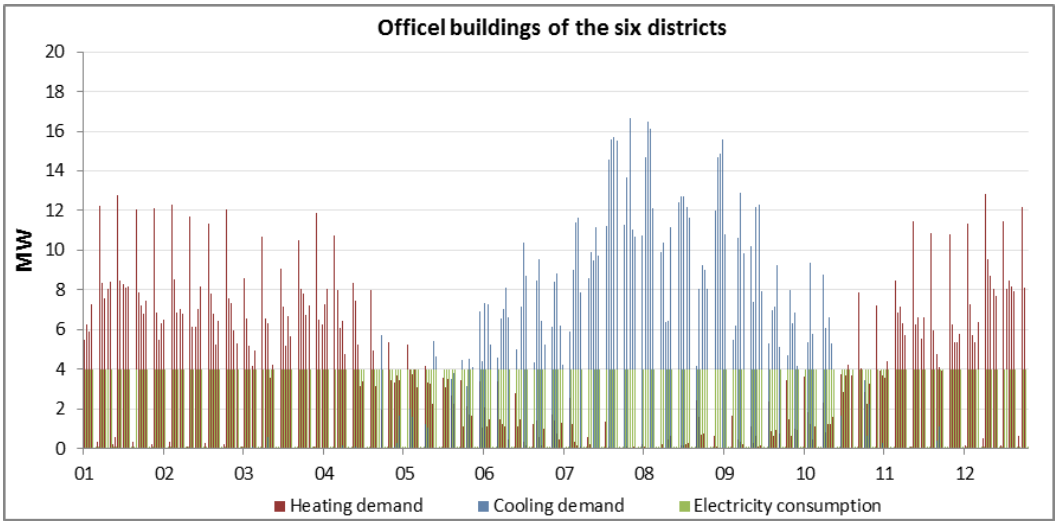

Figure 88. Hourly heating demand, cooling demand, and electricity use of the office buildings included in the six districts evaluated.

6.2. Chapter 4. Section 4.3.3. Identification of the potential technologies and interventions

In this section, the main considerations for the analysis of interventions are described. On the one hand, the main technical aspects and parameters of the models used for the analysis of the operational stage of interventions are described. Besides, a disaggregation of processes used in the life cycle analysis of district scale interventions is presented. Finally, a disaggregation of the environmental impact assessment results of all the interventions included in the study are provided.

6.2.1. Energy modelling of interventions

Solar thermal systems

The thermal energy generated by solar thermal systems installed on buildings has been calculated according to the British Standard EN 15316-4-3: 2007 (BS EN 15316-4-3, 2007), to cover a minimum of 55% of the domestic hot water demand. In the study, an annual solar irradiation in a horizontal surface of 1171.15 kW/m^2 year has been considered. With regard to the solar panels, protected flat plate solar collectors with an efficiency of 50%, oriented to the south, and with an inclination of 45 degrees has been considered, with the corresponding thermal storage systems in each case. Finally, it has been considered that the distribution elements of the systems are thermally well insulated. For the reference case evaluated in section 4.3.3, in which 11000 m^2 of collectors are progressively installed in building roofs of the city, an average energy generation of 404.9 MWh_{th}/m^2 is considered, with an average auxiliary energy consumption of 4 kWh_e/m^2, and 7 kWh_{th}/m^2 of heat losses in the tank.

Solar photovoltaic systems

The electricity generation by solar photovoltaic systems installed in buildings has been calculated according to the British Standard EN 15316-4-6:2007 (BS EN 15316-4-6, 2007). The selected solar panels correspond to mono-crystalline silicon collectors oriented to the south, with an inclination of 45 degrees, a performance of 0.8, and a peak power coefficient of 0.15. The annual amount of power generated per m^2 of panel will be 137 kWh.

Individual and central boilers and heat pumps

Different efficiencies have been considered for the boilers used in the study. For the case of new systems, natural gas-fired individual and central boilers are assumed condensing boilers with a nominal efficiency of 0.97, and in the case of biomass central boilers an efficiency of 0.87 has been considered, as proposed in the report on cost optimal calculations and comparison with the current and future energy performance requirements of buildings in Spain (Ministerio de Fomento de España, 2013).

In the case of the existing buildings, the energy performances of energy generation systems have been considered as is defined by the Spanish regulation of energy certification of existing buildings (IDAE, 2011), which proposes a performance of 0.75 for individual natural gas-fired boilers, 0.7 for natural gas, gas oil and biomass central boilers, 0.65 for gas oil-fired individual boilers, and 0.99 for electric boilers. In all the cases, 3% of efficiency loss is assumed due to the internal distribution and aging losses. Finally, in the case of the electric heat pump (source: ambient temperature), a nominal coefficient of performance of 3.5 has been considered.

For the reference case evaluated in section 4.3.3, it has been considered that 4432 heating systems (3842 individual natural gas boilers, 86 central heating systems and 333 electric heating systems) are replaced by new systems.

Building refurbishment

In all the buildings that are susceptible to be refurbished, a combination of measures is proposed (depending on their initial energy performance) in such a way that an energy demand equivalent to the reference building defined as ‘C’ is achieved after being refurbished. In this regard, a combination of advanced insulation and the advanced window measures are applied for those buildings with an energy efficiency level of G according to the classification defined. A combination of efficient insulation and advanced window is proposed in the case of buildings classified as ‘F’. A combination of basic insulation and advanced window for those buildings classified as ‘E’ and advanced windows are assumed for buildings classified as ‘D’.

The energy measures characterisation has been made according to the description and data provided in (Oregi, 2015), that describes the measures as follows:

- Windows advanced: Low-emissivity coated glazing 1.4 W/(m^2·K) and wooden frames 1.2 W/(m^2·K).
- Insulation basic: An increase of 5 cm for the façade, 8 cm for the deck and 6 cm for the first floor slab.
- Insulation efficient: An increase of 9 cm for the façade, 13 cm for the deck and 10 cm for the first floor slab.
- Insulation advanced: An increase of 25 cm for the façade, 30 cm for the deck and 15 cm for the first floor slab

District scale energy generation, storage and distribution technologies

The energy calculations for the selected energy generation, storage, and distribution technologies have been made according to the specifications of (EINSTEIN project. D5.6, 2015) ‘Decision Support Tool for stakeholders for selection, design and evaluation of STES’, that provides a free decision support tool for the techno-economic analysis of district scale energy generation, storage, and distribution solutions. The deliverable describes in detail all the equations used in the tool for the simulations, including the energy generation, the storage, and the distribution to the final user. The tool, therefore, allows designing different configurations of district heating and storage solutions, and an estimation of the energy consumption and the CAPEX and OPEX of the system.

For all the district scale interventions considered in the study, a centralised generation configuration has been used. In this configuration, boilers, cogeneration units, and the energy generated by solar thermal collectors are placed at the storage tank level (supply side), in order to heat water from the storage tank when is required. Later, this hot water is distributed to the load side through the district heating network.

- Supply side

Regarding the supply side, efficiencies considered for the district heating boiler are the same as those described for the central heating systems, depending on the fuel used. In the case of configurations that include cogeneration units, a thermal efficiency of 0.45 and an electric efficiency of 0.37 have been assumed for natural gas-fired options and a thermal efficiency of 0.57 and an electric efficiency of 0.26 has been adopted for the case of wood chips-fired option.

Finally, in case that system configuration includes solar thermal energy generation, total solar collector area has been dimensioned in order to achieve a solar fraction (share of solar heat at the total heating demand) of 40%. High performing Flat Plate Collector (FPCh) have been modelled with an optical efficiency η_0 [-] of 0.79, a first order heat loss coefficient (λ_1) of 3.6 W/Km^2, and a second order heat loss coefficient λ_2 of 0.0071 W/K^2 m^2.

- Storage

From the different types of storage available for district heating with seasonal thermal storage, the water tank thermal energy storage option is selected for those cases, in which smaller storage volumes are necessary, and the pit thermal storage concept for other cases with storage volumes bigger than a few thousand m^3. The storage volume has been defined according to the following equation, where A_{SC} is the solar collector area, and where a value of 1.5 for the coefficient c_2 has been considered.

$$V_{STES}[m^3] = A_{SC}\ [m^2] * c_2\ [m^3/m^2]$$

Equation 24

For the initial temperature in the STES (Tmin), a reference value of 10 °C has been considered. A maximum temperature of 90 and 80 °C have been defined for the hot water tank concept and for the pit storage concept respectively. The H/D ratio has been defined as 1 (Milewski et al., 2014). The thickness of the insulation for the top and the bottom is assumed as 0.3 m, with a conductivity (λ) of 0.036 W/mK, and a thickness of 0.6 m, with a conductivity (λ) of 0.06 W/mK for the walls.

- Distribution network

The district heating network distance has been defined, when unavailable, according to the equation of (Persson & Werner, 2010). Where, A is the total heated area by the district heating network, and e_u is the relation between total heated area and plotted area of the district.

$$L = \frac{A}{e_u \times 61.8 \times e_u^{-0.15}}$$

Equation 25

A required temperature in the buildings between 60 and 80 °C has been assumed for conventional high temperature radiators, with a delta T in the district heating system of 30°C. The pipe internal diameter is assumed as 0.38 m, with an insulation of a U value of 0.78 W/mK. Finally, a district heating pump with an electrical efficiency of 0.62 and a hydraulic head of 60 m.w.c has been considered.

As an example of the type of results obtained with the model, the case of the CSHPNG intervention is presented.

Table 40. Example of the type of results obtained for the case of the intervention CSHPNG.

Month	Heating demand of buildings (MWh)	Demand covered by the STES (MWh)	Demand covered by the Boiler (MWh)	Consumption of the NG boiler (MWh)	Electricity consumption (MWh)
Jan	1,01E+04	0.00E+00	1.08E+04	1.05E+04	7.87E+01
Feb	8.21E+03	8.36E-01	8.91E+03	8.65E+03	6.42E+01
Mar	7.50E+03	1.46E+03	6.82E+03	6.62E+03	5.87E+01
Apr	6.04E+03	1.47E+03	5.32E+03	5.17E+03	4.73E+01
May	2.98E+03	1.77E+03	1.98E+03	1.92E+03	2.33E+01
Jun	7.06E+02	1.25E+03	2.10E+02	2.04E+02	5.52E+00
Jul	6.90E+02	1.46E+03	9.29E-01	9.02E-01	5.40E+00
Aug	7.01E+02	1.48E+03	0.00E+00	0.00E+00	5.49E+00
Sep	6.87E+02	1.44E+03	0.00E+00	0.00E+00	5.37E+00
Oct	2.29E+03	2.79E+03	2.70E+02	2.62E+02	1.79E+01
Nov	6.28E+03	2.13E+03	4.89E+03	4.75E+03	4.91E+01
Dec	9.48E+03	1.10E+03	9.15E+03	8.88E+03	7.42E+01

The results showed in Table 40 correspond to a system designed for a heating demand of 55612 MWh/year, a solar collector area of 40000 m^2, a storage volume of 6,000m^3, and a distribution network of 14 km.

6.2.2. Life Cycle Analysis of the interventions

Main processes considered in the life cycle analysis of the district heating interventions

The table below includes the main processes considered in the life cycle assessment of the district heating interventions. This table complements the information provided in Table 18.

Table 41. Main processes used of the district heating interventions.

System	Lifetime (years)	Product / process	Source	Unit
District heating solutions	50		(Oliver-Solà et al., 2009)	
Supply side	20	Cogen unit 1MWe, common components for heat + electricity	Ecoinvent	1 unit
		Gas boiler, RER	Ecoinvent	1 unit
		Furnace, wood chips, mixed, 1000kW	Ecoinvent	1 unit
Trench-works	20	CH: cement, unspecified, at plant	Ecoinvent	Kg
		DE: concrete block, at plant	Ecoinvent	Kg
		Sand, at mine	Ecoinvent	Kg
		Diesel, burned in building machine	Ecoinvent	MJ
Principal pipes	20	RER: steel, low-alloyed, at plant	Ecoinvent	Kg
		RER: polyurethane, rigid foam, at plant	Ecoinvent	Kg
		RER: polyethylene, HDPE, granulate, at plant	Ecoinvent	Kg
Surface box	15	RER: tap water, at user	Ecoinvent	kg
		CH: sand, at mine	Ecoinvent	kg
		CH: gypsum plaster board, at plant	Ecoinvent	kg
		CH: cement, unspecified, at plant	Ecoinvent	kg
		RER: cast iron, at plant	Ecoinvent	kg
		RER: brick, at plant	Ecoinvent	kg
		ES: electricity, low voltage, production ES, at grid	Ecoinvent	MJ
Tap	10	CH: bronze, at plant	Ecoinvent	kg
		RER: silicone product, at plant	Ecoinvent	kg
		CH: disposal, packaging cardboard, 9.6% water, to inert material landfill	Ecoinvent	kg
Pump	10	DE: stainless steel sheet PE	Ecoinvent	kg
		RER: cast iron, at plant	Ecoinvent	kg
Service pipes	20	RER: steel, low-alloyed, at plant	Ecoinvent	kg
		RER: polyurethane, rigid foam, at plant	Ecoinvent	kg

		RER: polyethylene, HDPE, granulate, at plant	Ecoinvent	kg
Components in buildings: Flow limiting	15	CH: brass, at plant	Ecoinvent	kg
Components in buildings: Heat meter	15	RER: sheet rolling, aluminium	Ecoinvent	kg
		RER: polyvinylchloride, at regional storage	Ecoinvent	kg
		RER: acrylonitrile-butadiene-styrene copolymer, ABS, at plant	Ecoinvent	kg
Components in the dwellings: Heat exchangers	15	DE: steel sheet galvanized PE	Ecoinvent	kg
		DE: stainless steel sheet PE	Ecoinvent	kg
		RER: copper, at regional storage	Ecoinvent	kg
		RER: polyurethane, rigid foam, at plant	Ecoinvent	kg
		RER: polyvinyl chloride, at regional storage	Ecoinvent	kg
		CH: disposal, building, waste wood, untreated, to final disposal	Ecoinvent	kg
		RER: packaging film, LDPE, at plant	Ecoinvent	kg
		CH: disposal, packaging cardboard, 19.6% water, to inert material landfill	Ecoinvent	kg
Components in the dwellings: tap (1 unit)	15	CH: bronze, at plant	Ecoinvent	kg
		RER: silicone product, at plant	Ecoinvent	kg
		CH: disposal, packaging cardboard, 19.6% water, to inert material landfill	Ecoinvent	kg

Environmental impacts of the interventions evaluated in the study

Table 42 shows the disaggregated environmental impact results of the interventions for the reference case described in section 4.3.3. The results are provided for CGWPR and CNR-PER environmental impact indicators, referred to the reference unit defined for the comparison of interventions (kWh of NR-PE savings in the operational phase during the life cycle of the intervention).

Table 42. Environmental impacts of the interventions evaluated in the reference case by phase of the life cycle.

	CGWPR (A1-A3, B4) (kGCO2eq./RU)	CGWPR (B6) (kGCO2eq./RU)	CNR-PER (A1-A3, B4) (kWh NR-PR/RU)	CNR-PER (B6) (kWh NR-PR/RU)
SPV	-2.74E-02	1.78E-01	-1.20E-01	1.00E+00
ST	-9.25E-03	2.17E-01	-3.98E-02	1.00E+00
PIFB	-2.87E-03	2.18E-01	-2.44E-02	1.00E+00
INGB	-1.32E-02	2.24E-01	-6.13E-02	1.00E+00
CNGB	-1.58E-03	2.24E-01	-7.37E-03	1.00E+00
CBB	-3.91E-03	2.16E-01	-1.08E-02	1.00E+00
HP	-2.71E-02	2.34E-01	-3.44E-02	1.00E+00
DHCHPNG	-3.93E-02	1.49E-01	-1.91E-01	1.00E+00
DHCHPB	-3.01E-03	2.18E-01	-1.42E-02	1.00E+00
DHNGB	-4.03E-03	2.51E-01	-1.90E-02	1.00E+00
CSHPNG	-2.02E-02	2.41E-01	-8.83E-02	1.00E+00
CSHPB	-1.10E-02	2.27E-01	-4.64E-02	1.00E+00

6.3. Chapter 4. Section 4.4. Definition of the potential transition scenarios of the city

This section provides the correspondence of the scenario numbers and their code. This code allows identifying the main characteristics of each scenario according to the description provided in section 4.4.

Table 43. Correspondence of the scenario number and code (characteristics).

Nº SC	CODE	Nº SC	CODE	Nº SC	CODE
Nº1	SC 1.A.0	**Nº24**	SC 1.E.2.a	**Nº47**	SC 2.E.3
Nº2	SC 1.A.1	**Nº25**	SC 1.E.3	**Nº48**	SC 3.A.0
Nº3	SC 1.A.2	**Nº26**	SC 2.A.0	**Nº49**	SC 3.A.1
Nº4	SC 1.A.2.a	**Nº27**	SC 2.A.1	**Nº50**	SC 3.A.2
Nº5	SC 1.A.3	**Nº28**	SC 2.A.2	**Nº51**	SC 3.A.3
Nº6	SC 1.B.0	**Nº29**	SC 2.A.3	**Nº52**	SC 3.B.0
Nº7	SC 1.B.1	**Nº30**	SC 2.B.0	**Nº53**	SC 3.B.1
Nº8	SC 1.B.2	**Nº31**	SC 2.B.1	**Nº54**	SC 3.B.2
Nº9	SC 1.B.2.a	**Nº32**	SC 2.B.2	**Nº55**	SC 3.B.3
Nº10	SC 1.B.3	**Nº33**	SC 2.B.2.a	**Nº56**	SC 3.C.0
Nº11	SC 1.C.0	**Nº34**	SC 2.B.3	**Nº57**	SC 3.C.1
Nº12	SC 1.C.1	**Nº35**	SC 2.C.0	**Nº58**	SC 3.C.2
Nº13	SC 1.C.2	**Nº36**	SC 2.C.1	**Nº59**	SC 3.C.3
Nº14	SC 1.C.2.a	**Nº37**	SC 2.C.2	**Nº60**	SC 3.D.0
Nº15	SC 1.C.3	**Nº38**	SC 2.C.3	**Nº61**	SC 3.D.1
Nº16	SC 1.D.0	**Nº39**	SC 2.D.0	**Nº62**	SC 3.D.2
Nº17	SC 1.D.1	**Nº40**	SC 2.D.1	**Nº63**	SC 3.D.3
Nº18	SC 1.D.2	**Nº41**	SC 2.D.2	**Nº64**	SC 3.E.0
Nº19	SC 1.D.2.a	**Nº42**	SC 2.D.3	**Nº65**	SC 3.E.1
Nº20	SC 1.D.3	**Nº43**	SC 2.E.0	**Nº66**	SC 3.E.2
Nº21	SC 1.E.0	**Nº44**	SC 2.E.1	**Nº67**	SC 3.E.2.a
Nº22	SC 1.E.1	**Nº45**	SC 2.E.2	**Nº68**	SC 3.E.3
Nº23	SC 1.E.2	**Nº46**	SC 2.E.2.a		

Further information related to the data gathered for identifying the main barriers, which can limit the implementation level of each intervention in the different areas of the city is available at the end of the Appendix in Section 6.6.1.

6.4. Chapter 4. Section 4.5.4. Environmental, economic, and social impact assessment

6.4.1. Input Output framework in the Basque Country

Classification of sectors in the Basque Country according to the IO framework

Table 44. Classification of sectors in the Basque Country according to Eustat (in Spanish).

1. Agricultura, ganadería y caza	31. Artículos metálicos	61.Telecomunicaciones
2. Silvicultura y explotación forestal	32. Prod. informáticos y electrónicos	62 .Informática
3. Pesca y acuicultura	33. Material y equipo eléctrico	63. Serv. financieros, excepto seguros
4. Industrias extractivas	34. Aparatos domésticos	64. Seguros
5. Industrias cárnicas	35. Maquinaria de uso general	65. Auxiliares financieros
6. Procesado de pescados	36. Máquinas herramienta	66. Actividades inmobiliarias
7. Productos lácteos	37. Fabricación de vehículos de motor	67. Activ. jurídicas y de contabilidad
8. Panadería y molinería	38. Construcción naval	68. Serv. de arquitectura e ingeniería
9. Otras industrias alimentarias	39. Otro material de transporte	69. Investigación y desarrollo
10. Bebidas	40. Fabricación de muebles	70. Publicidad y estudios de mercado
11. Tabaco	41. Otras industrias manufactureras	71. Otras activ. profesionales
12. Textil, confección, cuero y calzado	42. Reparación e instalación	72. Actividades de alquiler
13. Industria de la madera y del corcho	43. Energía eléctrica	73. Activ. relacionadas con el empleo
14. Industria del papel	44. Gas, vapor y aire acondicionado	74. Agencias de viajes
15. Artes gráficas y reproducción	45. Suministro de agua	75. Otras actividades auxiliares
16. Coquerías y refino de petróleo	46. Saneamiento y gestión de residuos	76. Administración Pública
17. Productos químicos básicos	47. Construcción	77. Educación de mercado
18. Pinturas y otra química final	48. Venta y reparación de vehículos	78. Educación no de mercado
19. Productos farmacéuticos	49. Comercio al por mayor	79. Actividades sanitarias de mercado
20. Productos de caucho	50. Comercio al por menor	80. Actividades sanitarias no mercado
21. Productos de plástico	51. Transporte por ferrocarril	81. Servicios sociales de mercado
22. Industria del vidrio	52. Otro transp. terrestre de pasajeros	82. Servicios sociales no mercado
23. Cemento, cal y yeso	53. Otro transp. terrestre mercancías	83. Actividades culturales; juego
24. Otra industria no metálica	54. Transporte marítimo y fluvial	84. Activ. deportivas y recreativas
25. Siderurgia	55. Transporte aéreo	85. Actividades asociativas
26. Producción de metales no férreos	56. Actividades anexas al transporte	86. Rep. ordenadores y otros artículos
27. Fundición de metales	57. Actividades postales y de correos	87. Otros servicios personales
28. Construcción metálica	58. Hostelería	88. Actividades de los hogares
29. Forja y estampación de metales	59. Edición	
30. Ingeniería mecánica	60. Audiovisuales, cine, radio	

Classification of commodities in the Basque Country according to the IO framework

Table 45. Classification of commodities in the Basque Country according to Eustat (in Spanish).

1. Productos agrícolas	36. Productos de construcción metálica	71. Correos y mensajería
2. Productos ganaderos	37. Forja y estampación	72. Alojamiento
3. Productos de la silvicultura	38. Tratamiento de metales	73. Comidas y bebidas
4. Productos de la pesca y acuicultura	39. Ingeniería mecánica	74. Edición
5. Carbones	40. Otros productos metálicos	75. Servicios audiovisuales
6. Petróleo crudo	41. Mat. informát., electrón. y óptico	76. Telecomunicaciones
7. Gas natural	42. Material y equipo eléctrico	77. Serv. informáticos y de información
8. Minerales metálicos	43. Aparatos domésticos	78. Servicios financieros
9. Minerales no metálicos	44. Maquinaria	79. Seguros y planes de pensiones
10. Carne y productos cárnicos	45. Máquinas herramienta	80. Auxiliares financieros
11. Pescado en conserva, elaborado y congelado	46. Vehículos de motor y sus piezas	81. Serv. inmobiliarios (incluye rentas inmobil. imputadas)
12. Leche y productos lácteos	47. Construcción naval	82. Servicios jurídicos y contables y de sedes centrales
13. Pan, molinería y pasta alimenticia	48. Material ferroviario	83. Arquitec.., ingen. y ensayos técn.
14. Otros productos alimenticios	49. Aeronaves	84. Investigación y desarrollo
15. Productos para alimentación animal	50. Otro material de transporte	85. Publicidad y marketing
16. Bebidas alcohólicas	51. Muebles	86. Otros servicios profesionales
17. Bebidas no alcohólicas	52. Otros productos manufacturados	87. Servicios de alquiler
18. Tabaco manufacturado	53. Repar. e instal. de maquinaria y equipos	88. Servicios de empleo
19. Textil, confección, cuero y calzado	54. Energía eléctrica	89. Agencias de viaje
20. Madera y corcho	55. Servicios de distribución de gas	90. Seguridad e investigación
21. Pasta de papel y cartón	56. Agua natural	91. Servicios de limpieza
22. Artículos de papel y cartón	57. Aguas residuales	92. Otros servicios de ayuda a empresas
23. Artes gráficas y soportes grabados	58. Gestión de residuos	93. Administración pública
24. Coque y productos de refino de petróleo	59. Edificaciones	94. Educación
25. Productos químicos básicos	60. Obras de ingeniería civil	95. Sanidad
26. Productos químicos de consumo final	61. Construcción especializada	96. Servicios sociales
27. Productos farmacéuticos	62. Venta y reparación de vehículos	97. Servicios artísticos y espectáculos
28. Productos de caucho	63. Comercio al por mayor	98. Servicios culturales
29. Productos de plástico	64. Comercio al por menor	99. Juegos de azar y apuestas
30. Vidrio y productos de vidrio	65. Transporte ferrocarril	100. Actividades deportivas
31. Cemento, cal y yeso	66. Otro transp. terrestre de pasajeros	101. Actividades recreativas
32. Otros prod. minerales no metálicos	67. Otro transp. terrestre de mercancías	102. Actividades asociativas
33. Productos de la siderurgia	68. Transporte marítimo	103. Reparación de artículos
34. Metales preciosos y no férreos	69. Transporte aéreo	104. Otros servicios personales
35. Fundición de metales	70. Anexos al transporte	105. Servicio doméstico

Margins (national reference) and Import shares used in the study according to the commodity classification in the Basque Country

Table 46. Parameters used in the study for the analysis of the margins and the import shares.

Com.	(BP/PP)	Import share	Com.	(BP/PP)	Import share
Com. 1	0.63	0.84	**Com. 54**	0.88	0.00
Com. 2	0.63	0.39	**Com. 55**	0.88	0.00
Com. 3	0.72	0.70	**Com. 56**	0.94	0.00
Com. 4	0.43	0.78	**Com. 57**	0.75	0.00
Com. 5	0.81	1.00	**Com. 58**	0.80	0.00
Com. 6	1.00	1.00	**Com. 59**	1.00	0.00
Com. 7	1.00	1.00	**Com. 60**	1.00	0.00
Com. 8	1.00	1.00	**Com. 61**	0.88	0.00
Com. 9	0.81	0.56	**Com. 62**	0.88	0.00
Com. 10	0.64	0.86	**Com. 63**	-	0.00
Com. 11	0.64	0.72	**Com. 64**	-	0.00
Com. 12	0.66	0.64	**Com. 65**	0.99	0.25
Com. 13	0.64	0.59	**Com. 66**	0.94	0.06
Com. 14	0.64	0.88	**Com. 67**	1.59	0.11
Com. 15	0.64	0.21	**Com. 68**	0.93	0.75
Com. 16	0.61	0.69	**Com. 69**	0.88	0.87
Com. 17	0.64	0.61	**Com. 70**	0.88	0.00
Com. 18	0.61	1.00	**Com. 71**	1.00	0.18
Com. 19	0.44	0.88	**Com. 72**	0.94	0.00
Com. 20	0.47	0.17	**Com. 73**	0.94	0.00
Com. 21	1.00	0.00	**Com. 74**	0.51	0.56
Com. 22	0.71	0.53	**Com. 75**	0.84	0.21
Com. 23	0.87	0.30	**Com. 76**	0.88	0.00
Com. 24	0.66	0.06	**Com. 77**	0.88	0.00
Com. 25	0.65	0.50	**Com. 78**	0.88	0.08
Com. 26	0.65	0.74	**Com. 79**	1.00	0.10
Com. 27	0.41	0.97	**Com. 80**	0.88	0.20
Com. 28	0.71	0.87	**Com. 81**	0.88	0.01
Com. 29	0.71	0.59	**Com. 82**	0.88	0.02
Com. 30	0.58	0.70	**Com. 83**	0.88	0.00
Com. 31	0.58	0.76	**Com. 84**	1.00	0.00
Com. 32	0.58	0.70	**Com. 85**	0.88	0.00
Com. 33	1.00	0.00	**Com. 86**	0.87	0.03
Com. 34	0.80	0.85	**Com. 87**	0.88	0.03
Com. 35	1.00	0.00	**Com. 88**	1.00	0.00
Com. 36	0.80	0.26	**Com. 89**	0.88	0.00
Com. 37	0.80	0.00	**Com. 90**	0.88	0.00
Com. 38	1.00	0.00	**Com. 91**	0.94	0.00
Com. 39	1.00	0.00	**Com. 92**	0.88	0.00
Com. 40	0.66	0.56	**Com. 93**	1.00	0.00
Com. 41	0.48	0.78	**Com. 94**	0.88	0.00
Com. 42	0.64	0.77	**Com. 95**	0.88	0.00
Com. 43	0.60	0.91	**Com. 96**	0.94	0.00
Com. 44	0.60	0.64	**Com. 97**	0.86	0.17
Com. 45	1.00	0.00	**Com. 98**	0.86	0.00
Com. 46	0.69	0.93	**Com. 99**	0.86	0.00
Com. 47	0.78	0.50	**Com. 100**	0.88	0.00
Com. 48	1.00	0.00	**Com. 101**	0.88	0.00
Com. 49	0.78	1.00	**Com. 102**	1.00	0.00
Com. 50	0.78	0.81	**Com. 103**	0.88	0.00
Com. 51	0.40	0.43	**Com. 104**	0.88	0.01
Com. 52	0.40	0.72	**Com. 105**	0.88	0.00
Com. 53	0.88	0.00			

Main components of the interventions included in city transition scenarios and their corresponding commodities according to the classification in the Basque Country

Table 47. Components considered in district scale interventions and their corresponding commodity.

Components	Commodity
Natural gas boiler	(See central natural gas boiler)
Biomass boiler	(See central biomass boiler)
Storage tank	Commodity 40
Cogeneration system	Commodity 40
Pumps	Commodity 44
Valves and accessories	Commodity 44
Hydraulic	Commodity 40
Insulation	Commodity 9
Masonry works	Commodity 61
Management system	Commodity 42
Electric installation High Voltage	Commodity 42
Electric installation Low Voltage	Commodity 42
Building (supply side of district heating)	Commodity 59
District heating pipe (component1)	Commodity 40
District heating pipe (component2)	Commodity 9
District heating pipe (Trenchworks)	Commodity 60
Substations	Commodity 61
Natural gas installation	Commodity 61
Installation works	Commodity 53
Transport of the components	Commodity 70
Design and project	Commodity 83
Complementary for STES	
Solar thermal collector	(See solar thermal system)
Storage	Commodity 40
Insulation of the storage	Commodity 32
Concrete	Commodity 31
Transport of components	Commodity 70
Heat pumps	(See heat pumps)
Installation costs	Commodity 53
Building and terrain costs	Commodity 59
Control system	Commodity 42
Design and project	Commodity 83

Table 48. Components considered in solar thermal, solar photovoltaic and refurbishment interventions and their corresponding commodity.

Components	Commodity
Solar thermal system	
Installation	Commodity 53
Project	Commodity 83
Collectors	Commodity 61
Structure for the installation of systems in building roofs	Commodity 40
Hydraulic connection	Commodity 44
Automatic purger	Commodity 44
Security valve	Commodity 44
Storage	Commodity 40
Antifreeze	Commodity 26
Spherical valve	Commodity 44
Pipe	Commodity 61
Insulation	Commodity 9
Exchanger	Commodity 44
Solar photovoltaic	
Rails	Commodity 40
Clamps	Commodity 40
Fittings	Commodity 40
Modules	Commodity 42
Wire	Commodity 42
Connectors	Commodity 42
Inverter	Commodity 42
Installation	Commodity 53
Transport of components	Commodity 70
Project costs	Commodity 83
Refurbishment interventions	
Refurbishment of the envelope - Mortar	Commodity 31
Refurbishment of the envelope - Insulation	Commodity 32
Substitution of windows – glass	Commodity 30
Substitution of windows – frame	Commodity 36
Substitution of windows – frame	Commodity 20
Transport of components	Commodity 70
Installation - construction	Commodity 61
Project costs	Commodity 83

Table 49. Components considered boilers and heat pump systems for buildings and their corresponding commodity.

Components	Commodity
Individual natural gas boiler	
Boiler	Commodity 40
Storage tank	Commodity 40
Control system	Commodity 42
Auxiliary components: valves, etc	Commodity 44
Installation	Commodity 53
Other costs	Commodity 83
Central natural gas boiler	
Boiler with exchanger	Commodity 40
Control system	Commodity 42
Sensors	Commodity 42
pipes	Commodity 29
Wire	Commodity 42
Auxiliary material for heating installation	Commodity 40
Auxiliary material - plumbing	Commodity 40
Installation, labour force	Commodity 53
Other costs	Commodity 83
Central biomass gas boiler	
Boiler	Commodity 40
Base for support	Commodity 40
Control systems	Commodity 42
Sensors	Commodity 42
Pressure regulator	Commodity 44
Mounting of the generation system	Commodity 53
Management training and start up	Commodity 83
Installation, labour force	Commodity 53
Other costs	Commodity 83
Heat pump	
Heat pump	Commodity 40
Filters	Commodity 61
Anti-vibration rubber sleeves	Commodity 28
Temperature sensors	Commodity 42
Spherical valve	Commodity 44
Installation, labour force	Commodity 53
Other costs	Commodity 83

6.4.2. The results of energy transition scenarios

Table 50. The results of scenarios from Nº1 to 25. The results are provided for the reference unit.

SC Nº	CNPV M€	DPP Years	CNPC-S M€	CNPC-PPC M€	CGWPR $TnCO_2eq$	CNR-PER MWh	CDRLEG MWh	RGDP M€	RE 10^3Emp
Nº1	3.2E+01	3.7E+01	3.5E+02	3.2E+00	1.5E+06	7.3E+06	2.3E+06	7.4E+01	1.3E+00
Nº2	3.5E+01	3.6E+01	3.5E+02	3.2E+00	9.3E+05	4.7E+06	1.4E+06	7.0E+01	1.3E+00
Nº 3	2.6E+01	4.1E+01	3.6E+02	3.2E+00	1.8E+06	9.0E+06	2.6E+06	7.5E+01	1.4E+00
Nº 4	2.5E+01	4.1E+01	3.6E+02	3.2E+00	1.7E+06	8.7E+06	2.4E+06	7.3E+01	1.3E+00
Nº 5	3.0E+01	3.9E+01	3.5E+02	3.2E+00	1.6E+06	8.2E+06	2.5E+06	7.4E+01	1.3E+00
Nº 6	3.4E+01	3.7E+01	3.5E+02	3.5E+00	1.5E+06	7.5E+06	2.4E+06	7.4E+01	1.3E+00
Nº 7	3.7E+01	3.5E+01	3.5E+02	3.5E+00	9.9E+05	5.0E+06	1.4E+06	7.0E+01	1.3E+00
Nº 8	2.4E+01	4.1E+01	3.6E+02	3.5E+00	1.8E+06	9.2E+06	2.7E+06	7.5E+01	1.4E+00
Nº 9	2.7E+01	4.0E+01	3.6E+02	3.5E+00	1.8E+06	8.9E+06	2.5E+06	7.3E+01	1.3E+00
Nº10	3.2E+01	3.8E+01	3.5E+02	3.5E+00	1.7E+06	8.5E+06	2.6E+06	7.4E+01	1.3E+00
Nº11	3.3E+01	3.7E+01	3.5E+02	2.8E+00	1.5E+06	7.4E+06	2.3E+06	7.3E+01	1.3E+00
Nº 12	3.5E+01	3.6E+01	3.5E+02	2.8E+00	9.7E+05	4.8E+06	1.4E+06	7.0E+01	1.3E+00
Nº 13	2.6E+01	4.1E+01	3.6E+02	2.8E+00	1.8E+06	9.2E+06	2.7E+06	7.4E+01	1.3E+00
Nº 4	2.6E+01	4.1E+01	3.6E+02	2.8E+00	1.7E+06	8.8E+06	2.4E+06	7.2E+01	1.3E+00
Nº15	3.1E+01	3.9E+01	3.5E+02	2.8E+00	1.7E+06	8.4E+06	2.5E+06	7.3E+01	1.3E+00
Nº16	3.3E+01	3.7E+01	3.5E+02	5.0E+00	1.5E+06	7.4E+06	2.3E+06	7.5E+01	1.3E+00
Nº17	3.6E+01	3.6E+01	3.5E+02	5.0E+00	9.7E+05	4.9E+06	1.4E+06	7.1E+01	1.3E+00
Nº18	2.6E+01	4.1E+01	3.6E+02	5.0E+00	1.8E+06	9.2E+06	2.6E+06	7.6E+01	1.4E+00
Nº19	2.6E+01	4.1E+01	3.6E+02	5.0E+00	1.7E+06	8.8E+06	2.4E+06	7.4E+01	1.3E+00
Nº20	3.1E+01	3.9E+01	3.5E+02	5.0E+00	1.7E+06	8.4E+06	2.5E+06	7.5E+01	1.3E+00
Nº21	3.3E+01	3.8E+01	3.5E+02	6.4E+00	1.5E+06	7.6E+06	2.4E+06	7.5E+01	1.4E+00
Nº22	3.6E+01	3.6E+01	3.5E+02	6.4E+00	1.0E+06	5.0E+06	1.5E+06	7.2E+01	1.3E+00
Nº23	2.6E+01	4.1E+01	3.6E+02	6.4E+00	1.8E+06	9.3E+06	2.7E+06	7.7E+01	1.4E+00
Nº24	2.6E+01	4.1E+01	3.6E+02	6.4E+00	1.8E+06	9.0E+06	2.5E+06	7.4E+01	1.3E+00

Table 51. The results of scenarios from Nº26 to 47. The results are provided for the reference unit.

SC Nº	CNPV M€	DPP Years	CNPC-S M€	CNPC-PPC M€	CGWPR $TnCO_2eq$	CNR-PER MWh	CDRLEG MWh	RGDP M€	RE 10^3Emp
Nº25	3.1E+01	3.9E+01	3.5E+02	6.4E+00	1.7E+06	8.5E+06	2.6E+06	7.6E+01	1.4E+00
Nº26	5.5E+01	3.0E+01	3.7E+02	1.5E+01	1.1E+06	5.7E+06	2.3E+06	7.4E+01	1.3E+00
Nº27	5.7E+01	2.9E+01	3.7E+02	1.5E+01	7.6E+05	3.9E+06	1.7E+06	7.2E+01	1.3E+00
Nº28	5.0E+01	3.3E+01	3.7E+02	1.5E+01	1.4E+06	7.1E+06	2.6E+06	7.5E+01	1.4E+00
Nº29	5.3E+01	3.1E+01	3.7E+02	1.5E+01	1.3E+06	6.5E+06	2.4E+06	7.4E+01	1.3E+00
Nº30	6.2E+01	2.9E+01	3.7E+02	1.9E+01	1.6E+06	7.9E+06	2.7E+06	7.6E+01	1.4E+00
Nº31	6.4E+01	2.9E+01	3.7E+02	1.9E+01	1.2E+06	6.1E+06	2.2E+06	7.3E+01	1.3E+00
Nº32	5.7E+01	3.2E+01	3.7E+02	1.9E+01	1.9E+06	9.3E+06	3.0E+06	7.6E+01	1.4E+00
Nº33	5.7E+01	3.1E+01	3.7E+02	1.9E+01	1.8E+06	9.0E+06	2.8E+06	7.5E+01	1.4E+00
Nº34	6.0E+01	3.0E+01	3.7E+02	1.9E+01	1.7E+06	8.6E+06	2.9E+06	7.6E+01	1.4E+00
Nº35	5.5E+01	3.1E+01	3.7E+02	1.5E+01	1.4E+06	6.8E+06	2.4E+06	7.4E+01	1.3E+00
Nº36	5.7E+01	2.9E+01	3.7E+02	1.5E+01	1.1E+06	5.1E+06	1.9E+06	7.2E+01	1.3E+00
Nº37	5.0E+01	3.3E+01	3.7E+02	1.5E+01	1.7E+06	8.2E+06	2.7E+06	7.5E+01	1.4E+00
Nº38	5.4E+01	3.2E+01	3.7E+02	1.5E+01	1.6E+06	7.6E+06	2.6E+06	7.4E+01	1.3E+00
Nº39	5.9E+01	3.1E+01	3.7E+02	2.6E+01	1.4E+06	6.6E+06	2.3E+06	8.2E+01	1.5E+00
Nº40	6.1E+01	2.9E+01	3.7E+02	2.6E+01	9.9E+05	4.8E+06	1.7E+06	8.0E+01	1.4E+00
Nº41	5.3E+01	3.3E+01	3.7E+02	2.6E+01	1.6E+06	8.0E+06	2.6E+06	8.3E+01	1.5E+00
Nº42	5.7E+01	3.2E+01	3.7E+02	2.6E+01	1.5E+06	7.3E+06	2.5E+06	8.2E+01	1.5E+00
Nº43	5.5E+01	3.3E+01	3.7E+02	3.7E+01	1.7E+06	8.3E+06	3.1E+06	8.6E+01	1.5E+00
Nº44	5.7E+01	3.2E+01	3.7E+02	3.7E+01	1.4E+06	6.5E+06	2.5E+06	8.4E+01	1.5E+00
Nº45	5.0E+01	3.5E+01	3.7E+02	3.7E+01	2.0E+06	9.7E+06	3.4E+06	8.7E+01	1.6E+00
Nº46	5.0E+01	3.5E+01	3.7E+02	3.7E+01	1.9E+06	9.5E+06	3.2E+06	8.6E+01	1.5E+00
Nº47	5.3E+01	3.4E+01	3.7E+02	3.7E+01	1.9E+06	9.1E+06	3.3E+06	8.6E+01	1.5E+00

Table 52. The results of scenarios from Nº48 to 68. The results are provided for the reference unit.

SC Nº	CNPV M€	DPP Years	CNPC-S M€	CNPC-PPC M€	CGWPR $TnCO_2eq$	CNR-PER MWh	CDRLEG MWh	RGDP M€	RE 10^3Emp
Nº48	6.5E+01	3.0E+01	3.6E+02	2.7E+01	7.7E+05	3.9E+06	2.4E+06	7.5E+01	1.3E+00
Nº49	6.7E+01	2.9E+01	3.6E+02	2.7E+01	5.4E+05	2.8E+06	2.1E+06	7.3E+01	1.3E+00
Nº50	6.3E+01	3.1E+01	3.6E+02	2.7E+01	9.2E+05	4.7E+06	2.5E+06	7.5E+01	1.4E+00
Nº51	6.5E+01	3.0E+01	3.6E+02	2.7E+01	8.5E+05	4.3E+06	2.5E+06	7.5E+01	1.3E+00
Nº52	7.5E+01	2.9E+01	3.6E+02	3.6E+01	1.8E+06	8.3E+06	3.2E+06	7.8E+01	1.4E+00
Nº53	7.7E+01	2.9E+01	3.6E+02	3.6E+01	1.5E+06	7.2E+06	2.8E+06	7.6E+01	1.4E+00
Nº54	7.3E+01	3.0E+01	3.6E+02	3.6E+01	1.9E+06	9.1E+06	3.3E+06	7.8E+01	1.4E+00
Nº55	7.5E+01	2.9E+01	3.6E+02	3.6E+01	1.8E+06	8.7E+06	3.2E+06	7.8E+01	1.4E+00
Nº56	6.5E+01	3.1E+01	3.6E+02	2.6E+01	1.4E+06	6.2E+06	2.6E+06	7.4E+01	1.3E+00
Nº57	6.7E+01	3.0E+01	3.6E+02	2.6E+01	1.2E+06	5.1E+06	2.3E+06	7.3E+01	1.3E+00
Nº58	6.3E+01	3.1E+01	3.6E+02	2.6E+01	1.5E+06	7.0E+06	2.8E+06	7.5E+01	1.3E+00
Nº59	6.5E+01	3.1E+01	3.6E+02	2.6E+01	1.5E+06	6.6E+06	2.7E+06	7.4E+01	1.3E+00
Nº60	7.6E+01	2.9E+01	3.6E+02	4.1E+01	1.2E+06	5.5E+06	2.4E+06	8.8E+01	1.5E+00
Nº61	7.8E+01	2.9E+01	3.6E+02	4.1E+01	9.9E+05	4.4E+06	2.1E+06	8.6E+01	1.5E+00
Nº62	7.4E+01	3.1E+01	3.6E+02	4.1E+01	1.4E+06	6.3E+06	2.6E+06	8.8E+01	1.6E+00
Nº63	7.6E+01	2.9E+01	3.6E+02	4.1E+01	1.3E+06	5.9E+06	2.5E+06	8.8E+01	1.5E+00
Nº64	6.6E+01	3.4E+01	3.6E+02	6.5E+01	2.0E+06	9.1E+06	3.9E+06	9.7E+01	1.7E+00
Nº65	6.8E+01	3.3E+01	3.6E+02	6.5E+01	1.8E+06	8.0E+06	3.6E+06	9.5E+01	1.7E+00
Nº66	6.4E+01	3.4E+01	3.6E+02	6.5E+01	2.1E+06	9.9E+06	4.0E+06	9.7E+01	1.7E+00
Nº67	6.5E+01	3.4E+01	3.6E+02	6.5E+01	2.2E+06	1.0E+07	3.9E+06	9.6E+01	1.7E+00
Nº68	6.6E+01	3.4E+01	3.6E+02	6.5E+01	2.1E+06	9.5E+06	4.0E+06	9.7E+01	1.7E+00

6.4.3. Sensitivity analysis

This section includes the results of the sensitivity analysis for the evaluation carried out in Chapter 4 respect to various key parameters.

Discount rate

Table 53. Sensitivity analysis of scenarios respect to the discount rate.

CNPV (euro)	SC.1.C.2	SC 2.E.2	SC.3.E.2.a
Reference	2.58E+07	4.99E+07	6.53E+07
Min	5.38E+07	9.03E+07	1.15E+08
Max	6.91E+06	2.21E+07	3.07E+07
Max.variation (%)	109%	81%	77%
DPP (year)			
Reference	4.10E+01	3.50E+01	3.40E+01
Min	3.70E+01	3.10E+01	3.10E+01
Max	4.70E+01	4.00E+01	3.80E+01
Max.variation (%)	15%	14%	12%
CNPC-PPC (euro)			
Reference	2.77E+06	3.70E+07	6.46E+07
Min	3.03E+06	4.13E+07	7.25E+07
Max	2.58E+06	3.37E+07	5.86E+07
Max.variation (%)	9%	12%	12%
CNPC-S (euro)			
Reference	3.58E+08	3.73E+08	3.61E+08
Min	4.08E+08	4.40E+08	4.41E+08
Max	3.21E+08	3.24E+08	3.02E+08
Max.variation (%)	14%	18%	22%
RGDP (euro)			
Reference	7.45E+07	8.72E+07	9.60E+07
Min	9.09E+07	1.05E+08	1.14E+08
Max	6.24E+07	7.42E+07	8.25E+07
Max.variation (%)	22.07%	20.23%	19.10%
RE (jobs)			
Reference	1.35E+03	1.56E+03	1.70E+03
Min	1.65E+03	1.88E+03	2.03E+03
Max	1.13E+03	1.33E+03	1.46E+03
Max.variation (%)	22.09%	20.32%	19.22%

Implementation rate

Table 54. Sensitivity analysis of scenarios respect to the Implementation rate.

CNPV (euro)	SC.1.C.2	SC 2.E.2	SC.3.E.2.a
Reference	2.58E+07	4.99E+07	6.53E+07
Min	2.38E+07	4.81E+07	6.34E+07
Max	2.79E+07	5.22E+07	6.74E+07
Max.variation (%)	8%	5%	3%
DPP (year)			
Reference	4.10E+01	3.50E+01	3.40E+01
Min	4.00E+01	3.40E+01	3.40E+01
Max	4.10E+01	3.50E+01	3.40E+01
Max.variation (%)	3%	3%	0%
CNPC-S (euro)			
Reference	3.58E+08	3.73E+08	3.61E+08
Min	3.35E+08	3.54E+08	3.46E+08
Max	3.67E+08	3.81E+08	3.67E+08
Max.variation (%)	7%	5%	4%
CGWPR (kg CO2equ.)			
Reference	1.81E+09	1.99E+09	2.17E+09
Min	1.67E+09	1.86E+09	2.05E+09
Max	1.88E+09	2.04E+09	2.22E+09
Max.variation (%)	8%	7%	6%
CNR-PER (kWh NR-PE)			
Reference	9.15E+09	9.71E+09	1.00E+10
Min	8.49E+09	9.11E+09	9.51E+09
Max	9.44E+09	9.97E+09	1.03E+10
Max.variation (%)	8%	7%	6%
CDRLEG (kWh)			
Reference	2.67E+09	3.38E+09	3.91E+09
Min	2.52E+09	3.27E+09	3.83E+09
Max	2.76E+09	3.46E+09	3.97E+09
Max.variation (%)	6%	4%	2%
RGDP (euro)			
Reference	7.45E+07	8.72E+07	9.60E+07
Min	7.01E+07	8.30E+07	9.21E+07
Max	7.64E+07	8.90E+07	9.77E+07
Max.variation (%)	6%	5%	4%
RE (jobs)			
Reference	1.35E+03	1.56E+03	1.70E+03
Min	1.27E+03	1.48E+03	1.63E+03
Max	1.38E+03	1.59E+03	1.73E+03
Max.variation (%)	6%	5%	4%

Shadow Price of the CO_2 emissions

Table 55 shows the comparison of the results of CNPV and DPP indicators for the base scenario without considering the shadow Price of the CO_2 emissions respect to the alternative scenario, in which this effect is included.

Table 55. Comparison of the results for the base case respect to the equivalent case in which the shadow prices of the CO2 are considered.

SC.1.C.2	CNPV (M€)	DPP (years)
Base case	2.58E+07	4.10E+01
With CO_2 shadow costs	5.92E+07	3.10E+01
SC.2.E.2		
Base case	4.99E+07	3.50E+01
With CO_2 shadow costs	8.61E+07	2.80E+01
SC.3.E.2.a		
Base case	6.53E+07	3.40E+01
With CO_2 shadow costs	1.03E+08	2.80E+01

Energy Price increase

Table 56. Sensitivity analysis of scenarios respect to the energy price increase.

CNPV (euro)	SC.1.C.2	SC 2.E.2	SC.3.E.2.a
Reference	2.58E+07	4.99E+07	6.53E+07
Min	2.11E+06	2.12E+07	3.30E+07
Max	5.27E+07	8.24E+07	1.02E+08
Max.variation (%)	104%	65%	56%
DPP (year)			
Reference	4.10E+01	3.50E+01	3.40E+01
Min	5.00E+01	4.20E+01	3.80E+01
Max	3.50E+01	3.10E+01	3.10E+01
Max.variation (%)	22%	20%	12%
CNPC-S (euro)			
Reference	3.58E+08	3.73E+08	3.61E+08
Min	3.56E+08	3.65E+08	3.47E+08
Max	3.60E+08	3.82E+08	3.76E+08
Max.variation (%)	1%	2%	4%

CAPEX Price increase

Table 57. Sensitivity analysis of scenarios respect to the CAPEX price increase.

CNPV (euro)	SC.1.C.2	SC 2.E.2	SC.3.E.2.a
Reference	2.58E+07	4.99E+07	6.53E+07
Min	3.60E+07	6.12E+07	7.70E+07
Max	1.55E+07	3.86E+07	5.36E+07
Max.variation (%)	40%	23%	18%
DPP (year)			
Reference	4.10E+01	3.50E+01	3.40E+01
Min	3.70E+01	3.20E+01	3.20E+01
Max	4.50E+01	3.80E+01	3.60E+01
Max.variation (%)	11%	9%	6%
CNPC-PPC (euro)			
Reference	2.77E+06	3.70E+07	6.46E+07
Min	2.63E+06	3.51E+07	6.13E+07
Max	2.91E+06	3.88E+07	6.78E+07
Max.variation (%)	5%	5%	5%
CNPC-S (euro)			
Reference	3.58E+08	3.73E+08	3.61E+08
Min	3.48E+08	3.64E+08	3.52E+08
Max	3.68E+08	3.82E+08	3.69E+08
Max.variation (%)	3%	3%	2%
RGDP (euro)			
Reference	7.45E+07	8.72E+07	9.60E+07
Min	7.08E+07	8.29E+07	9.12E+07
Max	7.82E+07	9.16E+07	1.01E+08
Max.variation (%)	5%	5%	5%
RE (jobs)			
Reference	1.35E+03	1.56E+03	1.70E+03
Min	1.28E+03	1.48E+03	1.62E+03
Max	1.41E+03	1.64E+03	1.79E+03
Max.variation (%)	5%	5%	5%

Energy technology cost trends

Table 58. Sensitivity analysis of scenarios respect to the energy technology cost trends

CNPV (euro)	SC.1.C.2	SC 2.E.2	SC.3.E.2.a
Reference	2.58E+07	4.99E+07	6.53E+07
Min	2.67E+07	5.07E+07	6.59E+07
Max	2.50E+07	4.92E+07	6.47E+07
Max.variation (%)	3%	2%	1%
DPP (year)			
Reference	4.10E+01	3.50E+01	3.40E+01
Min	4.00E+01	3.50E+01	3.40E+01
Max	4.10E+01	3.50E+01	3.40E+01
Max.variation (%)	3%	0%	0%
CNPC-S (euro)			
Reference	3.58E+08	3.73E+08	3.61E+08
Min	3.57E+08	3.72E+08	3.60E+08
Max	3.59E+08	3.74E+08	3.61E+08
Max.variation (%)	0.25%	0.21%	0.19%
RGDP (euro)			
Reference	7.45E+07	8.72E+07	9.60E+07
Min	7.42E+07	8.69E+07	9.58E+07
Max	7.48E+07	8.75E+07	9.62E+07
Max.variation (%)	0.43%	0.33%	0.25%
RE (jobs)			
Reference	1.35E+03	1.56E+03	1.70E+03
Min	1.34E+03	1.55E+03	1.70E+03
Max	1.35E+03	1.56E+03	1.71E+03
Max.variation (%)	0.43%	0.33%	0.25%

Marginal propensity of consumption

Table 59. Sensitivity analysis of the scenarios respect to the Marginal propensity of consumption

RGDP (euro)			
Reference	7.45E+07	8.72E+07	9.60E+07
Min	7.27E+07	8.52E+07	9.38E+07
Max	7.62E+07	8.92E+07	9.82E+07
Max.variation (%)	2.23%	2.23%	2.24%
RE (jobs)			
Reference	1.35E+03	1.56E+03	1.70E+03
Min	1.32E+03	1.52E+03	1.67E+03
Max	1.38E+03	1.59E+03	1.74E+03
Max.variation (%)	2.09%	2.12%	2.14%

6.5. Chapter 4. Section 4.8.3. Life Cycle Analysis of the transition scenarios

The tables included in this section provide information with regard to the life cycle environmental impacts of the scenarios evaluated. The information is provided distinguishing the main phases of the life cycle considered in the study.

Table 60. Cumulative GWP impact reduction of the scenarios at the end of the transition period in (Tn CO_2 equi./RU).

SC Nº	A1-A3, B4					B6				
	H&DHW	PIFB	SFV	ST	DH int.	H&DHW	PIFB	SFV	ST	DH int.
Nº1	-9.2E+04	-3.4E+04	-9.4E+04	-1.0E+04	-3.8E+03	5.3E+05	7.2E+05	3.2E+05	1.2E+05	-1.3E+03
Nº2	-4.6E+04	-3.4E+04	-9.4E+04	-1.0E+04	-3.8E+03	2.8E+05	3.9E+05	3.2E+05	1.2E+05	-1.3E+03
Nº 3	-2.0E+05	-3.4E+04	-9.4E+04	-1.0E+04	-3.8E+03	7.1E+05	9.6E+05	3.2E+05	1.2E+05	-1.3E+03
Nº 4	-2.0E+05	-3.4E+04	-1.1E+05	0.0E+00	-3.8E+03	7.1E+05	9.6E+05	3.7E+05	0.0E+00	-1.3E+03
Nº 5	-1.5E+05	-3.4E+04	-9.4E+04	-1.0E+04	-3.8E+03	6.3E+05	8.5E+05	3.2E+05	1.2E+05	-1.3E+03
Nº 6	-9.2E+04	-3.4E+04	-9.4E+04	-1.0E+04	-3.7E+03	5.3E+05	7.3E+05	3.2E+05	1.2E+05	4.7E+04
Nº 7	-4.6E+04	-3.4E+04	-9.4E+04	-1.0E+04	-3.7E+03	2.8E+05	4.0E+05	3.2E+05	1.2E+05	4.7E+04
Nº 8	-2.0E+05	-3.4E+04	-9.4E+04	-1.0E+04	-3.7E+03	7.1E+05	9.7E+05	3.2E+05	1.2E+05	4.8E+04
Nº 9	-2.0E+05	-3.4E+04	-1.1E+05	0.0E+00	-3.7E+03	7.1E+05	9.7E+05	3.7E+05	0.0E+00	4.7E+04
Nº10	-1.5E+05	-3.4E+04	-9.4E+04	-1.0E+04	-3.7E+03	6.3E+05	8.6E+05	3.2E+05	1.2E+05	4.7E+04
Nº11	-9.2E+04	-3.4E+04	-9.4E+04	-1.0E+04	-3.5E+03	5.3E+05	7.2E+05	3.2E+05	1.2E+05	2.9E+04
Nº 12	-4.6E+04	-3.4E+04	-9.4E+04	-1.0E+04	-3.5E+03	2.8E+05	3.9E+05	3.2E+05	1.2E+05	2.9E+04
Nº 13	-2.0E+05	-3.4E+04	-9.4E+04	-1.0E+04	-3.5E+03	7.1E+05	9.7E+05	3.2E+05	1.2E+05	2.9E+04
Nº 14	-2.0E+05	-3.4E+04	-1.1E+05	0.0E+00	-3.5E+03	7.1E+05	9.7E+05	3.7E+05	0.0E+00	2.9E+04
Nº15	-1.5E+05	-3.4E+04	-9.4E+04	-1.0E+04	-3.5E+03	6.3E+05	8.5E+05	3.2E+05	1.2E+05	2.9E+04
Nº16	-9.2E+04	-3.4E+04	-9.4E+04	-1.0E+04	-5.6E+03	5.3E+05	7.2E+05	3.2E+05	1.2E+05	3.4E+04
Nº17	-4.6E+04	-3.4E+04	-9.4E+04	-1.0E+04	-5.6E+03	2.8E+05	3.9E+05	3.2E+05	1.2E+05	3.4E+04
Nº18	-2.0E+05	-3.4E+04	-9.4E+04	-1.0E+04	-5.6E+03	7.1E+05	9.6E+05	3.2E+05	1.2E+05	3.4E+04
Nº19	-2.0E+05	-3.4E+04	-1.1E+05	0.0E+00	-5.6E+03	7.1E+05	9.6E+05	3.7E+05	0.0E+00	3.4E+04
Nº20	-1.5E+05	-3.4E+04	-9.4E+04	-1.0E+04	-5.6E+03	6.3E+05	8.5E+05	3.2E+05	1.2E+05	3.4E+04
Nº21	-9.2E+04	-3.4E+04	-9.4E+04	-1.0E+04	-5.7E+03	5.3E+05	7.3E+05	3.2E+05	1.2E+05	6.1E+04
Nº22	-4.6E+04	-3.4E+04	-9.4E+04	-1.0E+04	-5.7E+03	2.8E+05	4.0E+05	3.2E+05	1.2E+05	6.1E+04
Nº23	-2.0E+05	-3.4E+04	-9.4E+04	-1.0E+04	-5.7E+03	7.1E+05	9.7E+05	3.2E+05	1.2E+05	6.1E+04
Nº24	-2.0E+05	-3.4E+04	-1.1E+05	0.0E+00	-5.7E+03	7.1E+05	9.7E+05	3.7E+05	0.0E+00	6.1E+04

Table 61. Cumulative GWP impact reduction of the scenarios at the end of the transition period in (Tn CO_2 equi./RU).

SC Nº	A1-A3, B4					B6				
	H&DHW	PIFB	SFV	ST	DH int.	H&DHW	PIFB	SFV	ST	DH int.
Nº25	-1.5E+05	-3.4E+04	-9.4E+04	-1.0E+04	-5.7E+03	6.3E+05	8.6E+05	3.2E+05	1.2E+05	6.1E+04
Nº26	-7.3E+04	-3.4E+04	-9.4E+04	-7.3E+03	-7.8E+03	3.6E+05	5.8E+05	3.2E+05	9.1E+04	-1.5E+04
Nº27	-3.6E+04	-3.4E+04	-9.4E+04	-7.3E+03	-7.8E+03	2.0E+05	3.4E+05	3.2E+05	9.1E+04	-1.5E+04
Nº28	-1.6E+05	-3.4E+04	-9.4E+04	-7.3E+03	-7.8E+03	5.0E+05	7.9E+05	3.2E+05	9.1E+04	-1.5E+04
Nº29	-1.2E+05	-3.4E+04	-9.4E+04	-7.3E+03	-7.8E+03	4.4E+05	6.9E+05	3.2E+05	9.1E+04	-1.5E+04
Nº30	-7.3E+04	-3.4E+04	-9.4E+04	-7.3E+03	-6.9E+03	3.6E+05	7.9E+05	3.2E+05	9.1E+04	2.6E+05
Nº31	-3.6E+04	-3.4E+04	-9.4E+04	-7.3E+03	-6.9E+03	2.0E+05	5.5E+05	3.2E+05	9.1E+04	2.6E+05
Nº32	-1.6E+05	-3.4E+04	-9.4E+04	-7.3E+03	-6.9E+03	5.0E+05	9.9E+05	3.2E+05	9.1E+04	2.6E+05
Nº33	-1.6E+05	-3.4E+04	-1.0E+05	0.0E+00	-6.9E+03	5.0E+05	9.9E+05	3.5E+05	0.0E+00	2.6E+05
Nº34	-1.2E+05	-3.4E+04	-9.4E+04	-7.3E+03	-6.9E+03	4.4E+05	9.0E+05	3.2E+05	9.1E+04	2.6E+05
Nº35	-7.3E+04	-3.4E+04	-9.4E+04	-7.3E+03	-5.8E+03	3.6E+05	7.1E+05	3.2E+05	9.1E+04	1.6E+05
Nº36	-3.6E+04	-3.4E+04	-9.4E+04	-7.3E+03	-5.8E+03	2.0E+05	4.7E+05	3.2E+05	9.1E+04	1.6E+05
Nº37	-1.6E+05	-3.4E+04	-9.4E+04	-7.3E+03	-5.8E+03	5.0E+05	9.2E+05	3.2E+05	9.1E+04	1.6E+05
Nº38	-1.2E+05	-3.4E+04	-9.4E+04	-7.3E+03	-5.8E+03	4.4E+05	8.2E+05	3.2E+05	9.1E+04	1.6E+05
Nº39	-7.3E+04	-3.4E+04	-9.4E+04	-7.3E+03	-2.0E+04	3.6E+05	6.2E+05	3.2E+05	9.1E+04	1.9E+05
Nº40	-3.6E+04	-3.4E+04	-9.4E+04	-7.3E+03	-2.0E+04	2.0E+05	3.8E+05	3.2E+05	9.1E+04	1.9E+05
Nº41	-1.6E+05	-3.4E+04	-9.4E+04	-7.3E+03	-2.0E+04	5.0E+05	8.3E+05	3.2E+05	9.1E+04	1.9E+05
Nº42	-1.2E+05	-3.4E+04	-9.4E+04	-7.3E+03	-2.0E+04	4.4E+05	7.3E+05	3.2E+05	9.1E+04	1.9E+05
Nº43	-7.3E+04	-3.4E+04	-9.4E+04	-7.3E+03	-2.1E+04	3.6E+05	7.8E+05	3.2E+05	9.1E+04	4.0E+05
Nº44	-3.6E+04	-3.4E+04	-9.4E+04	-7.3E+03	-2.1E+04	2.0E+05	5.4E+05	3.2E+05	9.1E+04	4.0E+05
Nº45	-1.6E+05	-3.4E+04	-9.4E+04	-7.3E+03	-2.1E+04	5.0E+05	9.9E+05	3.2E+05	9.1E+04	4.0E+05
Nº46	-1.6E+05	-3.4E+04	-1.0E+05	0.0E+00	-2.1E+04	5.0E+05	9.9E+05	3.5E+05	0.0E+00	4.0E+05
Nº47	-1.2E+05	-3.4E+04	-9.4E+04	-7.3E+03	-2.1E+04	4.4E+05	8.9E+05	3.2E+05	9.1E+04	4.0E+05

Table 62. Cumulative GWP impact reduction of the scenarios at the end of the transition period in (Tn CO_2 equi./RU).

SC Nº	A1-A3, B4					B6				
	H&DHW	**PIFB**	**SFV**	**ST**	**DH int.**	**H&DHW**	**PIFB**	**SFV**	**ST**	**DH int.**
Nº48	-4.8E+04	-3.4E+04	-9.4E+04	-4.5E+03	-1.2E+04	2.1E+05	4.4E+05	3.2E+05	5.6E+04	-6.3E+04
Nº49	-2.1E+04	-3.4E+04	-9.4E+04	-4.5E+03	-1.2E+04	1.1E+05	2.8E+05	3.2E+05	5.6E+04	-6.3E+04
Nº50	-9.0E+04	-3.4E+04	-9.4E+04	-4.5E+03	-1.2E+04	2.8E+05	5.6E+05	3.2E+05	5.6E+04	-6.3E+04
Nº51	-7.0E+04	-3.4E+04	-9.4E+04	-4.5E+03	-1.2E+04	2.5E+05	5.0E+05	3.2E+05	5.6E+04	-6.3E+04
Nº52	-4.8E+04	-3.4E+04	-9.4E+04	-4.5E+03	-1.0E+04	2.1E+05	9.4E+05	3.2E+05	5.6E+04	4.2E+05
Nº53	-2.1E+04	-3.4E+04	-9.4E+04	-4.5E+03	-1.0E+04	1.1E+05	7.9E+05	3.2E+05	5.6E+04	4.2E+05
Nº54	-9.0E+04	-3.4E+04	-9.4E+04	-4.5E+03	-1.0E+04	2.8E+05	1.1E+06	3.2E+05	5.6E+04	4.2E+05
Nº55	-7.0E+04	-3.4E+04	-9.4E+04	-4.5E+03	-1.0E+04	2.5E+05	1.0E+06	3.2E+05	5.6E+04	4.2E+05
Nº56	-4.8E+04	-3.4E+04	-9.4E+04	-4.5E+03	-8.0E+03	2.1E+05	7.5E+05	3.2E+05	5.6E+04	2.4E+05
Nº57	-2.1E+04	-3.4E+04	-9.4E+04	-4.5E+03	-8.0E+03	1.1E+05	6.0E+05	3.2E+05	5.6E+04	2.4E+05
Nº58	-9.0E+04	-3.4E+04	-9.4E+04	-4.5E+03	-8.0E+03	2.8E+05	8.7E+05	3.2E+05	5.6E+04	2.4E+05
Nº59	-7.0E+04	-3.4E+04	-9.4E+04	-4.5E+03	-8.0E+03	2.5E+05	8.1E+05	3.2E+05	5.6E+04	2.4E+05
Nº60	-4.8E+04	-3.4E+04	-9.4E+04	-4.5E+03	-3.6E+04	2.1E+05	5.3E+05	3.2E+05	5.6E+04	3.2E+05
Nº61	-2.1E+04	-3.4E+04	-9.4E+04	-4.5E+03	-3.6E+04	1.1E+05	3.8E+05	3.2E+05	5.6E+04	3.2E+05
Nº62	-9.0E+04	-3.4E+04	-9.4E+04	-4.5E+03	-3.6E+04	2.8E+05	6.5E+05	3.2E+05	5.6E+04	3.2E+05
Nº63	-7.0E+04	-3.4E+04	-9.4E+04	-4.5E+03	-3.6E+04	2.5E+05	6.0E+05	3.2E+05	5.6E+04	3.2E+05
Nº64	-4.8E+04	-3.4E+04	-9.4E+04	-4.5E+03	-3.8E+04	2.1E+05	9.3E+05	3.2E+05	5.6E+04	6.9E+05
Nº65	-2.1E+04	-3.4E+04	-9.4E+04	-4.5E+03	-3.8E+04	1.1E+05	7.8E+05	3.2E+05	5.6E+04	6.9E+05
Nº66	-9.0E+04	-3.4E+04	-9.4E+04	-4.5E+03	-3.8E+04	2.8E+05	1.0E+06	3.2E+05	5.6E+04	6.9E+05
Nº67	-9.0E+04	-3.4E+04	-9.9E+04	0.0E+00	-3.8E+04	2.8E+05	1.1E+06	3.4E+05	0.0E+00	6.9E+05
Nº68	-7.0E+04	-3.4E+04	-9.4E+04	-4.5E+03	-3.8E+04	2.5E+05	9.9E+05	3.2E+05	5.6E+04	6.9E+05

Table 63. Cumulative Non Renewable Primary Energy Reduction of scenarios. (MWh of NR-PE/RU) savings at the end of the period.

SC Nº	A1-A3, B4					B6				
	H&DHW	PIFB	SFV	ST	DH int.	H&DHW	PIFB	SFV	ST	DH int.
Nº1	-2.5E+05	-2.6E+05	-4.1E+05	-4.3E+04	-1.8E+04	2.5E+06	3.4E+06	1.8E+06	5.7E+05	1.9E+04
Nº2	-2.1E+05	-2.6E+05	-4.1E+05	-4.3E+04	-1.8E+04	1.4E+06	1.9E+06	1.8E+06	5.7E+05	1.9E+04
Nº 3	-2.8E+05	-2.6E+05	-4.1E+05	-4.3E+04	-1.8E+04	3.2E+06	4.4E+06	1.8E+06	5.7E+05	1.9E+04
Nº 4	-2.8E+05	-2.6E+05	-4.7E+05	0.0E+00	-1.8E+04	3.2E+06	4.4E+06	2.1E+06	0.0E+00	1.9E+04
Nº 5	-2.6E+05	-2.6E+05	-4.1E+05	-4.3E+04	-1.8E+04	2.9E+06	3.9E+06	1.8E+06	5.7E+05	1.9E+04
Nº 6	-2.5E+05	-2.6E+05	-4.1E+05	-4.3E+04	-1.8E+04	2.5E+06	3.4E+06	1.8E+06	5.7E+05	2.3E+05
Nº 7	-2.1E+05	-2.6E+05	-4.1E+05	-4.3E+04	-1.8E+04	1.4E+06	1.9E+06	1.8E+06	5.7E+05	2.3E+05
Nº 8	-2.8E+05	-2.6E+05	-4.1E+05	-4.3E+04	-1.8E+04	3.2E+06	4.4E+06	1.8E+06	5.7E+05	1.9E+05
Nº 9	-2.8E+05	-2.6E+05	-4.7E+05	0.0E+00	-1.8E+04	3.2E+06	4.4E+06	2.1E+06	0.0E+00	2.3E+05
Nº10	-2.6E+05	-2.6E+05	-4.1E+05	-4.3E+04	-1.8E+04	2.9E+06	4.0E+06	1.8E+06	5.7E+05	2.3E+05
Nº11	-2.5E+05	-2.6E+05	-4.1E+05	-4.3E+04	-1.7E+04	2.5E+06	3.4E+06	1.8E+06	5.7E+05	1.3E+05
Nº 12	-2.1E+05	-2.6E+05	-4.1E+05	-4.3E+04	-1.7E+04	1.4E+06	1.9E+06	1.8E+06	5.7E+05	1.3E+05
Nº 13	-2.8E+05	-2.6E+05	-4.1E+05	-4.3E+04	-1.7E+04	3.2E+06	4.4E+06	1.8E+06	5.7E+05	1.3E+05
Nº 14	-2.8E+05	-2.6E+05	-4.7E+05	0.0E+00	-1.7E+04	3.2E+06	4.4E+06	2.1E+06	0.0E+00	1.3E+05
Nº15	-2.6E+05	-2.6E+05	-4.1E+05	-4.3E+04	-1.7E+04	2.9E+06	3.9E+06	1.8E+06	5.7E+05	1.3E+05
Nº16	-2.5E+05	-2.6E+05	-4.1E+05	-4.3E+04	-2.6E+04	2.5E+06	3.4E+06	1.8E+06	5.7E+05	1.6E+05
Nº17	-2.1E+05	-2.6E+05	-4.1E+05	-4.3E+04	-2.6E+04	1.4E+06	1.9E+06	1.8E+06	5.7E+05	1.6E+05
Nº18	-2.8E+05	-2.6E+05	-4.1E+05	-4.3E+04	-2.6E+04	3.2E+06	4.4E+06	1.8E+06	5.7E+05	1.6E+05
Nº19	-2.8E+05	-2.6E+05	-4.7E+05	0.0E+00	-2.6E+04	3.2E+06	4.4E+06	2.1E+06	0.0E+00	1.6E+05
Nº20	-2.6E+05	-2.6E+05	-4.1E+05	-4.3E+04	-2.6E+04	2.9E+06	3.9E+06	1.8E+06	5.7E+05	1.6E+05
Nº21	-2.5E+05	-2.6E+05	-4.1E+05	-4.3E+04	-2.6E+04	2.5E+06	3.4E+06	1.8E+06	5.7E+05	2.9E+05
Nº22	-2.1E+05	-2.6E+05	-4.1E+05	-4.3E+04	-2.6E+04	1.4E+06	1.9E+06	1.8E+06	5.7E+05	2.9E+05
Nº23	-2.8E+05	-2.6E+05	-4.1E+05	-4.3E+04	-2.6E+04	3.2E+06	4.4E+06	1.8E+06	5.7E+05	2.9E+05
Nº24	-2.8E+05	-2.6E+05	-4.7E+05	0.0E+00	-2.6E+04	3.2E+06	4.4E+06	2.1E+06	0.0E+00	2.9E+05

Table 64. Cumulative Non Renewable Primary Energy Reduction of scenarios. (MWh of NR-PE/RU) savings at the end of the period.

SC Nº	A1-A3, B4					B6				
	H&DHW	PIFB	SFV	ST	DH int.	H&DHW	PIFB	SFV	ST	DH int.
Nº25	-2.6E+05	-2.6E+05	-4.1E+05	-4.3E+04	-2.6E+04	2.9E+06	4.0E+06	1.8E+06	5.7E+05	2.9E+05
Nº26	-1.9E+05	-2.6E+05	-4.1E+05	-3.2E+04	-3.8E+04	1.7E+06	2.8E+06	1.8E+06	4.2E+05	-1.2E+05
Nº27	-1.7E+05	-2.6E+05	-4.1E+05	-3.2E+04	-3.8E+04	9.9E+05	1.7E+06	1.8E+06	4.2E+05	-1.2E+05
Nº28	-2.1E+05	-2.6E+05	-4.1E+05	-3.2E+04	-3.8E+04	2.3E+06	3.7E+06	1.8E+06	4.2E+05	-1.2E+05
Nº29	-2.0E+05	-2.6E+05	-4.1E+05	-3.2E+04	-3.8E+04	2.0E+06	3.3E+06	1.8E+06	4.2E+05	-1.2E+05
Nº30	-1.9E+05	-2.6E+05	-4.1E+05	-3.2E+04	-3.3E+04	1.7E+06	3.7E+06	1.8E+06	4.2E+05	1.1E+06
Nº31	-1.7E+05	-2.6E+05	-4.1E+05	-3.2E+04	-3.3E+04	9.9E+05	2.7E+06	1.8E+06	4.2E+05	1.1E+06
Nº32	-2.1E+05	-2.6E+05	-4.1E+05	-3.2E+04	-3.3E+04	2.3E+06	4.6E+06	1.8E+06	4.2E+05	1.1E+06
Nº33	-2.1E+05	-2.6E+05	-4.5E+05	0.0E+00	-3.3E+04	2.3E+06	4.6E+06	2.0E+06	0.0E+00	1.1E+06
Nº34	-2.0E+05	-2.6E+05	-4.1E+05	-3.2E+04	-3.3E+04	2.0E+06	4.2E+06	1.8E+06	4.2E+05	1.1E+06
Nº35	-1.9E+05	-2.6E+05	-4.1E+05	-3.2E+04	-2.8E+04	1.7E+06	3.3E+06	1.8E+06	4.2E+05	5.0E+05
Nº36	-1.7E+05	-2.6E+05	-4.1E+05	-3.2E+04	-2.8E+04	9.9E+05	2.2E+06	1.8E+06	4.2E+05	5.0E+05
Nº37	-2.1E+05	-2.6E+05	-4.1E+05	-3.2E+04	-2.8E+04	2.3E+06	4.1E+06	1.8E+06	4.2E+05	5.0E+05
Nº38	-2.0E+05	-2.6E+05	-4.1E+05	-3.2E+04	-2.8E+04	2.0E+06	3.8E+06	1.8E+06	4.2E+05	5.0E+05
Nº39	-1.9E+05	-2.6E+05	-4.1E+05	-3.2E+04	-8.8E+04	1.7E+06	2.9E+06	1.8E+06	4.2E+05	7.0E+05
Nº40	-1.7E+05	-2.6E+05	-4.1E+05	-3.2E+04	-8.8E+04	9.9E+05	1.8E+06	1.8E+06	4.2E+05	7.0E+05
Nº41	-2.1E+05	-2.6E+05	-4.1E+05	-3.2E+04	-8.8E+04	2.3E+06	3.7E+06	1.8E+06	4.2E+05	7.0E+05
Nº42	-2.0E+05	-2.6E+05	-4.1E+05	-3.2E+04	-8.8E+04	2.0E+06	3.4E+06	1.8E+06	4.2E+05	7.0E+05
Nº43	-1.9E+05	-2.6E+05	-4.1E+05	-3.2E+04	-8.9E+04	1.7E+06	3.7E+06	1.8E+06	4.2E+05	1.7E+06
Nº44	-1.7E+05	-2.6E+05	-4.1E+05	-3.2E+04	-8.9E+04	9.9E+05	2.6E+06	1.8E+06	4.2E+05	1.7E+06
Nº45	-2.1E+05	-2.6E+05	-4.1E+05	-3.2E+04	-8.9E+04	2.3E+06	4.5E+06	1.8E+06	4.2E+05	1.7E+06
Nº46	-2.1E+05	-2.6E+05	-4.5E+05	0.0E+00	-8.9E+04	2.3E+06	4.5E+06	2.0E+06	0.0E+00	1.7E+06
Nº47	-2.0E+05	-2.6E+05	-4.1E+05	-3.2E+04	-8.9E+04	2.0E+06	4.1E+06	1.8E+06	4.2E+05	1.7E+06

Table 65. Cumulative Non Renewable Primary Energy Reduction of scenarios. (MWh of NR-PE/RU) savings at the end of the period.

SC Nº	A1-A3, B4					B6				
	H&DHW	PIFB	SFV	ST	DH int.	H&DHW	PIFB	SFV	ST	DH int.
Nº48	-1.1E+05	-2.6E+05	-4.1E+05	-1.9E+04	-5.9E+04	1.0E+06	2.1E+06	1.8E+06	2.6E+05	-3.8E+05
Nº49	-9.7E+04	-2.6E+05	-4.1E+05	-1.9E+04	-5.9E+04	6.0E+05	1.4E+06	1.8E+06	2.6E+05	-3.8E+05
Nº50	-1.2E+05	-2.6E+05	-4.1E+05	-1.9E+04	-5.9E+04	1.3E+06	2.5E+06	1.8E+06	2.6E+05	-3.8E+05
Nº51	-1.2E+05	-2.6E+05	-4.1E+05	-1.9E+04	-5.9E+04	1.2E+06	2.3E+06	1.8E+06	2.6E+05	-3.8E+05
Nº52	-1.1E+05	-2.6E+05	-4.1E+05	-1.9E+04	-4.9E+04	1.0E+06	4.3E+06	1.8E+06	2.6E+05	1.8E+06
Nº53	-9.7E+04	-2.6E+05	-4.1E+05	-1.9E+04	-4.9E+04	6.0E+05	3.6E+06	1.8E+06	2.6E+05	1.8E+06
Nº54	-1.2E+05	-2.6E+05	-4.1E+05	-1.9E+04	-4.9E+04	1.3E+06	4.8E+06	1.8E+06	2.6E+05	1.8E+06
Nº55	-1.2E+05	-2.6E+05	-4.1E+05	-1.9E+04	-4.9E+04	1.2E+06	4.5E+06	1.8E+06	2.6E+05	1.8E+06
Nº56	-1.1E+05	-2.6E+05	-4.1E+05	-1.9E+04	-3.8E+04	1.0E+06	3.2E+06	1.8E+06	2.6E+05	7.3E+05
Nº57	-9.7E+04	-2.6E+05	-4.1E+05	-1.9E+04	-3.8E+04	6.0E+05	2.5E+06	1.8E+06	2.6E+05	7.3E+05
Nº58	-1.2E+05	-2.6E+05	-4.1E+05	-1.9E+04	-3.8E+04	1.3E+06	3.7E+06	1.8E+06	2.6E+05	7.3E+05
Nº59	-1.2E+05	-2.6E+05	-4.1E+05	-1.9E+04	-3.8E+04	1.2E+06	3.5E+06	1.8E+06	2.6E+05	7.3E+05
Nº60	-1.1E+05	-2.6E+05	-4.1E+05	-1.9E+04	-1.6E+05	1.0E+06	2.2E+06	1.8E+06	2.6E+05	1.2E+06
Nº61	-9.7E+04	-2.6E+05	-4.1E+05	-1.9E+04	-1.6E+05	6.0E+05	1.5E+06	1.8E+06	2.6E+05	1.2E+06
Nº62	-1.2E+05	-2.6E+05	-4.1E+05	-1.9E+04	-1.6E+05	1.3E+06	2.7E+06	1.8E+06	2.6E+05	1.2E+06
Nº63	-1.2E+05	-2.6E+05	-4.1E+05	-1.9E+04	-1.6E+05	1.2E+06	2.4E+06	1.8E+06	2.6E+05	1.2E+06
Nº64	-1.1E+05	-2.6E+05	-4.1E+05	-1.9E+04	-1.6E+05	1.0E+06	4.1E+06	1.8E+06	2.6E+05	2.9E+06
Nº65	-9.7E+04	-2.6E+05	-4.1E+05	-1.9E+04	-1.6E+05	6.0E+05	3.4E+06	1.8E+06	2.6E+05	2.9E+06
Nº66	-1.2E+05	-2.6E+05	-4.1E+05	-1.9E+04	-1.6E+05	1.3E+06	4.6E+06	1.8E+06	2.6E+05	2.9E+06
Nº67	-1.2E+05	-2.6E+05	-4.3E+05	0.0E+00	-1.6E+05	1.3E+06	4.8E+06	1.9E+06	0.0E+00	2.9E+06
Nº68	-1.2E+05	-2.6E+05	-4.1E+05	-1.9E+04	-1.6E+05	1.2E+06	4.3E+06	1.8E+06	2.6E+05	2.9E+06

6.6. Chapter 4. Complementary information for the Section 4.3.2. Energy characterisation of the area of study

6.6.1. Main characteristics used in the district energy modelling

This section includes complementary information for sections 6.1.1 and 6.3. Therefore, information related to the characteristics that are necessary for the energy modelling of the districts, and related to the main barriers that can limit the implementation level of each intervention is included. Besides, the blueprints of the buildings included in the districts evaluated in Donostia-San Sebastián are provided.

<u>Amara</u>

Figure 89. Buildings of the district of Amara.

Aldezaharra

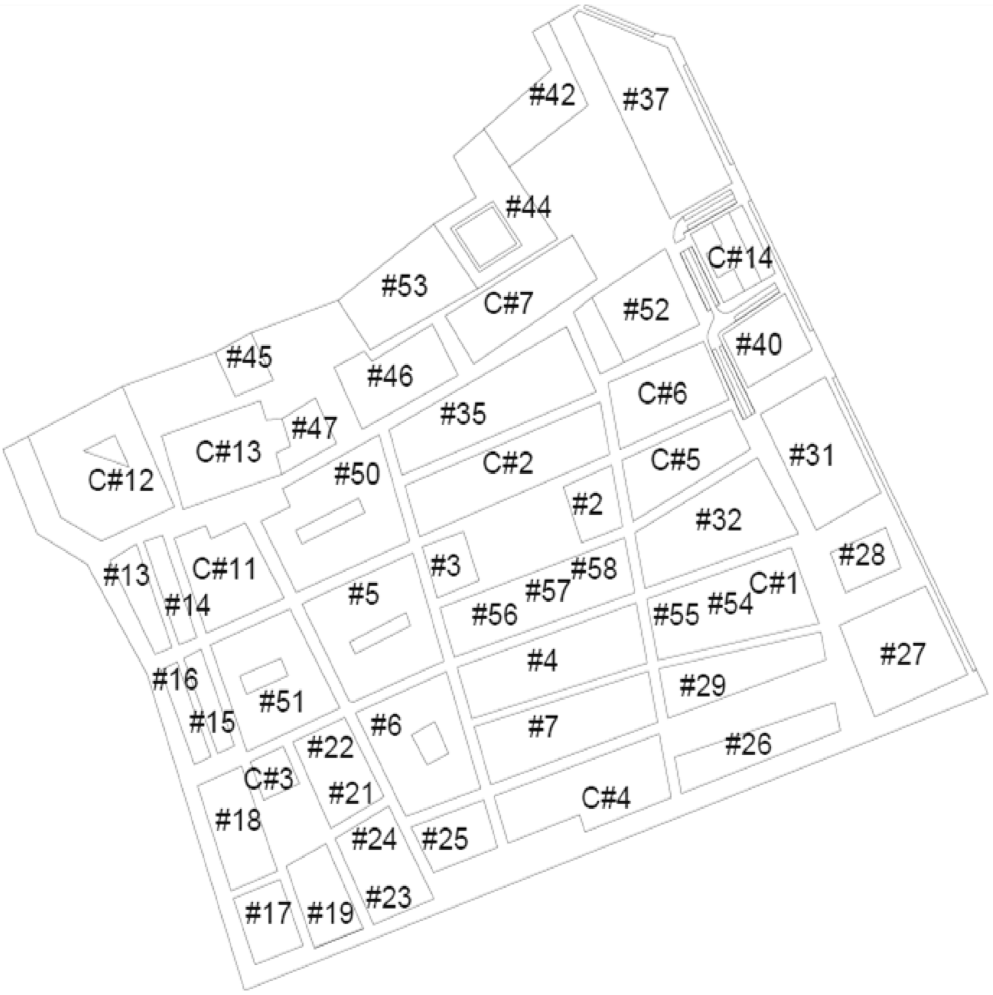

Figure 90. Buildings of the district of Aldezaharra.

<u>Cortazar</u>

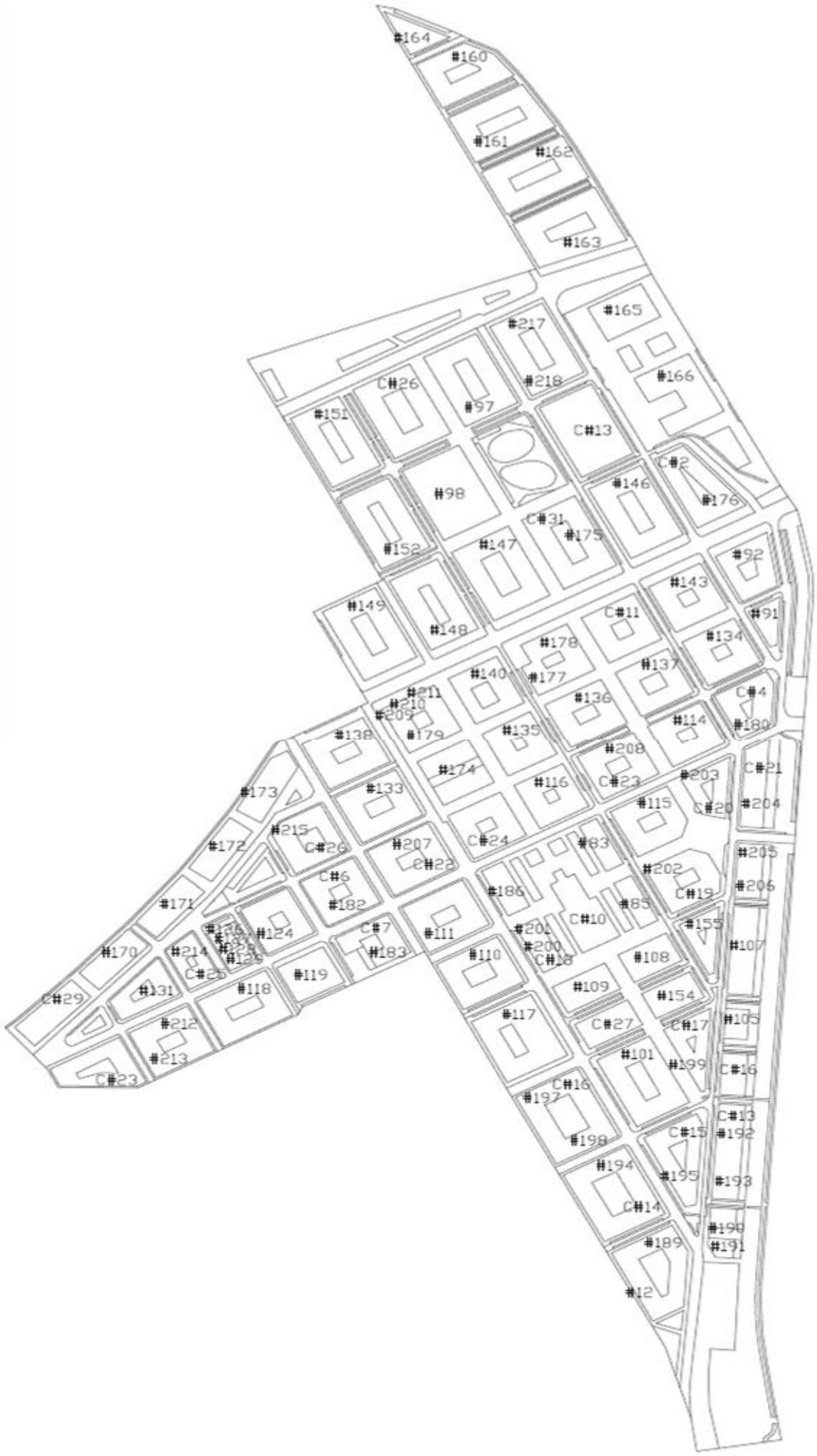

Figure 91. Buildings of the district of Cortazar.

Txomin Enea

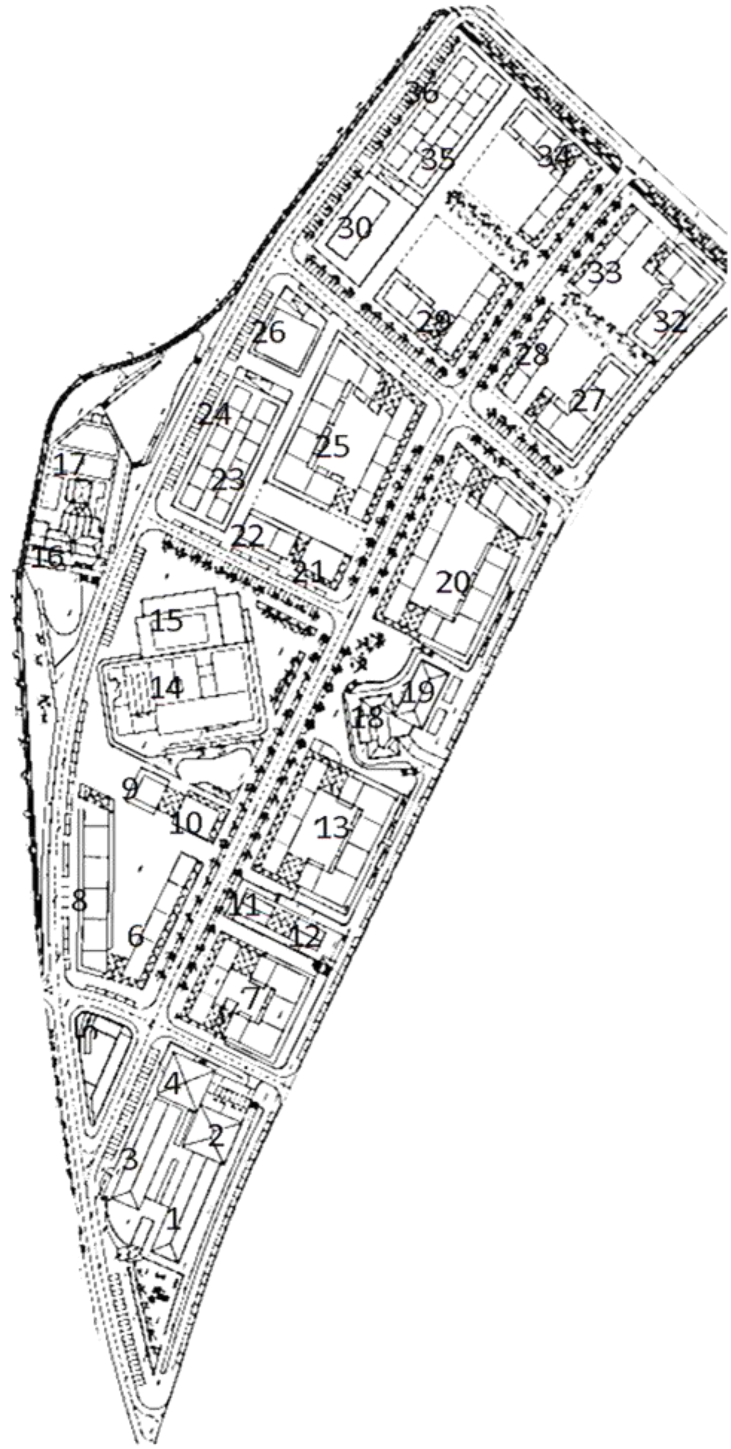

Figure 92. Buildings of the district of Txomin Enea.

Antiguo I

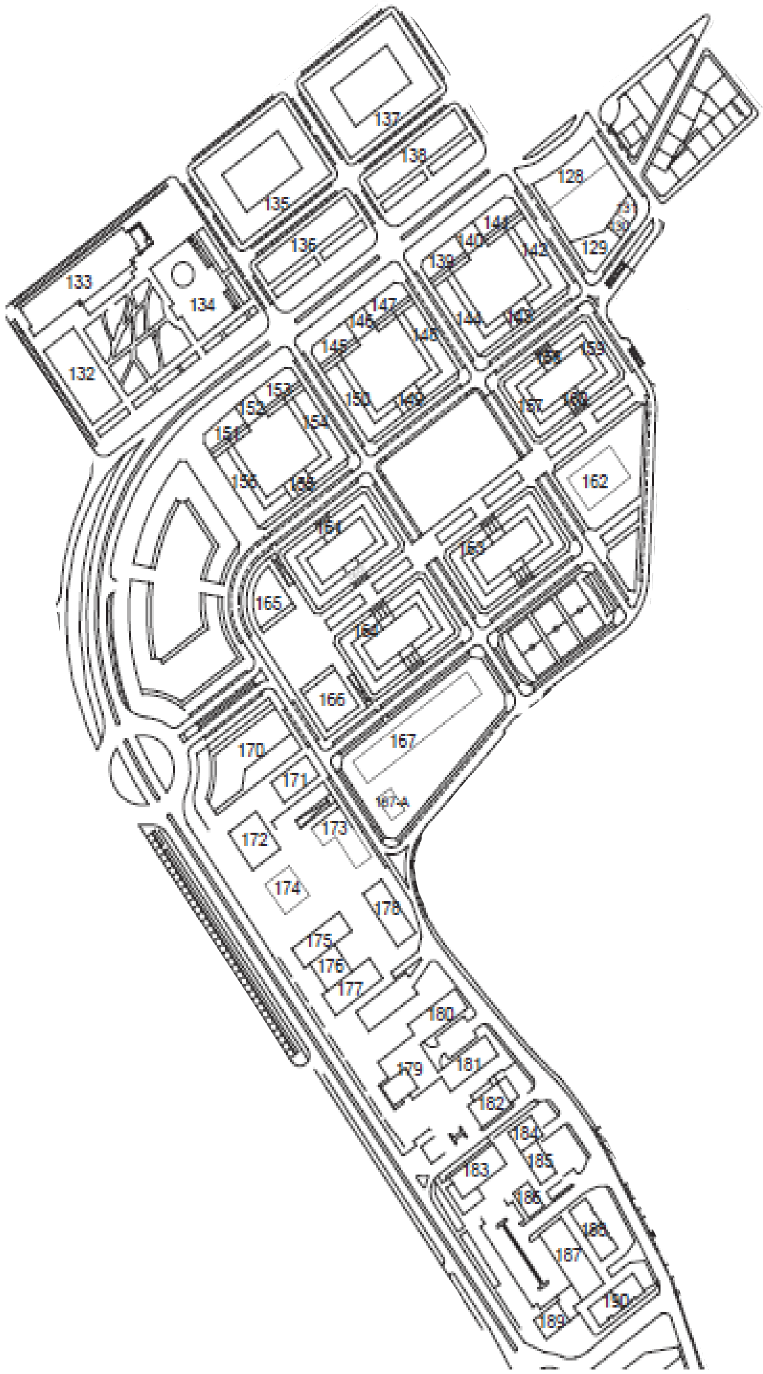

Figure 93. Buildings of the district of Antiguo I.

Antiguo II

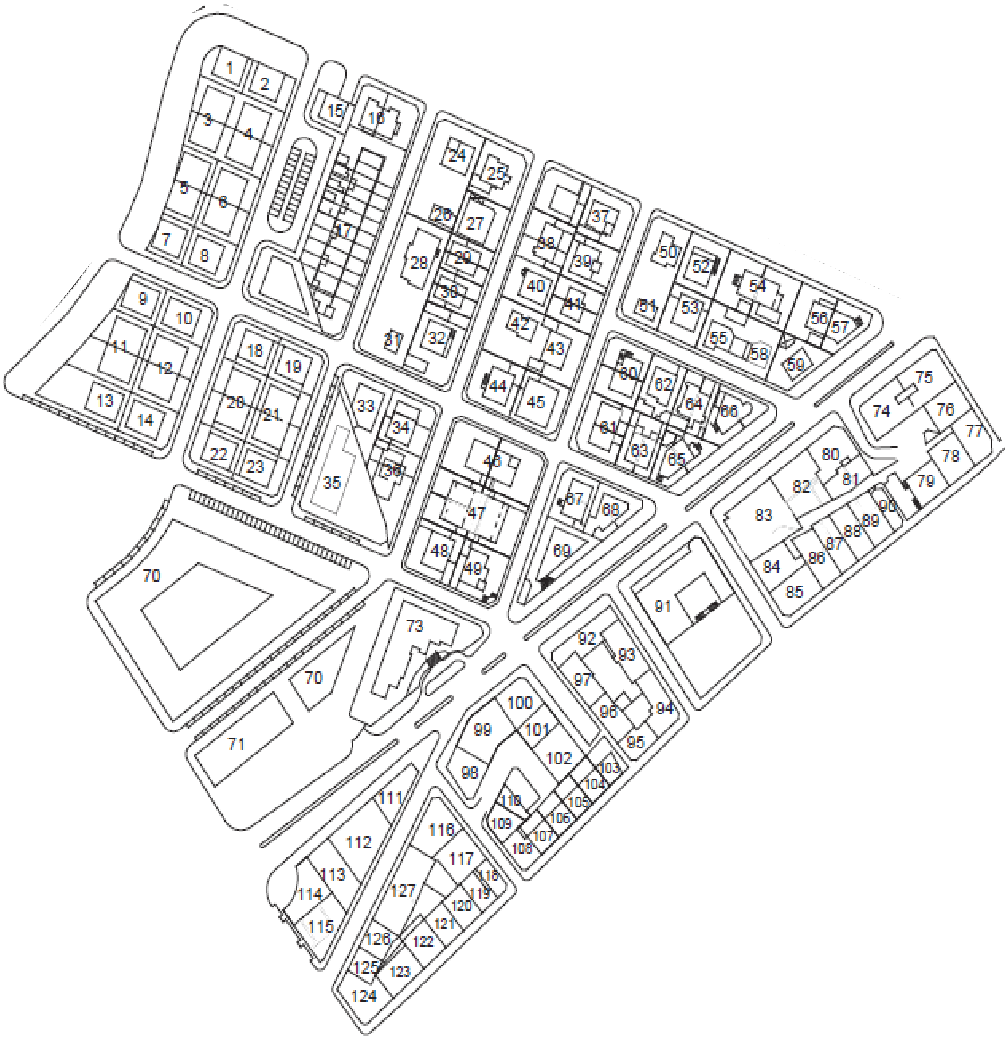

Figure 94. Buildings of the district of Antiguo II.

Gros

Figure 95. Buildings of the district of Gros.

Table 66. Energy efficiency level of buildings of the districts evaluated. Data obtained from the energy certifications available in the city.

Aldezaharra	Efficiency level
31 agosto Nº 19 5º - (20003) Donostia / San Sebastián	G
ALDAMAR Nº 12 (20003) Donostia / San Sebastián	E
Ibilbidea/Paseo Muelle Nº 11 2 ezkerra (20003) Donostia / San Sebastián	E
Ibilbidea/Paseo Muelle Nº 26 1ºD (20003) Donostia / San Sebastián	D
Ibilbidea/Paseo Salamanca Nº 13 5º F BIBLIOTECA DE LA CASA	E
Ibilbidea/Paseo Salamanca Nº 13 6 BIBLIOTECA DE LA CASA DE LA RIOJA	E
Kalea/Calle 31 de Agosto Nº 11 4º Izq. (20003) Donostia	E
Kalea/Calle 31 de Agosto Nº 19 5º Izq. (20003) Donostia	G
Kalea/Calle Campanario Nº 1 2 D (20003) Donostia	G
Kalea/Calle Embeltran Nº 10 4 (20003) Donostia	E
Kalea/Calle Euskalherria Nº 1 5º izda (20003) Donostia	G
Kalea/Calle General Jauregi Nº 9 2º DCHA (20003) Donostia	E
Kalea/Calle General Jauregi Nº 9 3ºIzda (20003) Donostia	D
Kalea/Calle Ijentea Nº 4 5ºD (20003) Donostia	G
Kalea/Calle Iñigo Nº 10 5 (20003) Donostia	E
Kalea/Calle Pescadería Nº 11 4º CTRO (20003) Donostia	F
Kalea/Calle San Jerónimo Nº 21 3º DERECHA (20003) Donostia	F
NARRICA Nº 18 1º CTRO (20003) Donostia	G
PESCADERIA Nº 11 1º IZDA. (20003) Donostia	G
Plaza/Plaza Sarriegi Nº 7 2º IZDA (20003) Donostia	E
Zumardia/Alameda Boulevard Nº 23 PISO 1ºD (20003) Donostia	E
Gros	
Etorbidea/Avenida Zurriola Nº 24 7º DERECHA (20002) Donostia	G
Ibilbidea/Paseo Colón Nº 21 2º Izq. (20002) Donostia	G
Ibilbidea/Paseo Colón Nº 27 2º B (20002) Donostia	E
Ibilbidea/Paseo Colón Nº 9 BAJO - LOCAL Nº 5 (20002) Donostia	D
Ibilbidea/Paseo Ramón María Lili Nº 8 2ºB (20002) Donostia	E
Kalea/Calle General Artetxe Nº 8 5ºdcha (20002) Donostia	E
Kalea/Calle Agirre Miramon Nº 7 Bajo comercial (20002) Donostia	E
Kalea/Calle Peña y Goñi Nº 1 3 Dcha-C (20002) Donostia	E
Kalea/Calle Peña y Goñi, 1 3 Dcha-A 20002 Donostia	D
Kalea/Calle Jose Mig.Barandiaran Nº 18 5º 1 (20002) Donostia	E
Kalea/Calle San Francisco Nº 32 5º A (20002) Donostia	G
Kalea/Calle San Francisco Nº 45 PISO (20002) Donostia	E
Kalea/Calle Zabaleta Nº 32 5-dcha-dcha (20002) Donostia	G
Kalea/Calle Zabaleta Nº 35 1 dcha (20002) Donostia	E
Kalea/Calle Zabaleta Nº 35 1 izda (20002) Donostia	F
Kalea/Calle Zabaleta Nº 35 4º Izquierda (20002) Donostia	F
Kalea/Calle Zabaleta Nº 4 5 A (20002) Donostia	D
Kalea/Calle Zabaleta Nº 6 6º B (20002) Donostia	F
UTM(x/y):(582953.036947221/4797136.21679642) Kalea/Calle Zabaleta Nº 2 7º	E

Table 67. Energy efficiency level of buildings of the districts evaluated. Data obtained from the energy certifications available in the city.

Antiguo	**Efficiency level**
AVDA. ZARAUTZ Nº 107 2º (20018) Donostia	E
AVENIDA DE AÑORGA Nº 12 1ºC (20018) Donostia	E
Alto Errondo Nº 86 1ºD (20018) Donostia	E
Bidea/Camino Pokopandegi Nº 24 3 VASCONGADA ADITIVOS (20018)	G
Bidea/Camino Zubiberri Nº 31 Bajo Local 4 Parque empresarial Zuatzu (20018)	D
Enparantza/Plaza Angela Figuera Nº 7 1ºA (20018) Donostia	E
Etorbidea/Avenida Tolosa Nº 11 1º (20018) Donostia	D
Etorbidea/Avenida Tolosa Nº 11 BAJO (20018) Donostia	E
Etorbidea/Avenida Tolosa Nº 81 2 (20018) Donostia	G
Etorbidea/Avenida Zarautz Nº 109 3º D (20018) Donostia	G
Etorbidea/Avenida Zarautz Nº 109 5º C (20018) Donostia	E
Etorbidea/Avenida Zarautz Nº 126 5ºB (20018) Donostia	E
Etorbidea/Avenida Zarautz Nº 13 1·IZDA GASOLINERA (20018) Donostia	E
Etorbidea/Avenida Zarautz Nº 17 3º Dcha (20018) Donostia	G
Etorbidea/Avenida Zarautz Nº 21 (20018) Donostia	G
Etorbidea/Avenida Zarautz Nº 23 (20018) Donostia	G
Etorbidea/Avenida Zarautz Nº 39 1º IZDA. (20018) Donostia	E
Etorbidea/Avenida Zarautz Nº 45 PISO 1ºD C. SAGASTIBELTZA (20018)	G
Etorbidea/Avenida Zarautz Nº 51 3º B (20018) Donostia	E
Etorbidea/Avenida Zarautz Nº 77 1º A (20018) Donostia	E
Etorbidea/Avenida Zarautz Nº 80 13 C EGUZKI LOREA (20018) Donostia	E
Etorbidea/Avenida Zarautz Nº 81 1º dcha C§ BIDEGAIN (20018) Donostia	G
Etorbidea/Avenida Zarautz Nº 81 Entlo izda C§ BIDEGAIN (20018) Donostia	G
Etorbidea/Avenida Zarautz Nº 83 2ºA GOIKOETXEA (20018) Donostia	E
Etorbidea/Avenida Zarautz Nº 84 6º E ITSAS LOREA (20018) Donostia	E
Ibilbidea/Paseo Arriola Nº 21 PISO 1ºD (20018) Donostia	G
Ibilbidea/Paseo Berio 1ºB (20018) Donostia	E
Ibilbidea/Paseo Berio Nº 15 2º B (20018) Donostia	D
Ibilbidea/Paseo Berio Nº 32 bajo A (20018) Donostia	E
Ibilbidea/Paseo Ondarreta Nº 11 1º D (20018) Donostia	E
Iruñea Nº 3 4ºB (20018) Donostia	D
Kalea/Calle Aizkorri Nº 59 5º Dcha LUGARIZ TXIKI (20018) Donostia	G
Kalea/Calle Aizkorri Nº 75 3ºB C.AVANCO (20018) Donostia	G
Kalea/Calle Aizkorri Nº 77 1ªD (20018) Donostia	E
Kalea/Calle Aizkorri Nº 77 2ºC C.AVANCO (20018) Donostia	E
Kalea/Calle Antonio Arzak Nº 1 6º DCHA. (20018) Donostia	E
Kalea/Calle Antonio Gaztañeta Nº 1 2º DCHA (20018) Donostia	E
Kalea/Calle Carmelo Etxegarai Nº 9 2ºDcha (20018) Donostia	E
Kalea/Calle Karmele Saint-Martin Nº 24 esc 1, 1ºB (20018) Donostia	G
Kalea/Calle Manuel Vázquez Montalbán Nº 1 - portales 1 y 3 portales 1 y 3	D
Kalea/Calle Manuel Vázquez Montalbán Nº 11 Portales 11-13-15-17-19 (20018)	D

Table 68. Energy efficiency level of buildings of the districts evaluated. Data obtained from the energy certifications available in the city.

Antiguo	**Efficiency level**
Kalea/Calle Manuel Vázquez Montalbán Nº 2 (20018) Donostia	D
Kalea/Calle Manuel Vázquez Montalbán Nº 21 Portales 21-23-25-27-29 (20018)	D
Kalea/Calle Oihenart Nº 1 OIH 1-3-5-7 X.BERS 12-14-16-18 (20018) Donostia	E
Kalea/Calle Oihenart Nº 2 2-4-6-8 R Mª A 1-3-5-7 (20018) Donostia	E
Kalea/Calle Portuene Nº 07 3 drch (20018) Donostia	E
Kalea/Calle Portuetxe Nº 45 4º - LOCALES 4 Y 5 UTM 579913 / 4794717	F
Kalea/Calle Portuetxe Nº 45 PISO 3, OFICINA 2 UTM 579915 / 4794711	E
Kalea/Calle Portuetxe Nº 47 3º PUERTA 46 ASKAIN (20018) Donostia	D
Kalea/Calle Portuetxe Nº 57 (20018) Donostia	D
Kalea/Calle Portuetxe Nº 83 planta segunda oficina 2 EDIFICIO ARAGI (20018)	E
Kalea/Calle Resurreccion M. Azkue Nº 10 3ºI (20018) Donostia	E
Kalea/Calle Vitoria-Gasteiz Nº 12 2º B (20018) Donostia	D
Kalea/Calle Vitoria-Gasteiz Nº 12 LOCAL (20018) Donostia	D
Kalea/Calle Vitoria-Gasteiz Nº 18 5 B (20018) Donostia	E
Kalea/Calle Xabier Lizardi Nº 4 2º IZDA UTM 580698 / 4794783 (20018)	G
LOGROÑO Nº 5 5ºC (20018) Donostia	D
PASEO DE BERIO Nº 17 1ºA-A (20018) Donostia	E
PASEO DE BERIO Nº 17 1ºA-B (20018) Donostia	G
Paseo Arriola Nº 15 (20018) Donostia	E
Paseo Domingo Aguirre Nº 3 3 A (20018) Donostia	D
Plaza/Plaza Iribar Nº 2 1º EDIFICIO INDUSTRIAL OFICINAS (20018) Donostia	D
Plaza/Plaza Jose Maria Sert Nº 8 7-8-9-10 X.BERS4-6-8-10 (20018) Donostia	E
Plaza/Plaza Karlos Santamaría Nº 1 4ºA (20018) Donostia	E
Plaza/Plaza Karlos Santamaría Nº 5 (20018) Donostia	D
Plaza/Plaza Karlos Santamaría Nº 6 5ºB (20018) Donostia	E
VITORIA Nº 18 5º C (20018) Donostia / San Sebastián	D
Cortazar	
Etorbidea/Avenida La Libertad Nº 33 5º A (20004) Donostia	D
Etorbidea/Avenida La Libertad Nº 43 5º DCHA UTM 582344 / 4796675 (20004)	E
HERNANI Nº 1 4º B (20004) Donostia	D
Hernani Nº 6 3º Esk (20004) Donostia	E
Kalea/Calle Andia Nº 5 1 CENTRO (20004) Donostia	D
Kalea/Calle Elkano Nº 8 6 DI (20004) Donostia	G
Kalea/Calle Camino Nº 5 3B (20004) Donostia	F
Kalea/Calle Camino Nº 7 LOCAL IDIAQUEZ 1 ACCESO CALLE IDIAQUEZ	E
Kalea/Calle Garibai Nº 5 3 A (20004) Donostia	E
Plaza/Plaza Gipuzkoa Nº 10 4ºDR (20004) Donostia	G
URBIETA Nº 44 3º IZDA. (20006) Donostia	E
Kalea/Calle Autonomía Nº 3 5º DCHA (20006) Donostia	E
Kalea/Calle Autonomía Nº 9 5 A (20006) Donostia	G
Kalea/Calle Easo Nº 27 7 iZQUIERDA (20006) Donostia	G

Table 69. Energy efficiency level of buildings of the districts evaluated. Data obtained from the energy certifications available in the city.

Cortazar	**Efficiency level**
Kalea/Calle Easo Nº 83 (20006) Donostia	E
Kalea/Calle Larraundi Nº 3 3º IZDA (20006) Donostia	E
Kalea/Calle Pedro Egaña Nº 10 6 IZQ (20006) Donostia	E
Kalea/Calle Pedro Egaña Nº 3 4 izquierda (20006) Donostia	E
Kalea/Calle Pedro Egaña Nº 6 5º DCHA (20006) Donostia	E
Kalea/Calle Moraza Nº 1 Bajo A (20006) Donostia	E
Kalea/Calle Prim Nº 18 5ºC (20006) Donostia	G
Kalea/Calle Prim Nº 19 1ºD (20006) Donostia	E
Kalea/Calle Prim Nº 21 1ºC (20006) Donostia	E
Kalea/Calle Prim Nº 3 3º B UTM 582755 / 4796643 (20006) Donostia	E
Kalea/Calle Prim Nº 59 PISO 2ºD (20006) Donostia	E
Kalea/Calle Reyes Católicos Nº 16 1º izda-izda UTM 582655 / 4796300 (20006)	G
Kalea/Calle Salud Nº 16 PISO CALLE SALUD 16 - 4ºA (20006) Donostia	E
Kalea/Calle Salud Nº 4 3 IZQUIERDA (20006) Donostia	E
Kalea/Calle Virgen del Carmen Nº 41 2ºC (20006) Donostia	E
Kalea/Calle Urbieta Nº 56 6 ESK (20006) Donostia	G
Kalea/Calle Urbieta Nº 64 1º Izq Local de oficinas (20006) Donostia	E
Kalea/Calle Urdaneta Nº 3 1ºIzda (20006) Donostia	G
LARRAMENDI Nº 3 6º DCHA. (20006) Donostia	E
PRIM Nº 30 LOCAL (20006) Donostia	G
Amara	
ERRONDO Nº 5 8º C (20010) Donostia	E
Etorbidea/Avenida Sancho el Sabio Nº 18 2º AB KIOSKO ONCE ANEXO	E
Etorbidea/Avenida Sancho el Sabio Nº 23 3 B (20010) Donostia	G
ISABEL II Nº 17 5º DCHA (20010) Donostia	E
ISABEL II Nº 5 4º E (20010) Donostia	D
Ibilbidea/Paseo Bizkaia Nº 16 9º D (20010) Donostia	G
Ibilbidea/Paseo Errondo Nº 4 5º C (20010) Donostia	G
Ibilbidea/Paseo Errondo Nº 4 5º D (20010) Donostia	E
JAVIER BARKAIZTEGI Nº 13 10º Atico (20010) Donostia	E
Kalea/Calle Catalina de Erauso Nº 9 4 c (20010) Donostia	E
Kalea/Calle Catalina de Erauso Nº 9 9ºD (20010) Donostia	E
Kalea/Calle Jose M. Salaberria Nº 29 5º-D (20010) Donostia	E
SAGRADA FAMILIA Nº 2 ESC. 3, 6º A (20010) Donostia	G
SALABERRIA Nº 7 1º A ESC. 3 (20010) Donostia	E
Kalea/Calle Los Amezketa Nº 14 10 C (20010) Donostia	G
Kalea/Calle Podabines Nº 6 10 B (20010) Donostia	G
SANCHO EL SABIO Nº 12 1º DCHA DCHA (20010) Donostia	E
SANCHO EL SABIO Nº 12 1º DCHA. IZDA. (20010) Donostia	F
SANCHO EL SABIO Nº 22 1º DCHA. (20010) Donostia	E
SANCHO EL SABIO Nº 25 1ºB (20010) Donostia	E

Table 70. Energy efficiency level of buildings of the districts evaluated. Data obtained from the energy certifications available in the city.

Amara	**Efficiency level**
AVENIDA DE MADRID Nº 21 7ºB (20011) Donostia	E
BALDOMERO ANABITARTE Nº 3 1º C (20011) Donostia	F
BALLENEROS Nº 12 6D (20011) Donostia	G
Etorbidea/Avenida Carlos I Nº 10 (20011) Donostia	E
Etorbidea/Avenida Carlos I Nº 12 (20011) Donostia	E
Etorbidea/Avenida Carlos I Nº 13 4ºC (20011) Donostia	F
Etorbidea/Avenida Carlos I Nº 13 Local (20011) Donostia	E
Etorbidea/Avenida Carlos I Nº 3 5ºB (20011) Donostia	E
Etorbidea/Avenida Carlos I Nº 38 14º C (20011) Donostia	E
Etorbidea/Avenida Felipe IV Nº 4 ESCAL. DCHA. ENTLO. B (20011) Donostia	G
Etorbidea/Avenida Felipe IV Nº 6 7º D Escalera izquierda (20011) Donostia	F
Etorbidea/Avenida Felipe IV Nº 8 5ºB Escalera Izquierda (20011) Donostia	F
Etorbidea/Avenida Felipe IV Nº 8 5º¡B Escalera Derecha (20011) Donostia	E
Etorbidea/Avenida Isabel II Nº 20 (20011) Donostia	E
Etorbidea/Avenida Isabel II Nº 31 9 A (20011) Donostia	E
Etorbidea/Avenida Isabel II Nº 4 3D escalera izquierda (20011) Donostia	E
Etorbidea/Avenida Isabel II Nº 5 4ºD (20011) Donostia	E
Etorbidea/Avenida Isabel II Nº 6 (20011) Donostia	D
Etorbidea/Avenida Madrid Nº 16 9º puerta 2 (20011) Donostia	E
Etorbidea/Avenida Madrid Nº 22 8º A (20011) Donostia	E
Etorbidea/Avenida Madrid Nº 26 4º D (20011) Donostia	E
Etorbidea/Avenida Madrid Nº 32 (20011) Donostia	E
Etorbidea/Avenida Madrid Nº 4 (20011) Donostia	E
Etorbidea/Avenida Madrid Nº 9 5ºA escalera IZ (20011) Donostia	E
Etorbidea/Avenida Madrid Nº 9 7. D (20011) Donostia	E
Etorbidea/Avenida Madrid Nº 9 ESCALERA DRCHA. ENTRESUELO B (20011)	G
FELIPE IV Nº 13 9º A (20011) Donostia	E
FELIPE IV Nº 8 3º B ESC. DCHA. (20011) Donostia	E
FERRERIAS Nº 3 9º A (20011) Donostia	E
Isabel II Nº 4 7ºD Escalera Centro (20011) Donostia	E
Kalea/Calle Consulado Nº 8 5ºC (20011) Donostia	E
Kalea/Calle Corsarios Vascos Nº 4 8ºC (20011) Donostia	E
Kalea/Calle Ferrerías Nº 3 1º F (20011) Donostia	E
Kalea/Calle Pescadores Gran Sol Nº 8 5º D UTM 583476 / 4795319 (20011)	E
Kalea/Calle Pescadores Terranova Nº 11 2ºC (20011) Donostia	D
Kalea/Calle Los Amezketa Nº 19 (20011) Donostia	D
Kalea/Calle Pescadores Terranova Nº 21 8ºE (20011) Donostia	E
Kalea/Calle Toribio Alzaga Nº 9 (20011) Donostia	D
PESCADORES DE TERRANOVA Nº 8 5ºA (20011) Donostia	D
Plaza/Plaza Las Armerias Nº 11 8C (20011) Donostia	E
Plaza/Plaza Marcelino Soroa Nº 6 4ºD (20011) Donostia	D

GROS

Table 71. Main characteristics of residential and office buildings of the district of Gros.

CODE	SUB-CODE	Nº of plants	Total Area of building (m2)	Floor area (m2)	Age of the building	Use of building	Total area of the facade (m2)	Any refurbishment measure applied?	Estimated useful space of roof	Protection grade	Central heating	Cooling system
1	4	8	1995	249	2000 - 2020	Residential	498	-	249	D	-	-
	6	8	4033	504	1900 - 1930	Residential	1007	-	504	D	-	-
	2	7	4414	631	1900 - 1930	Residential	1102	yes	631	D	yes	yes
	4	7	1924	275	1900 - 1930	Residential	480	-	275	D	-	-
	5	7	2289	327	1900 - 1930	Residential	571	yes	327	D	-	yes
	3	7	5325	761	1900 - 1930	Residential	1329	-	761	B	-	-
	2	7	4429	633	1900 - 1930	Residential	1105	-	316	B	-	-
	1	8	5264	658	1900 - 1930	Residential	1314	-	329	B	-	-
2	2	8	2008	251	1960 - 1980	Residential	537	yes	0	C	-	-
	4	7	1251	179	1900 - 1930	Residential	334	-	0	D	-	-
	6	7	2199	314	1900 - 1930	Residential	588	-	0	D	-	-
	8	7	1570	224	1900 - 1930	Residential	420	-	0	D	-	-
	10	7	1652	236	1900 - 1930	Residential	441	-	0	D	-	-
	12	7	1957	280	1900 - 1930	Residential	523	-	0	D	-	-
	14	7	1957	280	1900 - 1930	Residential	523	-	0	D	-	-
	16	7	1876	268	1900 - 1930	Residential	501	-	0	D	-	-
	9	7	1525	218	1900 - 1930	Residential	408	-	0	D	-	-
	7	7	1925	275	1900 - 1930	Residential	514	yes	0	D	-	-
	5	7	1718	245	1900 - 1930	Residential	459	-	0	D	-	-
	1	8	4760	595	1960 - 1980	Residential	1272	yes	0	C	-	-
	4	8	4760	595	1960 - 1980	Residential	1272	-	0	C	yes	-
	3	8	4760	595	1960 - 1980	Residential	1272	yes	0	C	yes	-
3	6	8	3055	382	2000 - 2020	Residential	957	-	0	D	-	-
	4	7	2815	402	1900 - 1930	Residential	881	-	402	D	-	-
	6	7	1246	178	1900 - 1930	Residential	390	-	178	D	-	-
	8	7	1079	154	1930 - 1960	Residential	338	-	154	C	-	-
	9	7	2585	369	1900 - 1930	Residential	809	-	369	C	-	-
	7	7	1638	234	1900 - 1930	Residential	513	-	0	D	-	-
	5	7	2235	319	1900 - 1930	Residential	700	-	319	D	-	-
	3bis	6	1217	203	1930 - 1960	Residential	381	-	203	C	-	-
	3	6	785	131	1930 - 1960	Residential	246	-	131	C	-	-
	1	8	5156	645	1930 - 1960	Residential	1615	-	0	B	yes	-
	9	7	2459	351	1900 - 1930	Residential	770	yes	351	D	-	-
	8	7	2474	353	1930 - 1960	Residential	775	-	353	D	-	-
	7	8	3547	443	1980 - 2000	Residential	1111	-	443	D	-	-
4	12	7	2934	419	1900 - 1930	Residential	782	-	419	D	-	yes
	14	7	3164	452	1900 - 1930	Residential	844	-	452	D	-	yes
	16	8	2817	352	1930 - 1960	Residential	751	-	352	D	-	-
	16bis	8	1279	160	1930 - 1960	Residential	341	yes	0	D	-	-
	4	8	1706	213	1930 - 1960	Residential	455	yes	0	D	-	-
	6	8	2402	300	1930 - 1960	Residential	641	yes	300	D	-	-
	8	7	1615	231	1900 - 1930	Residential	431	-	231	D	-	-

CODE	SUB-CODE	Nº of plants	Total Area of building (m^2)	Floor area (m^2)	Age of the building	Use of building	Total area of the facade (m^2)	Any refurbishment measure applied?	Estimated useful space of roof	Protection grade	Central heating	Cooling system
4	19	7	1577	225	1900 - 1930	Residential	421	-	225	D	-	-
	17	7	1401	200	1900 - 1930	Residential	374	-	0	D	-	-
	15	7	1596	228	1900 - 1930	Residential	426	-	228	D	-	-
	13	7	1513	216	1900 - 1930	Residential	403	yes	216	D	-	-
	11	7	1467	210	1900 - 1930	Residential	391	-	210	D	-	-
	9	7	1563	223	1900 - 1930	Residential	417	-	223	D	-	-
	7	7	1689	241	1900 - 1930	Residential	450	-	241	D	-	-
	5	7	1561	223	1900 - 1930	Residential	416	-	223	D	-	-
	3	7	2280	326	1900 - 1930	Residential	608	-	326	D	-	-
	1	7	3634	519	1900 - 1930	Residential	969	-	519	B	-	-
5	10	7	1419	203	1900 - 1930	Residential	443	-	0	D	-	-
	12	7	1398	200	1900 - 1930	Residential	437	-	200	D	-	-
	14	7	2046	292	1900 - 1930	Residential	639	-	292	D	-	-
	16	7	1142	163	1900 - 1930	Residential	357	yes	163	-	-	-
	18	7	1322	189	1900 - 1930	Residential	413	yes	0	-	-	-
	20	6	1119	187	1900 - 1930	Residential	350	-	0	D	-	-
	10	6	1659	277	1930 - 1960	Residential	518	-	277	D	-	yes
	23	7	1585	226	1930 - 1960	Residential	495	-	226	D	-	-
	21	7	1880	269	1930 - 1960	Residential	587	-	269	D	-	-
	19	6	1510	252	1930 - 1960	Residential	472	-	252	D	-	-
	17	6	1603	267	1900 - 1930	Residential	501	yes	267	D	-	-
	15	8	2400	300	1900 - 1930	Residential	750	yes	300	D	-	-
	13	7	1235	176	1900 - 1930	Residential	386	yes	176	D	-	-
	15	7	3048	435	1900 - 1930	Residential	952	-	435	D	-	-
	13	7	1000	143	1900 - 1930	Residential	312	-	143	D	-	-
	11	7	1752	250	1900 - 1930	Residential	547	-	250	D	-	-
	9	7	1580	226	1900 - 1930	Residential	494	-	226	D	-	-
6	18	6	1262	210	1930 - 1960	Residential	394	-	0	C	-	-
	20	7	1419	203	1900 - 1930	Residential	443	-	203	D	-	-
	22	8	1971	246	1930 - 1960	Residential	616	-	0	D	-	-
	22bis	8	3482	435	1930 - 1960	Residential	1088	-	261	D	-	-
	4	8	2928	366	1930 - 1960	Residential	915	-	110	D	-	-
	6	7	1499	214	1900 - 1930	Residential	468	-	214	D	-	-
	27	7	1758	251	1900 - 1930	Residential	549	-	0	D	-	-
	25	7	1390	199	1900 - 1930	Residential	434	-	199	D	-	-
	23	7	1341	192	1900 - 1930	Residential	419	-	192	D	-	-
	21	6	2779	463	1900 - 1930	Residential	868	yes	463	C	-	-
	5	7	1329	190	1900 - 1930	Residential	415	-	190	D	-	-
	3	7	1505	215	1930 - 1960	Residential	470	-	215	D	-	-
	1	6	1798	300	1930 - 1960	Residential	562	-	300	C	-	-
7	24	8	2337	292	1930 - 1960	Residential	649	yes	292	D	-	-
	26	7	1863	266	1930 - 1960	Residential	517	-	266	D	-	-
	28	6	1658	276	1930 - 1960	Residential	461	yes	276	D	-	yes
	30	8	1619	202	1960 - 1980	Residential	450	-	0	-	-	yes
	4	8	2049	256	1930 - 1960	Residential	569	-	0	-	-	-

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7	29	8	4377	547	1960 - 1980	Residential	1216	yes	164	D	-	-
	27	8	3625	453	1960 - 1980	Residential	1007	-	453	-	yes	yes
	29	8	3687	461	1930 - 1960	Residential	1024	-	0	-	yes	-
	5	8	2070	259	1900 - 1930	Residential	575	-	0	D	-	-
	3	8	2313	289	1930 - 1960	Residential	642	-	0	-	-	-
	1	7	1520	217	1930 - 1960	Residential	422	yes	0	D	-	yes
8	3	8	1244	156	1930 - 1960	Residential	362	-	0	C	-	yes
	32	8	986	123	1930 - 1960	Residential	287	-	247	C	-	yes
	34	8	1482	185	1930 - 1960	Residential	431	-	74	C	-	-
	1	7	2007	287	1930 - 1960	Residential	584	-	287	B	yes	-
	39	7	2718	388	1930 - 1960	Residential	791	-	388	-	-	-
	37	8	2837	355	1930 - 1960	Residential	825	yes	284	-	-	-
	35	8	3015	377	1930 - 1960	Residential	877	yes	302	-	-	-
	33	8	1557	195	1930 - 1960	Residential	453	-	0	C	-	-
	31	8	1539	192	1930 - 1960	Residential	448	-	0	C	-	yes
9	14	8	5657	707	1980 - 2000	Residential	2990	-	0	-	-	-
	12	8	5270	659	1960 - 1980	Residential	2785	yes	659	-	-	-
	1	8	4481	560	1930 - 1960	Residential	2368	-	0	D	-	-
10	2	8	1218	152	1960 - 1980	Residential	519	-	0	-	-	-
	9	8	5870	734	1930 - 1960	Residential	2502	yes	0	-	-	-
	1	8	2370	296	1960 - 1980	Residential	1010	-	148	-	-	-
11	6	9	3620	402	1930 - 1960	Residential	1391	yes	0	-	-	-
	4	9	4685	521	1960 - 1980	Residential	1800	yes	0	-	-	-
	2	8	2932	367	1930 - 1960	Residential	1126	-	257	-	-	yes
12	8	7	304	43	1900 - 1930	Residential	76	-	0	-	-	-
	10	8	1144	143	1960 - 1980	Residential	286	-	0	-	-	-
	12	8	2147	268	1960 - 1980	Residential	538	-	0	-	-	-
	17	8	2209	276	1980 - 2000	Residential	553	-	0	-	-	-
	15	8	7677	960	1960 - 1980	Residential	1922	-	0	-	yes	yes
	5	6	2478	413	1930 - 1960	Residential	621	-	0	-	-	-
	3	6	2154	359	1930 - 1960	Residential	539	-	0	-	-	-
13	7	8	3002	375	1930 - 1960	Residential	912	-	0	-	-	-
	5	7	1428	204	1900 - 1930	Residential	434	-	0	D	-	-
	3	7	1508	215	1930 - 1960	Residential	458	yes	0	D	-	-
	1	7	2134	305	1900 - 1930	Residential	648	yes	305	D	-	-
	1	6	1332	222	1900 - 1930	Residential	405	-	222	D	-	-
	2	7	2658	380	1900 - 1930	Residential	807	-	0	B	-	-
	4	7	1739	248	1930 - 1960	Residential	528	-	248	C	-	yes
	6	7	1467	210	1900 - 1930	Residential	446	-	210	C	-	-
	8	7	1520	217	1900 - 1930	Residential	462	-	217	C	-	-
	10	7	811	116	1900 - 1930	Residential	246	-	0	C	-	-
	2	7	1570	224	1900 - 1930	Residential	477	-	0	C	-	-
14	8	6	2165	361	1900 - 1930	Residential	636	-	361	D	-	-
	10	7	1548	221	2000 - 2020	Residential	455	-	0	D	-	-
	12	7	1419	203	1930 - 1960	Residential	417	-	0	-	-	-

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14	13	8	3570	446	1930 - 1960	Residential	1049	-	446	-	-	-
	11	8	2757	345	1960 - 1980	Residential	810	-	0	-	-	-
	1	8	3290	411	1930 - 1960	Residential	967	-	165	D	-	-
	9	7	1592	227	1930 - 1960	Residential	468	-	0	-	-	-
	7	7	1637	234	1930 - 1960	Residential	481	-	0	-	-	-
	5	6	2151	359	1900 - 1930	Residential	632	-	359	-	-	-
	2	8	3002	375	1960 - 1980	Residential	882	-	0	-	yes	-
	4	7	2884	412	1900 - 1930	Residential	847	-	412	D	-	-
	6	7	1939	277	1900 - 1930	Residential	570	-	277	D	-	-
15	15	8	2468	309	1960 - 1980	Residential	735	-	185	-	yes	-
	11	6	2007	335	1930 - 1960	Residential	598	-	335	D	-	-
	5	6	1074	179	1900 - 1930	Residential	320	-	179	D	-	-
	1	7	2632	376	1930 - 1960	Residential	784	-	0	-	-	-
	16	8	2358	295	1930 - 1960	Residential	702	yes	0	-	-	-
	18	9	2765	307	1960 - 1980	Residential	824	-	0	-	yes	yes
16	7	8	2044	256	1960 - 1980	Residential	1326	yes	0	-	-	-
	2	8	2341	293	1960 - 1980	Residential	1518	-	0	-	-	-
17	16	4	620	155	1900 - 1930	Residential	176	-	0	A	-	-
	18	4	896	224	1900 - 1930	Residential	254	-	0	A	-	-
	20	4	931	233	1900 - 1930	Residential	264	-	0	A	-	-
	22	4	942	236	1900 - 1930	Residential	267	-	0	A	-	-
	7	7	1976	282	1930 - 1960	Residential	560	-	282	C	-	-
	5	9	3062	340	1960 - 1980	Residential	868	-	0	-	yes	-
	3	8	2630	329	1930 - 1960	Residential	745	-	0	D	yes	-
	8	8	2460	308	1930 - 1960	Residential	697	-	0	D	-	-
18	1	9	4090	454	1930 - 1960	Residential	1591	yes	0	-	-	-
	17	9	3022	336	1930 - 1960	Residential	1176	-	336	-	-	-
	1	9	2355	262	1930 - 1960	Residential	916	-	262	-	-	-
	24	9	2287	254	1930 - 1960	Residential	890	-	0	-	-	-
19	2	8	3551	444	1980 - 2000	Residential	1120	yes	0	-	-	yes
	29	6	3229	538	1960 - 1980	Office	1018	-	538	-	-	yes
	33	8	3954	494	1960 - 1980	Residential	1247	-	494	-	yes	-
	35	7	1852	265	1900 - 1930	Residential	584	yes	0	D	-	-
	37	8	2001	250	2000 - 2020	Residential	631	yes	0	D	-	-
	10	8	2812	352	1930 - 1960	Residential	887	-	0	-	-	-
	8	8	2274	284	1930 - 1960	Residential	717	-	0	-	-	-
20	7	1	0	0	1980 - 2000	Other	0	-	0	-	-	-
21	2	7	1972	282	1930 - 1960	Residential	687	yes	0	-	-	-
	17	7	2084	298	1930 - 1960	Residential	726	-	0	C	-	-
	15	7	1906	272	1930 - 1960	Residential	664	yes	0	-	-	-
	12	7	2045	292	1930 - 1960	Residential	712	yes	0	-	-	-
22	1	8	2648	331	1980 - 2000	Office	792	-	0	-	-	yes
	2	8	3549	444	1980 - 2000	Residential	1062	-	444	-	-	-
	13	7	2488	355	2000 - 2020	Residential	745	-	0	D	-	-
	2	7	2701	386	1900 - 1930	Residential	808	-	386	D	-	-

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23	7	8	2724	341	1960 - 1980	Residential	714	-	0	-	-	-
	5	7	2433	348	1960 - 1980	Residential	638	yes	0	-	-	-
	3	6	1716	286	1900 - 1930	Residential	450	-	0	C	-	-
	1	7	1643	235	1900 - 1930	Residential	431	yes	141	C	-	-
	2	7	1648	235	1980 - 2000	Residential	432	-	47	-	-	-
	4	6	2062	344	1900 - 1930	Residential	541	-	0	-	-	-
	6	6	1049	175	1900 - 1930	Residential	275	-	0	-	-	-
	8	8	1739	217	1980 - 2000	Residential	456	-	0	-	-	-
24	12	7	1469	210	1900 - 1930	Residential	458	-	0	D	-	-
	14	8	2346	293	1900 - 1930	Residential	732	yes	0	D	-	-
	16	8	2404	301	1960 - 1980	Residential	750	-	301	D	-	-
	18	8	2447	306	1930 - 1960	Residential	763	yes	306	-	-	-
	20	8	2446	306	1900 - 1930	Residential	763	-	306	-	-	-
	12	7	2224	318	1960 - 1980	Residential	694	-	0	-	-	-
	14	7	1408	201	1900 - 1930	Residential	439	-	0	D	-	-
	16	7	1213	173	1900 - 1930	Residential	378	yes	0	-	-	-
	21	8	1717	215	1930 - 1960	Residential	535	-	0	-	-	-
	19	7	1765	252	1930 - 1960	Residential	550	-	0	-	-	-
	17	7	1641	234	1930 - 1960	Residential	512	-	0	-	-	-
	15	7	1773	253	1930 - 1960	Residential	553	-	0	-	-	-
	13	7	1801	257	1930 - 1960	Residential	562	-	0	-	-	-
	11	7	1763	252	1930 - 1960	Residential	550	-	0	-	-	-
	12	7	2536	362	1930 - 1960	Residential	791	-	0	D	-	-
	14	7	1611	230	1930 - 1960	Residential	502	-	0	D	-	-
	1	7	1943	278	1930 - 1960	Residential	606	-	278	D	-	-
25	8	7	2137	305	1930 - 1960	Residential	749	-	0	-	-	-
	10	7	1189	170	1930 - 1960	Residential	417	-	0	D	-	yes
	12	7	1423	203	1930 - 1960	Residential	499	-	203	-	-	-
	14	8	1693	212	1930 - 1960	Residential	593	-	212	-	-	-
	16	7	1439	206	1930 - 1960	Residential	504	-	0	-	-	-
	18	8	1615	202	1930 - 1960	Residential	566	-	0	D	-	-
	20	7	1196	171	1930 - 1960	Residential	419	-	0	D	-	-
	20	7	1521	217	1930 - 1960	Residential	533	-	0	-	-	-
	22	8	2024	253	1930 - 1960	Residential	709	-	0	-	-	-
	24	8	1862	233	1930 - 1960	Residential	652	-	70	-	-	-
	2	8	1242	155	1930 - 1960	Residential	435	-	0	-	-	-
	4	7	1983	283	1900 - 1930	Residential	695	-	0	-	-	-
	6	7	1741	249	1900 - 1930	Residential	610	yes	0	-	-	-
	8	7	1691	242	1930 - 1960	Residential	592	yes	242	-	-	-
	10	7	1742	249	1930 - 1960	Residential	610	-	249	-	-	-
	12	7	1383	198	1930 - 1960	Residential	485	-	0	D	-	-
	6	6	1512	252	1930 - 1960	Residential	530	-	0	-	-	-
	8	7	1633	233	1930 - 1960	Residential	572	-	187	D	-	-
26	9	8	2245	281	1930 - 1960	Residential	718	-	0	-	-	-
	7	8	3052	382	1930 - 1960	Residential	976	-	382	-	-	-

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26	5	7	1763	252	1930 - 1960	Residential	564	-	252	C	-	-
	3	7	1790	256	1900 - 1930	Residential	573	-	256	-	-	-
	1	7	1297	185	1900 - 1930	Residential	415	-	185	D	-	-
	26	7	2068	295	1930 - 1960	Residential	662	-	0	-	-	-
	28	7	1393	199	1930 - 1960	Residential	446	-	0	-	-	-
	30	7	2549	364	1930 - 1960	Residential	816	-	364	C	-	-
	7	7	1560	223	1930 - 1960	Residential	499	-	223	C	-	-
	5	6	2347	391	1930 - 1960	Residential	751	-	391	C	-	-
	3	7	2364	338	1930 - 1960	Residential	756	-	338	C	-	-
	1	7	2507	358	1900 - 1930	Residential	802	-	358	C	-	-
	17c	7	1419	203	1900 - 1930	Residential	454	yes	0	D	-	-
	17b	7	1308	187	1900 - 1930	Residential	418	yes	0	D	-	-
	17a	7	2504	358	1930 - 1960	Residential	801	-	358	D	-	-
27	19	6	2049	342	1900 - 1930	Residential	828	yes	342	-	-	-
	21	7	1338	191	1930 - 1960	Residential	541	yes	0	-	-	-
	23	7	1583	226	1900 - 1930	Residential	640	yes	0	-	-	-
	25	7	785	112	1900 - 1930	Residential	317	yes	0	-	-	-
	27	7	1483	212	1900 - 1930	Residential	600	yes	212	D	-	-
	2	7	1227	175	1900 - 1930	Residential	496	yes	0	-	-	-
28	1	8	3115	389	1980 - 2000	Residential	1029	-	0	-	-	-
	2	7	6206	887	1930 - 1960	Residential	2050	yes	887	B	-	-
29	4	6	2608	435	1900 - 1930	Residential	759	-	0	D	-	-
	6 & 8	7	2546	364	1900 - 1930	Residential	741	-	178	D	-	yes
	10	8	1910	239	1900 - 1930	Residential	556	-	0	D	-	-
	10a	8	2010	251	1960 - 1980	Residential	585	-	239	D	-	-
	10b	7	1722	246	1900 - 1930	Residential	501	-	251	D	-	-
	10c	8	1938	242	1900 - 1930	Residential	564	-	246	D	-	-
	5	8	1480	185	1900 - 1930	Residential	431	yes	97	D	-	-
	3	8	1622	203	2000 - 2020	Residential	472	-	0	D	-	-
	9	7	1725	246	1900 - 1930	Residential	502	-	0	D	-	-
	7	8	1910	239	1900 - 1930	Residential	556	-	246	D	-	-
	5	7	1771	253	1900 - 1930	Residential	515	-	239	D	yes	-
	3	7	1590	227	1900 - 1930	Residential	463	yes	253	D	-	-
	1	7	2392	342	1960 - 1980	Residential	696	yes	0	-	-	-
	5	7	3345	478	1900 - 1930	Residential	974	yes	0	D	-	-
	3	9	3282	365	1960 - 1980	Residential	955	-	478	-	-	-
30	14	6	1628	271	1900 - 1930	Residential	574	-	365	D	-	-
	6	7	685	98	1900 - 1930	Residential	242	-	0	-	-	-
	11	6	691	115	1900 - 1930	Residential	244	-	0	-	-	-
	2	6	538	90	1930 - 1960	Residential	190	yes	0	-	-	-
	2d	7	945	135	1900 - 1930	Residential	333	yes	0	-	-	-
	4	7	2668	381	1900 - 1930	Residential	941	yes	135	D	-	-
	6	9	2057	229	1960 - 1980	Residential	725	-	381	-	-	-
31	16	8	2524	316	1930 - 1960	Residential	853	-	0	-	-	-
	4	7	1670	239	1960 - 1980	Residential	564	-	0	-	-	-

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31	6	8	2112	264	1960 - 1980	Residential	714	-	0	-	-	-
	4	5	1431	286	1930 - 1960	Residential	484	-	264	-	-	-
	3	4	575	144	1900 - 1930	Residential	194	-	0	-	-	-
	2	5	772	154	1900 - 1930	Residential	261	-	0	-	-	-
32	18	7	1435	205	1900 - 1930	Residential	530	-	0	-	-	-
	20	7	743	106	1900 - 1930	Residential	275	-	205	-	-	-
	22	7	704	101	1900 - 1930	Residential	260	-	106	-	-	-
	24	7	1480	211	1900 - 1930	Residential	547	-	0	-	-	-
	4	6	1195	199	1900 - 1930	Residential	442	-	0	-	-	-
	5	6	803	134	1900 - 1930	Residential	297	-	0	-	-	-
	3	7	1630	233	1900 - 1930	Residential	602	-	0	-	-	-
33	26	7	2063	295	1930 - 1960	Residential	1121	yes	0	-	-	-
	28a	7	1781	254	1930 - 1960	Residential	968	-	0	D	-	-
	28b	7	1735	248	1900 - 1930	Residential	943	-	254	D	-	-
	28	5	565	113	1900 - 1930	Residential	307	yes	248	-	-	-
	30	6	671	112	1930 - 1960	Residential	365	yes	113	D	-	-
	32	7	1121	160	1900 - 1930	Residential	609	yes	0	-	-	-
	34	6	827	138	1900 - 1930	Residential	449	-	160	-	-	-
	38	1	0	0	1900 - 1930	Other	0	-	0	-	-	-
34	51	9	2693	299	1930 - 1960	Residential	622	-	0	-	-	-
	49	7	4209	601	2000 - 2020	Residential	972	-	0	D	-	-
	47	7	4186	598	1900 - 1930	Residential	966	-	601	D	-	-
	45	7	3315	474	1900 - 1930	Residential	765	-	598	D	-	-
	43	7	3274	468	1900 - 1930	Residential	756	yes	474	D	-	-
	7	7	3658	523	1900 - 1930	Residential	844	yes	468	-	-	-
35	2	7	3300	471	1930 - 1960	Residential	1119	-	523	-	-	-
	55	7	3837	548	1930 - 1960	Residential	1301	-	236	-	-	-
	1	7	3800	543	1930 - 1960	Residential	1289	-	274	-	-	-
36	44	8	2567	321	1930 - 1960	Residential	1140	yes	271	-	-	-
	46	8	1841	230	1930 - 1960	Residential	817	-	0	-	-	-
	59	7	2438	348	1930 - 1960	Residential	1082	-	184	-	-	-
37	26	8	1325	166	1900 - 1930	Residential	475	-	174	D	-	-
	28	8	1532	192	1900 - 1930	Residential	549	-	0	D	-	-
	30	8	1518	190	1900 - 1930	Residential	544	-	0	D	-	-
	32	6	1717	286	1900 - 1930	Residential	615	-	0	D	-	-
	34	6	1771	295	1900 - 1930	Residential	635	-	0	D	-	-
	36	7	2267	324	1900 - 1930	Residential	813	-	0	-	-	-
	6	7	1895	271	1900 - 1930	Residential	679	-	0	D	-	-
	8	7	1166	167	1930 - 1960	Residential	418	-	0	-	-	-
	25	8	2768	346	1930 - 1960	Residential	992	-	0	-	-	-
	23	9	2115	235	1960 - 1980	Residential	758	-	0	-	-	-
	21	7	1588	227	1930 - 1960	Residential	569	-	0	-	-	-
	19	9	2148	239	1930 - 1960	Residential	770	-	0	-	-	-
	17	8	2012	252	1930 - 1960	Residential	721	-	0	-	-	-
	15	8	1740	218	1930 - 1960	Residential	624	yes	0	-	-	-

CODE	SUB-CODE	Nº of plants	Total Area of building (m^2)	Floor area (m^2)	Age of the building	Use of building	Total area of the facade (m^2)	Any refurbishment measure applied?	Estimated useful space of roof	Protection grade	Central heating	Cooling system
37	13	6	939	157	1900 - 1930	Residential	337	yes	0	-	-	-
	15	6	917	153	1900 - 1930	Residential	329	yes	0	-	-	yes
	13	6	1106	184	1900 - 1930	Residential	396	-	0	-	-	yes
	11	6	937	156	1900 - 1930	Residential	336	-	0	-	-	yes
38	9	8	2474	309	1900 - 1930	Residential	887	-	0	-	-	-
	38	8	2580	323	1900 - 1930	Residential	762	-	0	D	-	-
	40	8	1915	239	1900 - 1930	Residential	565	-	0	D	-	-
	42	8	4972	622	1960 - 1980	Residential	1468	-	239	-	-	-
	44	8	7501	938	1960 - 1980	Residential	2215	yes	0	-	-	-
	37	8	4424	553	1960 - 1980	Residential	1306	-	0	-	-	-
	35	7	2904	415	1960 - 1980	Residential	857	yes	0	-	yes	yes
	33	7	1271	182	1900 - 1930	Residential	375	-	0	-	-	-
	31	7	1182	169	1900 - 1930	Residential	349	-	0	-	-	-
	11	7	2408	344	1930 - 1960	Residential	711	-	169	D	-	yes
	9	8	1279	160	1930 - 1960	Residential	378	-	0	D	-	-
	7	8	1377	172	1900 - 1930	Residential	407	-	0	D	-	-
	5	8	1692	212	1930 - 1960	Residential	500	yes	0	D	-	-
39	48	8	1914	239	1930 - 1960	Residential	639	yes	0	-	-	-
	50	9	2015	224	1930 - 1960	Residential	672	yes	0	-	-	-
	52	8	2587	323	1930 - 1960	Residential	863	-	0	-	-	yes
	54	9	2281	253	1930 - 1960	Residential	761	-	0	-	-	-
	2	7	2149	307	1900 - 1930	Residential	717	-	253	-	-	-
	4	5	3817	763	1930 - 1960	Other	1274	-	307	D	-	-
	53	7	1261	180	1900 - 1930	Residential	421	-	0	-	-	-
	51	7	1410	201	1900 - 1930	Residential	471	-	0	-	-	-
	49	7	1425	204	1900 - 1930	Residential	476	-	0	-	-	-
	47	7	1324	189	1930 - 1960	Residential	442	-	0	-	-	-
	45	8	2932	367	1930 - 1960	Residential	978	-	0	-	-	-
	7	8	1967	246	1930 - 1960	Residential	656	-	0	-	-	-
	5	8	2839	355	1960 - 1980	Residential	947	yes	0	-	-	-
40	28	7	1446	207	1930 - 1960	Residential	515	-	0	-	-	yes
	26	7	1427	204	1930 - 1960	Residential	508	-	0	-	-	yes
	24	7	1156	165	1930 - 1960	Residential	412	-	0	-	-	-
	19	7	1383	198	1930 - 1960	Residential	493	-	0	-	-	-
	21	7	2530	361	1930 - 1960	Residential	901	-	0	-	-	-
	23	8	2546	318	1930 - 1960	Residential	907	yes	0	-	-	-
	27	7	1464	209	1930 - 1960	Residential	522	-	0	-	-	-
	29	7	1544	221	1930 - 1960	Residential	550	-	0	-	-	-
41	32	6	1534	256	1900 - 1930	Residential	614	-	0	-	-	-
	34	6	1285	214	1900 - 1930	Residential	514	-	511	-	-	-
	2	6	1029	172	1900 - 1930	Residential	412	yes	214	-	-	-
	1	6	1314	219	1900 - 1930	Residential	526	-	0	-	-	-
42	6	6	2181	364	1900 - 1930	Residential	1218	-	219	-	-	-
	8	6	1348	225	1900 - 1930	Residential	753	-	364	-	-	-
	33	6	596	99	1980 - 2000	Residential	333	-	0	-	-	-

CODE	SUB-CODE	Nº of plants	Total Area of building (m^2)	Floor area (m^2)	Age of the building	Use of building	Total area of the facade (m^2)	Any refurbishment measure applied?	Estimated useful space of roof	Protection grade	Central heating	Cooling system
43	22	7	2062	295	1980 - 2000	Residential	664	-	0	-	-	-
	1	7	2088	298	1980 - 2000	Residential	673	-	0	-	-	-
	7	7	2051	293	1980 - 2000	Residential	661	-	0	-	-	-
	6	7	2046	292	1980 - 2000	Residential	659	-	0	-	-	-
44	5	7	3255	465	1960 - 1980	Residential	988	yes	0	-	-	-
	4	7	2490	356	1980 - 2000	Residential	755	-	0	-	-	-
	3	7	2195	314	1980 - 2000	Residential	666	-	0	-	-	-
	11	7	3760	537	1980 - 2000	Residential	1141	-	0	-	-	yes
	9	7	2242	320	1980 - 2000	Residential	680	-	0	-	-	-
	7	7	2076	297	1980 - 2000	Residential	630	-	0	-	-	-
	5	7	1240	177	1980 - 2000	Residential	376	-	0	-	-	-
	3	7	935	134	1980 - 2000	Residential	284	-	0	-	-	-
	1	7	1551	222	1980 - 2000	Residential	471	-	0	-	-	-
	35	7	3274	468	1980 - 2000	Residential	993	-	0	-	-	yes
	33	7	2581	369	1980 - 2000	Residential	783	-	0	-	-	yes
45	24	7	2460	351	1960 - 1980	Residential	1188	-	0	-	-	-
	28	7	2470	353	1960 - 1980	Residential	1193	-	0	-	-	-
	7	8	2448	306	1930 - 1960	Residential	1183	-	0	-	-	-
	5	8	1536	192	1930 - 1960	Residential	742	-	0	-	-	-
	3	8	1586	198	1930 - 1960	Residential	766	-	192	-	-	-
	1	7	1491	213	1960 - 1980	Residential	720	-	198	-	-	-
	2	7	2031	290	1960 - 1980	Residential	981	-	0	-	-	-
	4	7	3743	535	1960 - 1980	Residential	1808	-	0	-	-	-
46	38	8	1794	224	1960 - 1980	Residential	679	-	0	-	-	-
	40	8	1759	220	1960 - 1980	Residential	666	-	0	-	-	-
	42	8	2388	299	1960 - 1980	Residential	904	-	0	-	-	-
	44	8	2295	287	1960 - 1980	Residential	869	-	299	-	-	-
	46	6	1863	311	1930 - 1960	Residential	705	-	287	-	-	-
	10	8	2958	370	1960 - 1980	Residential	1120	-	0	-	-	-
	12	8	2570	321	1960 - 1980	Residential	973	-	0	-	-	-
	14	7	3118	445	1930 - 1960	Residential	1180	-	0	-	yes	-
	43	7	1403	200	1980 - 2000	Residential	531	-	0	-	-	-
	41	7	2250	321	1980 - 2000	Residential	852	-	0	-	-	yes
	39	7	2256	322	1980 - 2000	Residential	854	-	0	-	-	-
	17	7	3000	429	1980 - 2000	Residential	1136	-	0	-	-	-
	15	6	1377	230	1900 - 1930	Residential	521	-	0	D	-	-
47	52	7	2418	345	1930 - 1960	Residential	1033	yes	0	D	-	-
	54	8	3137	392	1900 - 1930	Residential	1340	-	0	D	-	-
	56	8	2775	347	1930 - 1960	Residential	1186	yes	392	D	-	-
	8	8	2037	255	1930 - 1960	Residential	870	-	0	D	-	-
	14	9	6584	732	1960 - 1980	Sanitary	2813	-	0	-	yes	-
	55	7	2492	356	1900 - 1930	Residential	1065	-	0	D	-	-
	53	7	2803	400	1900 - 1930	Residential	1198	-	356	D	-	-
	17	8	3757	470	1930 - 1960	Residential	1605	-	400	-	-	-
	15	7	1177	168	1900 - 1930	Residential	503	-	470	D	-	-

CODE	SUB-CODE	Nº of plants	Total Area of building (m^2)	Floor area (m^2)	Age of the building	Use of building	Total area of the facade (m^2)	Any refurbishment measure applied?	Estimated useful space of roof	Protection grade	Central heating	Cooling system
47	13	7	1270	181	1900 - 1930	Residential	543	yes	0	D	-	-
48	1	8	1690	211	1960 - 1980	Residential	557	yes	0	-	-	-
	2	8	1690	211	1960 - 1980	Residential	557	yes	0	-	-	-
	3	8	1690	211	1960 - 1980	Residential	557	yes	0	-	-	-
	5	8	1690	211	1960 - 1980	Residential	557	yes	0	-	-	-
	6	8	1690	211	1960 - 1980	Residential	557	yes	0	-	-	-
	7	8	1690	211	1960 - 1980	Residential	557	yes	0	-	yes	-
	8	8	1690	211	1960 - 1980	Residential	557	yes	0	-	yes	-
	9	8	1690	211	1960 - 1980	Residential	557	yes	0	-	-	-
	10	8	1690	211	1960 - 1980	Residential	557	yes	0	-	-	-
	11	8	1690	211	1960 - 1980	Residential	557	yes	0	-	-	-
	20	8	1690	211	1960 - 1980	Residential	557	yes	0	-	-	-
	18	8	1690	211	1960 - 1980	Residential	557	yes	0	-	-	-
	16	8	1690	211	1960 - 1980	Residential	557	yes	0	-	-	-
	40	8	1690	211	1960 - 1980	Residential	557	yes	0	-	-	-
	36	8	1690	211	1960 - 1980	Residential	557	yes	0	-	-	-
	21	8	1690	211	1960 - 1980	Residential	557	yes	0	-	-	-
	23	8	1690	211	1960 - 1980	Residential	557	yes	0	-	-	-
	25	8	1690	211	1960 - 1980	Residential	557	yes	0	-	-	-
49	44	7	3518	503	1960 - 1980	Residential	1201	-	0	-	-	-
	46	7	2425	346	1960 - 1980	Residential	828	-	0	-	-	-
	48	7	2398	343	1960 - 1980	Residential	819	yes	0	-	-	-
	16	8	3013	377	1960 - 1980	Residential	1029	-	0	-	-	-
	18	8	3334	417	1960 - 1980	Residential	1138	-	0	-	-	yes
	20	8	3132	392	1960 - 1980	Residential	1069	-	0	-	-	-
	5	7	2472	353	1960 - 1980	Residential	844	-	0	-	-	-
	3	7	2479	354	1960 - 1980	Residential	846	-	0	-	-	-
	1	7	3434	491	1960 - 1980	Residential	1172	-	0	-	-	-
	21	7	1488	213	1960 - 1980	Residential	508	yes	0	-	yes	-
	19	7	1488	213	1960 - 1980	Residential	508	yes	0	-	yes	-
50	12	8	1545	193	1960 - 1980	Residential	611	-	0	-	-	yes
	13	8	1545	193	1960 - 1980	Residential	611	-	0	-	-	-
	14	8	1545	193	1960 - 1980	Residential	611	-	0	-	-	-
	15	8	1545	193	1960 - 1980	Residential	611	-	0	-	-	-
	16	8	1545	193	1960 - 1980	Residential	611	-	0	-	-	-
	17	8	1545	193	1960 - 1980	Residential	611	-	0	-	-	-
	18	8	1545	193	1960 - 1980	Residential	611	-	0	-	-	-
	19	8	617	77	1960 - 1980	Office	244	-	0	-	-	-
	20	8	617	77	1960 - 1980	Office	244	-	0	-	-	-
	21	8	1545	193	1960 - 1980	Residential	611	-	0	-	-	-
	22	8	1545	193	1960 - 1980	Residential	611	-	0	-	-	-
	31	8	1545	193	1960 - 1980	Residential	611	-	0	-	-	-
	33	8	1545	193	1960 - 1980	Residential	611	-	0	-	-	-
	35	8	1545	193	1960 - 1980	Residential	611	-	0	-	-	-
	29	8	1545	193	1960 - 1980	Residential	611	-	0	-	-	-

CODE	SUB-CODE	Nº of plants	Total Area of building (m^2)	Floor area (m^2)	Age of the building	Use of building	Total area of the facade (m^2)	Any refurbishment measure applied?	Estimated useful space of roof	Protection grade	Central heating	Cooling system
51	3	8	1545	193	1960 - 1980	Residential	611	-	0	-	-	-
	7	8	1545	193	1960 - 1980	Residential	611	-	0	-	-	-
	30	8	1545	193	1960 - 1980	Residential	611	-	0	-	-	-
	28	8	1545	193	1960 - 1980	Residential	611	-	0	-	-	-
	26	8	1545	193	1960 - 1980	Residential	611	-	0	-	-	yes
	2	7	3335	476	1960 - 1980	Residential	1218	-	0	-	-	-
	4	7	2507	358	1980 - 2000	Residential	916	-	0	-	-	-
	6	7	2507	358	1980 - 2000	Residential	916	-	0	-	-	-
	8	8	3281	410	1980 - 2000	Residential	1199	-	0	-	-	-
	24	8	3639	455	1960 - 1980	Residential	1330	-	0	-	-	-
	17	8	3283	410	1980 - 2000	Residential	1199	-	0	-	-	-
	15	7	2452	350	1980 - 2000	Residential	896	-	0	-	yes	-
	13	7	2522	360	1980 - 2000	Residential	921	-	0	-	-	-
	11	7	2767	395	0	Residential	1011	yes	0	-	-	-
	29	7	1325	189	1960 - 1980	Residential	484	yes	0	-	-	-
	27	7	2380	340	1960 - 1980	Residential	870	-	0	-	-	-
52	2	7	1181	169	1960 - 1980	Residential	599	-	0	-	-	-
	4	7	1784	255	1960 - 1980	Residential	905	-	0	-	-	-
	6	7	1588	227	1960 - 1980	Residential	805	-	0	-	-	-
	8	7	1227	175	1960 - 1980	Residential	622	-	0	-	-	-
	32	7	2422	346	1960 - 1980	Residential	1228	-	0	-	-	-
	34	7	2307	330	1960 - 1980	Residential	1170	-	0	-	-	-
	21	8	1949	244	1930 - 1960	Residential	988	-	0	-	-	-
	19	8	1337	167	1930 - 1960	Residential	678	-	49	-	-	-
	17	8	1538	192	1930 - 1960	Residential	780	-	0	-	-	-
	15	8	1582	198	1930 - 1960	Residential	802	-	0	-	-	-
	13	8	1605	201	1960 - 1980	Residential	814	yes	0	-	-	-
	11	8	1572	197	1930 - 1960	Residential	797	yes	0	-	-	-
	37	8	1907	238	1960 - 1980	Residential	967	-	0	-	-	-
53	14	7	2128	304	1960 - 1980	Residential	835	yes	0	-	-	-
	16	7	3559	508	1960 - 1980	Residential	1397	-	0	-	-	-
	11	8	4036	505	1960 - 1980	Residential	1584	-	0	-	-	-
	35	7	1629	233	1960 - 1980	Residential	639	-	0	-	-	-
	33	7	1210	173	1960 - 1980	Residential	475	-	0	-	-	-
54	30	8	2700	338	1930 - 1960	Residential	1046	yes	0	-	-	-
	32	9	1827	203	1930 - 1960	Residential	708	yes	0	-	-	-
	34	8	1912	239	1930 - 1960	Residential	741	-	0	-	-	-
	17	8	1653	207	1960 - 1980	Residential	640	-	0	-	-	-
	25	8	2535	317	1960 - 1980	Residential	982	yes	0	-	-	-
	23	7	1762	252	1960 - 1980	Residential	682	yes	0	-	-	-
	12	7	2227	318	1960 - 1980	Residential	863	-	0	-	-	-
	14	7	1331	190	1960 - 1980	Residential	515	-	0	-	-	-
	16	7	1520	217	1960 - 1980	Residential	589	-	0	-	-	-
55	6	6	1128	188	1900 - 1930	Residential	413	-	0	-	-	-
	8	8	1432	179	1900 - 1930	Residential	524	-	188	-	-	-

CODE	SUB-CODE	Nº of plants	Total Area of building (m^2)	Floor area (m^2)	Age of the building	Use of building	Total area of the facade (m^2)	Any refurbishment measure applied?	Estimated useful space of roof	Protection grade	Central heating	Cooling system
56	10	7	2309	330	1900 - 1930	Residential	845	-	179	-	-	-
	3 y 1	7	2018	288	1900 - 1930	Residential	739	-	330	-	-	-
	7	5	1070	214	1900 - 1930	Residential	392	-	145	-	-	-
	5	6	1956	326	1900 - 1930	Residential	716	-	0	-	-	-
	3	6	2704	451	1900 - 1930	Residential	990	-	86	D	-	-
	3	7	3070	439	1900 - 1930	Residential	1124	-	0	B	-	-
	4	7	2018	288	1930 - 1960	Residential	449	-	451	-	-	-
	12	7	2937	420	1930 - 1960	Residential	654	-	0	-	yes	-
	2	7	5364	766	1930 - 1960	Residential	1194	-	0	-	yes	-
	9	7	2581	369	1930 - 1960	Residential	575	yes	0	-	yes	-
	11	7	1923	275	1930 - 1960	Residential	428	-	0	-	yes	-
	17		0	235	0	Other	262	-	369	D	-	-
	21		0	786	0	Other	700	-	0	D	-	-
	9		0	550	0	Other	367	-	0	-	-	-
57	22	7	1762	252	1930 - 1960	Residential	620	-	0	-	-	-
	13	8	2688	336	1930 - 1960	Residential	946	-	0	-	-	-
	11	8	1910	239	1930 - 1960	Residential	672	-	0	-	-	-
	9	8	2150	269	1930 - 1960	Residential	757	-	0	-	-	-
	7	7	2232	319	2000 - 2020	Residential	786	yes	0	-	-	-
	5	8	2054	257	1930 - 1960	Residential	723	-	0	-	-	-
	3	7	1220	174	1930 - 1960	Residential	430	-	0	-	-	-
	1	7	2715	388	1980 - 2000	Residential	956	-	0	-	-	-
	25	8	1762	220	1930 - 1960	Residential	620	yes	0	D	-	-
	23	8	2114	264	1930 - 1960	Residential	744	yes	0	D	-	-
	4	8	3935	492	1960 - 1980	Residential	1385	-	0	-	yes	-
	6	8	2472	309	1930 - 1960	Residential	870	-	0	-	-	-
	8	8	2414	302	1930 - 1960	Residential	850	-	0	-	-	-
	10	8	2270	284	1930 - 1960	Residential	799	-	0	-	-	-
58	28	8	1905	238	1930 - 1960	Residential	867	-	0	-	-	-
	36	8	1534	192	1960 - 1980	Residential	698	-	0	-	-	-
	38	8	1386	173	1960 - 1980	Residential	630	-	0	-	-	-
	40	8	1274	159	1960 - 1980	Residential	579	-	0	-	-	-
	9	8	2348	294	1960 - 1980	Residential	1068	-	0	-	-	-
	7	8	1407	176	1960 - 1980	Residential	640	-	0	-	-	-
	5	8	1967	246	1960 - 1980	Residential	895	-	0	-	-	-
	3	8	977	122	1930 - 1960	Residential	444	-	0	-	-	-
	1	8	2165	271	1930 - 1960	Residential	985	-	0	-	-	-
	10	8	1816	227	1930 - 1960	Residential	826	-	0	-	-	-
	12	8	1612	202	1930 - 1960	Residential	733	-	0	-	-	-
	14	9	1416	157	1930 - 1960	Residential	644	-	0	-	-	-
59	2	9	1705	189	1960 - 1980	Residential	805	-	0	-	-	-
	4	9	1340	149	1960 - 1980	Residential	633	-	0	-	-	-
	6	9	1610	179	1960 - 1980	Residential	760	-	0	-	-	-
	3	9	1917	213	1960 - 1980	Residential	905	-	0	-	-	-
	1	7	1752	250	1900 - 1930	Residential	827	-	0	-	-	-

CODE	SUB-CODE	Nº of plants	Total Area of building (m^2)	Floor area (m^2)	Age of the building	Use of building	Total area of the facade (m^2)	Any refurbishment measure applied?	Estimated useful space of roof	Protection grade	Central heating	Cooling system
59	31	9	1305	145	1960 - 1980	Residential	616	-	0	-	-	-
	29	9	2211	246	1960 - 1980	Residential	1044	-	250	-	-	-
	2	9	3421	380	1960 - 1980	Residential	1615	-	0	-	-	-
60	44	6	2418	403	1930 - 1960	Residential	1364	-	0	D	-	-
	46	6	1703	284	1930 - 1960	Residential	961	-	0	D	-	-
	48	7	563	80	1960 - 1980	Residential	318	-	0	-	-	-
	50	5	1400	280	1930 - 1960	Residential	790	-	284	D	-	-
	47	7	1946	278	1930 - 1960	Residential	1098	-	0	D	-	-
	45	7	1181	169	1930 - 1960	Residential	666	-	0	D	-	-
	43	7	1287	184	1930 - 1960	Residential	726	-	0	D	-	-
	41	7	1219	174	1930 - 1960	Residential	688	-	169	D	-	-
	39	7	1271	182	1930 - 1960	Residential	717	-	184	D	-	-
	37	7	1240	177	1930 - 1960	Residential	700	-	174	D	-	-
	35	7	1765	252	1930 - 1960	Residential	996	-	182	D	-	-
	4	7	1693	242	1930 - 1960	Residential	955	-	177	D	-	-
	6	7	1749	250	1930 - 1960	Residential	987	-	252	D	-	-

AMARA

Table 72. Main characteristics of residential and office buildings of the district of Amara.

CODE	Nº of plants	Total Area of building (m^2)	Floor area (m^2)	Age of the building	Use of building	Total area of the facade (m^2)	Any refurbishment measure applied	Estimation of useful space of roof	Protection grade	Central heating	Cooling system
#89	11	30254	2750	<1960	Office	9240	-	0	-	-	-
#90	6	10839	1807	<1960	Residential	5220	-	0	-	-	yes
#79	10	1803	180	<1960	Residential	1800	-	0	-	-	-
#80	10	1796	180	<1960	Residential	1800	-	0	-	-	-
C#26	11	25671	2334	<1960	Office	6765	-	2334	-	-	yes
#108	10	44458	4446	<1960	Residential	15000	-	4446	-	yes	-
#109	10	8505	850	<1960	Office	3900	-	850	-	-	-
#77	10	69135	6913	1960-1980	Residential	19500	yes	5185	-	yes	yes
#134	10	8164	816	<1960	Residential	4500	yes	0	-	-	-
C#10	10	3906	391	<1960	Residential	3390	yes	0	-	-	-
#101	11	6775	616	<1960	Residential	4092	-	308	-	-	-
#118	11	11808	1073	<1960	Residential	4389	-	966		-	-
#117	11	4051	368	<1960	Residential	1452	yes	368	-	-	-
C#5	11	5305	482	<1960	Residential	1881	-	434	-	-	-
#116	11	13417	1220	1960-1980	Residential	4191	-	1098	-	yes	yes
#115	11	7799	709	1960-1980	Residential	3498	yes	709	-	-	-
C#4	11	11097	1009	1960-1980	Residential	3795	-	908	-	yes	-
#18	20	17168	858	<1960	Residential	7200	yes	858	-	yes	-
#133	11	13315	1210	1960-1980	Residential	4092	-	1210	-	-	-
#132	11	12304	1119	1960-1980	Residential	3135	yes	1119	-	-	yes
C#9	11	4234	385	1960-1980	Residential	990	yes	385	-	yes	-
C#8	11	6199	564	1960-1980	Residential	2541	-	564	-	yes	-
#15	11	12102	1100	<1960	Residential	4356	yes	715	-	yes	-
#20	11	20549	1868	<1960	Residential	6930	yes	934	-	yes	-
C#7	11	63567	5779	1960-1980	Residential	18150	-	5779	-	yes	-
#127	11	7854	714	1960-1980	Residential	1980	-	714	-	yes	-
#128	11	10974	998	1960-1980	Residential	2838	-	0	-	yes	-
#129	11	6406	582	1960-1980	Residential	1221	yes	0	-	yes	-
#131	11	22858	2078	1960-1980	Residential	6105	-	0	-	yes	-
#7	11	12008	1092	1960-1980	Residential	4686	-	0	-	yes	-
#8	11	12229	1112	1960-1980	Office	4686	-	0	-	-	-
#9	11	12373	1125	1960-1980	Residential	4686	yes	0	-	-	-
#13	6	8499	1417	<1960	Office	3510	-	1417	-	-	-
#4	11	10426	948	<1960	Residential	4620	-	0	-	yes	-
#3	11	10442	949	<1960	Residential	4653	-	0	-	yes	yes
#2	11	10411	946	<1960	Residential	4686	-	0	-	-	-

CODE	Nº of plants	Total Area of building (m^2)	Floor area (m^2)	Age of the building	Use of building	Total area of the facade (m^2)	Any refurbishment measure applied	Estimation of useful space of roof	Protection grade	Central heating	Cooling system
#35	11	10450	950	<1960	Residential	4752	-	0	-	-	-
#38	11	10426	948	<1960	Residential	4785	-	0	-	-	-
#31	11	4962	451	<1960	Residential	3234	-	451	-	yes	yes
#30	11	4987	453	<1960	Residential	3234	yes	453	-	-	-
C#8	11	4928	448	<1960	Residential	3234	yes	336	-	-	-
#34	11	4974	452	<1960	Residential	3234	-	339	-	-	-
#37	11	4944	449	<1960	Residential	3234	yes	0	-	yes	-
#39	11	4937	449	<1960	Residential	3234	-	0	-	-	-
#26	11	10533	958	<1960	Residential	4620	-	0	-	-	-
#27	11	10503	955	<1960	Residential	4620	-	0	-	-	-
#32	11	10462	951	<1960	Residential	4620	-	0	-	-	yes
#33	11	10459	951	<1960	Residential	4620	-	0	-		-
#36	11	10498	954	<1960	Residential	4620	yes	0	-	-	-
#40	11	10436	949	<1960	Residential	4620	-	0	-	-	-
C#7	11	12407	1128	<1960	Residential	4818	-	0	-	-	yes
#60	11	12335	1121	<1960	Residential	4818	yes	0	-	yes	-
C#9	10	11158	1116	<1960	Residential	4380	-	0	-	-	-
#29	11	12298	1118	<1960	Residential	4818	yes	0	-	-	-
#65	11	11244	1022	<1960	Residential	4818	yes	1022	-	-	-
#61	11	12386	1126	<1960	Residential	4818	yes	1126	-	-	-
#56	11	12279	1116	<1960	Residential	4818	-	0	-	-	-
#41	10	11228	1123	<1960	Residential	4380	-	0	-	-	-
#64	11	11239	1022	<1960	Residential	4818	-	1022	-	-	-
#62	11	12289	1117	<1960	Residential	4818	-	0	-		-
#55	11	12380	1125	<1960	Residential	4818	-	1125	-	-	-
#42	10	11200	1120	<1960	Residential	4380	-	1120	-	-	yes
#28	19	8616	453	<1960	Residential	5472	-	0	-	-	-
#63	19	8611	453	<1960	Residential	5472	-	453	-	-	-
#57	19	1182	62	<1960	Residential	5472	yes	62	-	yes	-
#46	2	2293	1147	<1960	Office	1236	-	1147	-	-	-
#93	6	19049	3175	<1960	Residential	8370	-	3175	-	-	yes
#92	6	23018	3836	<1960	Residential	9414	-	3069	-	-	yes
C#17	6	20169	3361	<1960	Residential	8352	-	0	-	-	yes
#105	6	12562	2094	<1960	Residential	5400	-	0	-	-	-
#106	6	15015	2503	<1960	Residential	6480	-	0	-	-	yes
#78	10	96300	9630	1960-1980	Residential	25200	yes	6259	-	-	yes
#74	11	32647	2968	1960-1980	Residential	8844	-	0	-	yes	yes
#17	11	14536	1321	<1960	Office	7788	-	0	-	-	-
#54	3	1500	500	<1960	Other	900	-	500	-	-	-
#126	11	24667	2242	1960-1980	Residential	7458	yes	1682	-	yes	-
#125	11	10389	944	1960-1980	Residential	3696	-	944	-	-	-

CODE	Nº of plants	Total Area of building (m^2)	Floor area (m^2)	Age of the building	Use of building	Total area of the facade (m^2)	Any refurbishment measure applied	Estimation of useful space of roof	Protection grade	Central heating	Cooling system
C#6	11	5146	468	1960-1980	Residential	792	-	234	-	-	yes
C#20	11	14503	1318	1960-1980	Other	3465	-	989	-	yes	yes
#104	11	11728	1066	1960-1980	Office	2904	-	0	-	-	-
#123	11	26085	2371	<1960	Residential	7029	-	2371	-	-	-
#124	11	9356	851	<1960	Residential	4059	yes	0	-	-	-
#122	11	5245	477	<1960	Residential	1815	yes	0	-	-	-
#121	11	4614	419	<1960	Residential	1980	-	419	-	-	-
#120	11	4624	420	<1960	Residential	1122	yes	420	-	-	yes
#119	11	16916	1538	<1960	Residential	4686	-	0	-	yes	-
#110	11	4963	451	<1960	Residential	1815	-	451	-	-	-
#111	11	9413	856	<1960	Residential	3300	-	856	-	-	-
#113	11	47660	4333	1960-1980	Residential	14190	yes	0	-	-	-
#114	11	6110	555	1960-1980	Residential	1782	yes	555	-	-	-
C#3	11	16935	1540	1960-1980	Residential	5478	-	0	-	-	-
#112	11	6180	562	1960-1980	Residential	2310	yes	0	-	-	-
#86	10	5509	551	<1960	Office	3630	yes	551	-	-	-
#14	17	16527	972	<1960	Office	7446	-	972	-	yes	-
#51	2	686	343	<1960	Office	432	-	0	-	-	-
#43	4	3851	963	<1960	Office	1884	-	963	-	-	-
C#10	2	689	344	<1960	Office	432	-	0	-	-	yes
#97	2	2100	1050	<1960	Other	420	-	1050	-	-	-
#98	6	5200	867	<1960	Other	2214	-	867	-	-	-
C#18	4	2340	585	<1960	Other	1140	-	585	-	-	-
#96	1	755	755	<1960	Other	180	-		-	-	-
C#19	4	8572	2143	<1960	Other	2940	-	1286	-	yes	yes
#99	4	5054	1264	<1960	Other	2112	-	758	-	-	-
#100	4	2617	654	<1960	Other	1680	-	393	-	-	-
#22	1	1169	1169	<1960	Other	378	-	1169	-	-	-
#19	3	4163	1388	<1960	Other	1827	-	1388	-	-	-
#67	2	1464	732	<1960	Other	1170	-	732	-	-	-
#66	2	679	339	<1960	Other	630	-	339	-	-	-
#58	1	212	212	<1960	Other	240	-	0	-	yes	-
#59	1	314	314	<1960	Other	240	-	0	-	-	-
#45	4	4505	1126	<1960	Other	1872	-	1126	-	-	
#48	5	1751	350	<1960	Other	375	-	350	-	-	-
#47	4	2570	643	<1960	Other	792	-	643	-	-	-
#50	1	1152	1152	<1960	Other	420	-	0	-	-	-
#75	1	188	188	<1960	Other	0	-	0	-	-	-
C#13	1	73	73	<1960	Other	105	-	0	-	-	-
#53	1	1160	1160	<1960	Other	447	-	580	-	-	-
#52	1	1600	1600	<1960	Other	615	-	1600	-	-	-

#103	1	383	383	<1960	Other	243	-	383	-	-	-
#25	1	186	186	<1960	Other	225	-	0	-	yes	-
#24	1	308	308	<1960	Other	240	-	0	-	-	-
#23	1	204	204	<1960	Other	219	-	204	-	-	-
#94	6	5967	994	<1960	Residential	3060	-	0	-	-	-
C#25	11	20539	1867	<1960	Residential	6996	yes	1587	-	-	-
#5	11	10539	958	<1960	Residential	4719	-	0	-	yes	-

ALDEZAHARRA

Table 73. Main characteristics of residential and office buildings of the district of Aldezaharra.

CODE	Nº of plants	Total Area of building (m^2)	Floor area (m^2)	Age of the building	Use of building	Total area of the facade (m^2)	Any refurbishment measure applied?	Estimated useful space of roof	Protection grade	Central heating	Cooling system
#17	3	2309	770	<1960	Residential	1017	-	385	II	-	-
#18	7	8322	1189	<1960	Residential	2730	yes	416	IV	yes	-
#16	5	1874	375	<1960	Residential	1740	-	103	IV	-	-
#15	5	1587	317	<1960	Residential	1725	-	317	IV	-	-
#13	5	2745	549	<1960	Residential	1995	-	148	-	-	-
#14	4	1741	435	<1960	Residential	1404	-	0	-	-	-
#19	5	4754	951	<1960	Residential	2025	-	285	IV	-	-
C#3	6	1933	322	<1960	Residential	1206	-	322	IV	-	-
#23	7	3715	531	<1960	Residential	1344	-	531	II	-	-
#24	3	2485	828	<1960	Residential	864	-	828	IV	-	yes
#21	7	5008	715	<1960	Residential	2058	-	358	II	-	-
C#11	5	7878	1576	<1960	Residential	2550	-	788	IV	-	-
#45	4	1762	441	<1960	Residential	1056	-	441	IV	-	-
#25	6	4742	790	<1960	Residential	2214	-	395	IV	-	-
#47	5	2241	448	<1960	Residential	1275	-	224	IV	-	-
C#4	6	13098	2183	<1960	Residential	5436	-	835	IV	-	yes
#7	5	11047	2209	<1960	Residential	3900	yes	746	IV	-	-
#4	5	11705	2341	<1960	Residential	3825	yes	351	IV	-	yes
#56	5	7801	1560	<1960	Residential	2025		0	III	-	-
#57	5	1104	221	<1960	Residential	450	yes	0	IV	-	-
#58	5	2235	447	<1960	Residential	1185	-	0	IV	-	-
#2	5	3123	625	<1960	Residential	1620	-	0	III	-	-
C#2	5	12025	2405	<1960	Residential	3870	-	361	III	-	-
#35	6	16216	2703	<1960	Residential	4698	yes	1351	IV	-	-
#46	6	8499	1417	<1960	Residential	3420	yes	283	IV	-	-
C#7	6	10453	1742	<1960	Residential	3060	yes	1045	IV	-	-

CODE	Nº of plants	Total Area of building (m^2)	Floor area (m^2)	Age of the building	Use of building	Total area of the facade (m^2)	Any refurbishment measure applied?	Estimated useful space of roof	Protection grade	Central heating	Cooling system
#26	5	5903	1181	<1960	Residential	3030	yes	590	IV	-	-
#29	6	8900	1483	<1960	Residential	3690	-	371	IV	-	-
#55	5	6381	1276	<1960	Residential	1665	-	0	IV	-	-
#54	5	1736	347	<1960	Residential	450	yes	174	IV	-	-
C#1	5	4124	825	<1960	Residential	12360	-	289	IV	-	yes
#32	6	14244	2374	<1960	Residential	3978	-	831	IV	-	-
C#5	5	7234	1447	<1960	Residential	2655	-	506	IV	-	-
C#6	5	7926	1585	<1960	Residential	2595	yes	555	IV	-	yes
#40	5	4913	983	<1960	Residential	2295	-	368	C	yes	yes
#37	7	21193	3028	<1960	Residential	5460	yes	3028	D	-	
C#12	4	11271	2818	<1960	Residential	5460	-	1409	II	-	
#51	5	10752	2150	<1960	Residential	4095	yes	430	IV	-	yes
#6	5	10737	2147	<1960	Residential	3795	yes	913	IV	-	
#5	5	12848	2570	<1960	Residential	4590	yes	1092	IV	-	yes
#50	5	13428	2686	<1960	Residential	4350	-	1611	IV	-	yes
#3	3	1487	0	<1960	Office	855	-	124	II	-	-
#22	5	2257	451	<1960	Residential	1005	-	0	IV	-	-
C#13	1	2009	2009	<1960	Other	573	-	1004	A	-	-
#53	1	1852	1852	<1960	Other	429	-	926	A	-	-
#44	3	3385	1128	<1960	Other	2502	-	564	A	yes	yes
#42	4	11369	2842	<1960	Other	0	-	0	IV	-	-
#52	1	1507	1507	<1960	Other	537	-	0	A	-	-
#27	2	4262	2131	<1960	Other	1170	-	1066	C	-	-
#28	1	556	556	<1960	Other	246	-	556	IV	-	-
#31	2	4252	2126	<1960	Other	1200	-	1063	C	-	-
C#14	5	2065	413	<1960	Other	1725	-	413	C	-	-

CORTAZAR

Table 74. Main characteristics of residential and office buildings of the district of Cortazar.

CODE	Nº of plants	Total Area of building (m^2)	Floor area (m^2)	Age of the building	Use of building	Total area of the facade (m^2)	Any refurbishment measure applied?	Estimated useful space of roof	Protection grade	Central heating	Cooling system
C#29	8	15604	1950	1960-1980	Residential	4152	-	858	-	-	-
#170	8	13538	1692	<1960	Residential	4248	yes	338	-	-	-
#171	8	14031	1754	1960-1980	Residential	4200	-	438	C	yes	-
#172	8	13581	1698	1960-1980	Residential	4320	-	1698	-	yes	-
#173	8	15658	1957	<1960	Office	4560	-	1076	C	-	yes
#190	3	690	230	<1960	Other	180	-	230	B	-	-
#191	6	1000	167	<1960	Residential	3150	-	167	B	-	-
#193	7	9453	1350	<1960	Residential	2730	-	219	D	-	yes
#192	7	1826	261	<1960	Residential	504	yes	261	D	-	-
C#13	7	6070	867	<1960	Residential	1974	-	867	D	-	-
C#16	7	7279	1040	<1960	Residential	2940	yes	1040	D	-	-
#107	7	18016	2574	<1960	Residential	4893	-	2574	D	-	-
#206	8	8970	1121	<1960	Residential	2736	-	280	D	-	-
#205	8	1946	243	<1960	Residential	1296	-	0	-	-	-
C#27	7	11626	1661	<1960	Office	3654	-	0	D	-	-
C#18	6	1528	255	<1960	Residential	1602	-	0	C	-	-
#200	6	4341	724	<1960	Residential	360	-	724	C	-	yes
#201	6	1102	184	<1960	Residential	900	-	0	C	-	-
#186	6	7199	1200	<1960	Residential	2808	-	600	C	-	yes
#85	6	5883	981	<1960	Residential	2664	-	0	C	-	-
#83	6	5850	975	<1960	Residential	2700	-	488	C	-	-
#204	8	4117	515	<1960	Residential	1560	-	0	C	-	-
C#21	8	10984	1373	<1960	Residential	3720	-	535	C	-	-
#91	8	6915	864	1960-1980	Residential	3144	-	0	-	-	-
#164	7	7459	1066	<1960	Office	3255	-	0	-	-	yes
#189	8	25961	3245	<1960	Residential	8664	-	3245	-	-	-
#12	8	2514	314	<1960	Residential	936	-	204	D	yes	-
#194	8	30093	3762	<1960	Residential	9192	-	1881	D	-	-
C#14	8	2981	373	<1960	Residential	984	-	373	C	-	yes
#197	8	19607	2451	<1960	Residential	5928	-	2451	D	-	-
#198	8	1229	154	<1960	Residential	384	yes	154	D	-	yes
#196	8	9486	1186	<1960	Residential	3000	-	1186	D	-	-
C#16	8	3069	384	<1960	Residential	960	-	384	D	-	-
#110	7	21043	3006	<1960	Office	6972	-	225	D	-	yes
#111	7	21981	3140	<1960	Residential	6615	-	785	D	yes	-
#207	7	18862	2695	<1960	Residential	5754	-	2695	D	-	yes
C#22	7	2634	376	<1960	Residential	798	yes	0	D	-	-
#133	7	22092	3156	<1960	Residential	7035	yes	1578	D	-	yes

CODE	Nº of plants	Total Area of building (m^2)	Floor area (m^2)	Age of the building	Use of building	Total area of the facade (m^2)	Any refurbishment measure applied?	Estimated useful space of roof	Protection grade	Central heating	Cooling system
#138	8	25656	3207	<1960	Residential	8088	-	321	D	-	yes
#183	7	5016	717	<1960	Office	1827	-	0	B	-	-
C#7	7	8127	1161	<1960	Residential	3990	-	581	D	-	yes
#182	7	11436	1634	<1960	Residential	3570	-	531	D	-	yes
C#6	7	7483	1069	<1960	Office	2415	-	1069	D	yes	yes
C#26	7	15429	2204	<1960	Residential	3234	-	0	D	yes	-
#215	7	2308	330	<1960	Residential	693	-	330	D	yes	-
#124	7	17239	2463	<1960	Residential	5565	-	985	D	yes	yes
#118	7	24515	3502	<1960	Residential	7308	-	1051	D	-	-
#214	7	8017	1145	<1960	Residential	3297	-	1145	D	-	-
C#25	7	2063	295	<1960	Residential	987	-	147	D	-	-
#213	7	18191	2599	<1960	Residential	5460	-	0	D	-	-
#212	7	2527	361	<1960	Residential	987	-	87	-	-	-
#131	6	10781	1797	<1960	Residential	4752	yes	898	D	-	-
C#23	7	17498	2500	<1960	Residential	7014	yes	300	D	-	-
#195	5	11591	2318	<1960	Residential	4200	yes	2318	D	-	yes
C#15	5	1840	368	1960-1980	Residential	825	yes	184	D	-	-
#101	7	27097	3871	<1960	Residential	8274	-	387	D	yes	-
#199	5	6800	1360	<1960	Residential	2775	-	1360	C	yes	yes
C#17	5	2665	533	<1960	Residential	1170	-	533	C	-	-
#155	7	9472	1353	<1960	Residential	5040	-	677	D	-	-
C#19	7	16464	2352	<1960	Residential	5040	-	0	D	-	-
#202	7	2661	380	<1960	Residential	840	-	190	D	-	-
#115	7	19908	2844	<1960	Residential	6300	-	1138	D	-	yes
C#20	7	9106	1301	<1960	Residential	3780	-	1301	D	-	-
#203	7	2087	298	<1960	Residential	1134	yes	149	-	-	yes
#92	8	17982	2248	1960-1980	Residential	6816	yes	0	D	yes	yes
#180	8	7229	904	<1960	Office	2760	-	0	D	yes	-
C#4	8	10848	1356	<1960	Residential	3504	-	0	D	-	-
#134	7	19011	2716	<1960	Residential	5922	-	1358	D	-	-
#143	8	22441	2805	<1960	Residential	7320	-	1403	D	yes	yes
#114	8	21008	2626	<1960	Residential	6648	-	656	D	yes	yes
#137	7	18073	2582	<1960	Residential	6090	yes	710	D	yes	-
C#11	7	19513	2788	<1960	Residential	6384	yes	976	D	yes	yes
#208	7	18022	2575	<1960	Residential	5628	yes	644	D	-	yes
C#23	7	1156	165	<1960	Residential	378	-	41	D	-	yes
#136	7	20032	2862	<1960	Residential	6195	yes	1402	D	-	yes
#178	8	16952	2119	<1960	Residential	5040	-	2119	B	-	yes
#177	8	5378	672	<1960	Office	1728	-	336	C	-	yes
#116	7	17674	2525	<1960	Residential	5418	-	1262	D	-	-
#135	7	18085	2584	<1960	Residential	5544	-	388	D	-	-

CODE	Nº of plants	Total Area of building (m²)	Floor area (m²)	Age of the building	Use of building	Total area of the facade (m²)	Any refurbishment measure applied?	Estimated useful space of roof	Protection grade	Central heating	Cooling system
#140	8	19301	2413	<1960	Residential	7392	-	2413	D	yes	-
C#24	7	18890	2699	>2006	Residential	5964	-	945	D	-	yes
#179	8	13543	1693	<1960	Residential	4248	-	677	D	-	yes
#211	8	2984	373	<1960	Office	912	yes	373	C	yes	-
#210	8	2293	287	<1960	Office	648	yes	143	-	yes	-
#209	8	2895	362	<1960	Office	1080	yes	0	-	yes	-
#149	8	31698	3962	<1960	Residential	9840	-	3962	D	yes	yes
#148	8	29849	3731	<1960	Residential	9048	-	3731	D	yes	yes
#152	6	22551	3758	<1960	Residential	7020	yes	0	D	-	yes
#151	6	22178	3696	<1960	Residential	7002	yes	0	D	yes	yes
#147	8	32724	4091	<1960	Residential	10200	-	2045	D	-	yes
C#26 [2]	6	24785	4131	<1960	Residential	7650	-	2065	D	-	yes
C#31	8	24313	3039	<1960	Residential	7320	-	760	C	-	yes
#175	8	6865	858	<1960	Office	2496	yes	429	D	-	yes
#97	6	24025	4004	<1960	Residential	7164	-	2002	D	yes	-
#146	8	31666	3958	<1960	Residential	9840	-	792	D	-	yes
C#13	7	28159	4023	<1960	Residential	5880	-	1408	D	-	-
#217	6	21010	3502	<1960	Residential	6300	yes	2801	D	-	yes
#218	6	2338	390	<1960	Residential	954	-	0	C	-	-
#176	8	13645	1706	<1960	Residential	4608	-	0	D	yes	yes
C#2	8	10306	1288	<1960	Office	4272	-	0	D	yes	yes
#163	7	30530	4361	<1960	Residential	8820	-	2181	D	yes	yes
#162	7	25998	3714	<1960	Residential	8358	yes	1857	D	yes	-
#161	7	26353	3765	<1960	Residential	8211	yes	3765	D	yes	yes
#160	7	22167	3167	<1960	Residential	6825	yes	3167	D	-	-
#119	5	10440	2088	<1960	Office	2865	-	2088	C	-	yes
#108	4	6642	1661	<1960	Office	2052	-	415	C	-	yes
#109	4	6906	1727	<1960	Office	2220	-	432	C	-	yes
#154	7	10611	1516	<1960	Office	3360	yes	758	D	-	-
#98	6	25196	4199	<1960	Office	6030	-	630	D	-	-
C#17/#117	3	12600	4200	<1960	Other	3240	-	1050	C	-	yes
#127	8	4790	599	<1960	Other	2280	-	599	-	-	-
#128	13	4505	347	<1960	Other	3510	-	347	-	-	-
#129	1	118	118	<1960	Other	75	-	118	-	-	-
#126	1	120	120	<1960	Other	75	-	120	-	-	-
C#10	1	2750	2750	<1960	Other	810	-	1375	A	-	-
#166	6	20667	3444	<1960	Other	5580	-	3444	B	-	yes
#165	5	11212	2242	<1960	Other	3000	-	336	B	-	-
#174	4	11307	2827	<1960	Other	2664	-	1413	-	-	yes
#105	6	4125	687	<1960	Other	1980	-	206	C	-	-

TXOMIN ENEA

Table 75. Main characteristics of the residential and office buildings of the district of Txomin Enea.

CODE	Nº of plants	Total Area of building (m^2)	Floor area (m^2)	Age of the building	Use of building	Characteristic	Total area of the facade (m^2)
1	3	2676	892	1967	Residential	Existing	1108
2	7	3514	502	1968	Residential	Existing	1891
3	3	2592	864	1967	Residential	Existing	1135
4	4	2180	545	1968	Residential	Existing	901
5	3	2232	744	New	Other	New	1536
6	10	11688	1461	New	Residential	New	7651
7	7	10474	1930	New	Residential	New	5890
8	7	4725	675	New	Residential	New	2542
9	10	2790	279	New	Residential	New	2011
10	10	3960	396	New	Office	New	2401
11	5	800	160	1980	Residential	Existing	751
12	5	800	160	1980	Residential	Existing	751
13	7	13365	2459	New	Residential	New	7301
14	2	0	0	New	Other	To be replaced	-
15	3	0	0	New	Sport	To be replaced	-
16	-	-	-	New	Other	To be replaced	-
17	-	-	-	New	Other	To be replaced	-
18	3	1659	553	1978	Residential	Existing	991
19	3	1338	446	1976	Residential	Existing	811
20	7	13377	2531	New	Residential	New	8966
21	7	1980	396	New	Residential	New	1681
22	10	4680	468	New	Residential	To be replaced	2641
23	5	3068	614	New	Residential	New	2506
24	5	2678	536	New	Residential	New	2146
25	7	18827	3510	New	Residential	New	8317
26	5	2760	552	New	Other	New	1411
27	7	4704	672	New	Residential	New	2962
28	7	6440	1288	New	Residential	New	2290
29	7	6974	1338	New	Residential	New	4243
30	3	1260	420	New	Other	New	847
31	2	517	258	New	Other	To be replaced	388
32	7	4452	636	New	Residential	To be replaced	2752
33	7	2027	405	New	Residential	New	2362
34	7	6944	1332	New	Residential	New	4264
35	5	21473	614	New	Residential	New	2506
36	5	19278	536	New	Residential	New	2146

ANTIGUO

Table 76. Main characteristics of residential and office buildings of the district of Antiguo.

CODE	Nº of plants	Total Area of building (m^2)	Floor area (m^2)	Age of the building	Use of building	Total area of the facade (m^2)	Any refurbishment measure applied?	Estimated useful space of roof	Protection grade	Central heating	Cooling system
1	3	651	217	1995	Residential	567	-	0	-	-	-
2	3	573	191	1995	Residential	540	-	0	-	-	-
3	4	1248	312	1995	Residential	972	-	156	-	-	-
4	4	1200	300	1995	Residential	1080	-	0	-	-	-
5	4	1248	312	1995	Residential	972	-	0	-	-	-
6	4	1200	300	1995	Residential	1080	-	0	-	-	-
7	4	612	153	1998	Residential	636	-	77	-	-	-
8	3	630	210	1995	Residential	540	-	0	-	-	-
9	4	580	145	1995	Residential	660	-	73	-	-	-
10	4	840	210	1996	Residential	756	-	105	-	-	-
11	3	951	317	1994	Residential	756	-	159	-	-	-
12	4	1456	364	1994	Residential	1080	-	182	-	-	-
13	3	600	200	1995	Residential	540	-	0	-	-	-
14	3	612	204	1994	Residential	558	-	102	-	-	-
15	4	1088	272	1994	Other	840	-	136	-	-	yes
16	3	750	250	1925	Residential	567	-	125	D	-	-
17	3	2646	882	1946	Residential	1926	-	441	D	-	-
18	3	576	192	1994	Residential	558	-	96	-	-	-
19	3	648	216	1994	Residential	576	-	108	-	-	-
20	3	1251	417	1994	Residential	846	-	209	-	-	-
21	3	1068	356	1994	Residential	810	-	178	-	-	-
22	3	600	200	1994	Residential	549	-	100	-	-	-
23	3	624	208	1994	Residential	576	-	104	-	-	-
24	3	597	199	1948	Residential	522	-	100	D	-	-
25	3	456	152	1918	Residential	486	-	76	D	-	-
26	2	108	54	1950	Other	180	-	0	-	-	-
27	3	657	219	1985	Residential	522	-	0	-	-	-
28	3	1035	345	1926	Residential	702	-	173	D	-	-
29	4	580	145	1981	Residential	612	-	0	-	-	-
30	3	408	136	1977	Residential	439	-	0	D	-	-
31	2	164	82	1926	Residential	222	-	41	-	-	-
32	4	1168	292	2009	Residential	852	-	146	-	-	-
33	4	1064	266	1993	Residential	852	-	133	-	-	-
34	3	795	265	1947	Residential	594	-	133	D	-	-
35	4	1308	327	1995	Residential	1164	-	164	-	-	-
36	3	729	243	1934	Residential	612	-	243	-	-	-
37	4	636	159	1940	Residential	636	-	80	D	-	-
38	4	824	206	1994	Other	696	-	103	-	-	-

CODE	Nº of plants	Total Area of building (m^2)	Floor area (m^2)	Age of the building	Use of building	Total area of the facade (m^2)	Any refurbishment measure applied?	Estimated useful space of roof	Protection grade	Central heating	Cooling system
39	4	680	170	1932	Residential	636	-	0	D	-	-
40	2	380	190	1940	Residential	336	-	95	D	-	-
41	3	537	179	1905	Residential	504	-	90	D	-	-
42	2	314	157	1987	Residential	306	-	79	-	-	-
43	2	460	230	2004	Residential	390	-	115	-	-	-
44	3	615	205	1977	Residential	513	-	103	-	-	-
45	2	450	225	1974	Residential	360	-	113	-	-	-
46	4	1464	366	1948	Residential	960	-	183	D	-	-
47	3	1761	587	1928	Other	990	-	294	D	-	-
48	3	744	248	1960	Office	567	-	124	-	-	-
49	2	450	225	2011	Residential	360	-	225	-	-	-
50	5	785	157	1900	Residential	795	-	94	D	-	-
51	2	186	93	1900	Residential	240	-	47	-	-	-
52	3	558	186	1970	Residential	495	-	93	-	-	-
53	3	504	168	1951	Residential	486	-	84	D	-	-
54	3	1134	378	1918	Residential	855	-	189	D	-	-
55	3	603	201	2003	Residential	522	-	101	-	-	-
56	2	308	154	1900	Residential	306	-	77	D	-	-
57	3	441	147	1970	Residential	450	-	74	-	-	-
58	4	684	171	2003	Residential	660	-	86	-	-	-
59	3	477	159	1931	Residential	513	-	80	D	-	-
60	3	648	216	1930	Residential	549	-	108	D	-	-
61	3	969	323	1929	Residential	684	-	162	D	-	-
62	3	582	194	1920	Residential	513	-	97	D	-	-
63	3	696	232	1926	Residential	630	-	116	D	-	-
64	3	600	200	1946	Residential	513	-	200	D	-	-
65	3	687	229	1902	Residential	567	-	229	D	-	-
66	3	822	274	1948	Residential	639	-	274	D	-	-
67	3	579	193	1948	Residential	522	-	97	D	-	-
68	2	436	218	1950	Residential	366	-	0	-	-	-
69	4	1144	286	1965	Residential	996	-	286	-	-	-
70	7	28210	4030	1994	Residential	11256	-	3763	-	-	yes
71	8	6840	855	1994	Other	3216	-	428	-	-	yes
72	5	2375	475	1994	Office	1590	-	0	-	-	yes
73	6	6306	1051	1971	Other	3204	-	1051	-	-	-
74	8	4048	506	1930	Residential	2112	yes	0	-	-	-
75	8	3808	476	1931	Residential	2088	yes	476	-	-	-
76	8	2416	302	1970	Residential	1680	-	0	-	-	-
77	7	2205	315	1920	Residential	1470	-	0	D	-	-
78	7	2170	310	1945	Residential	1491	-	0	-	-	-

CODE	Nº of plants	Total Area of building (m²)	Floor area (m²)	Age of the building	Use of building	Total area of the facade (m²)	Any refurbishment measure applied?	Estimated useful space of roof	Protection grade	Central heating	Cooling system
79	7	1974	282	1900	Residential	1407	-	141	D	-	-
80	10	3860	386	1965	Residential	2430	yes	0	-	yes	-
81	4	864	216	1960	Residential	732	-	0	-	-	-
82	8	4408	551	2004	Residential	2304	-	0	-	-	-
83	8	6640	830	1967	Residential	2736	-	415	-	-	-
84	6	1956	326	1920	Residential	1386	-	0	D	-	-
85	7	2492	356	1900	Residential	1575	-	0	D	-	-
86	7	2436	348	1900	Residential	1680	-	174	-	-	-
87	4	1068	267		Residential	876	-	0	-	-	-
88	7	1547	221	1989	Residential	1386	-	0	-	-	-
89	7	2107	301	1997	Residential	1554	-	0	-	-	-
90	7	819	117	1978	Residential	1050	-	0	-	-	-
91	3	3084	1028	1900	Other	1719	-	565	-	-	-
92	8	2880	360	1964	Residential	2424	-	360	-	-	-
93	8	2560	320	1963	Residential	1944	-	320	-	-	-
94	6	2046	341	1962	Residential	1530	yes	341	-	-	-
95	7	1400	200	1965	Residential	1218	-	200	-	yes	-
96	7	1841	263	1965	Residential	1428	-	0	-	-	-
97	8	2112	264	1965	Residential	1680	-	264	-	-	-
98	7	2380	340	1950	Residential	1512	-	170	-	-	-
99	8	4192	524	1953	Residential	2256	-	0	-	-	-
100	7	2618	374	1960	Residential	1617	-	0	-	-	-
101	7	1519	217	1956	Residential	1302	-	109	-	-	-
102	8	3448	431	1960	Residential	1992	-	216	-	-	-
103	5	775	155	1900	Residential	765	-	78	-	-	-
104	7	1015	145	1910	Residential	1008	yes	0	D	-	-
105	5	695	139	1900	Residential	705	-	70	D	-	-
106	8	1232	154	1910	Residential	1200	-	0	D	-	-
107	7	1071	153	1900	Residential	1050	-	77	D	-	-
108	6	1338	223	1915	Residential	1098	-	178	-	-	-
109	6	1260	210	1900	Residential	1044	-	0	-	-	-
110	8	992	124	1970	Residential	1248	-	124	-	-	-
111	7	2044	292	1961	Other	1638	-	292	-	-	yes
112	7	4683	669	1951	Residential	2226	-	335	-	-	yes
113	8	3744	468	1976	Residential	2328	-	0	-	-	-
114	7	3479	497	1951	Residential	1953	-	497	-	-	-
115	6	2658	443	1973	Office	1512	-	288	-	-	-
116	8	3232	404	1969	Residential	1920	-	0	-	-	yes
117	8	4056	507	1969	Residential	2232	-	254	-	yes	yes
118	4	572	143	1915	Residential	612	-	43	D	-	-

CODE	Nº of plants	Total Area of building (m^2)	Floor area (m^2)	Age of the building	Use of building	Total area of the facade (m^2)	Any refurbishment measure applied?	Estimated useful space of roof	Protection grade	Central heating	Cooling system
119	4	628	157	1915	Residential	636	-	141	D	-	-
120	4	712	178	1900	Residential	636	-	89	D	-	-
121	6	1308	218	1900	Residential	1062	yes	109	D	-	-
122	7	1771	253	1900	Residential	1344	-	127	D	-	-
123	6	1722	287	1900	Residential	1242	-	287	D	-	-
124	9	3519	391	1958	Residential	2268	-	313	-	-	-
125	7	1204	172	1930	Residential	1092	-	0	-	-	-
126	7	1274	182	1922	Residential	1134	-	0	-	-	yes
127	7	4543	649	1976	Residential	2394	-	325	-	-	-
128	7	9303	1329	2003	Other	3507	-	0	-	-	yes
129	5	3675	735	2002	Residential	1635	-	478	-	-	-
130	4	716	179	1900	Residential	636	yes	90	-	-	-
131	7	1225	175	1942	Residential	1092	yes	0	-	-	-
132	6	16440	2740	1994	Other	4158	-	2740	-	-	-
133	6	16578	2763	1944	Other	5130	-	2763	-	-	-
134	5	13880	2776	1989	Other	3435	yes	2776	-	-	-
135	8	34248	4281	1999	Residential	11952	-	2141	-	-	-
136	7	11263	1609	1999	Residential	4536	-	805	-	-	-
137	7	30450	4350	1996	Residential	10416	-	2175	-	-	-
138	7	11599	1657	1992	Other	4557	-	1657	-	-	-
139	7	4522	646	1997	Residential	2226	-	323	-	-	-
140	6	1644	274	1997	Office	1188	-	0	-	-	-
141	7	4445	635	1997	Residential	2184	-	318	-	-	-
142	7	10227	1461	1997	Residential	4137	-	731	-	-	yes
143	6	1416	236	1997	Office	1152	-	0	-	-	-
144	7	10472	1496	1997	Residential	4200	-	748	-	-	-
145	7	4522	646	1997	Residential	2226	-	323	-	-	-
146	6	1644	274	1997	Office	1188	-	0	-	-	yes
147	7	4445	635	1997	Residential	2184	-	318	-	-	-
148	7	10227	1461	1997	Residential	4137	-	731	-	-	-
149	6	1416	236	1997	Office	1152	-	0	-	-	yes
150	7	10472	1496	1997	Residential	4200	-	748	-	-	yes
151	7	4522	646	1996	Residential	2226	-	323	-	-	-
152	6	1644	274	1996	Office	1188	-	0	-	-	yes
153	7	4445	635	1996	Residential	2184	-	318	-	-	-
154	7	10227	1461	1996	Residential	4137	-	731	-	-	-
155	6	1416	236	1996	Office	1152	-	0	-	-	-
156	7	10472	1496	1996	Residential	4200	-	748	-	-	-
157	7	11704	1672	1996	Residential	4473	-	836	-	-	-
158	6	1530	255	1996	Office	1188	yes	0	-	-	yes

CODE	Nº of plants	Total Area of building (m^2)	Floor area (m^2)	Age of the building	Use of building	Total area of the facade (m^2)	Any refurbishment measure applied?	Estimated useful space of roof	Protection grade	Central heating	Cooling system
159	7	11361	1623	1996	Residential	4515	-	812	-	-	-
160	6	1308	218	1996	Office	1098	yes	0	-	-	-
161	7	27447	3921	1998	Office	9618	-	1961	-	-	-
162	3	8289	2763		Other	1890	-	2763	-	-	-
163	7	27447	3921	1998	Residential	9618	-	1961	-	-	-
164	7	27447	3921	1998	Residential	9618	-	1961	-	-	-
165	5	4615	923	1997	Office	1830	-	923	-	-	yes
166	3	3549	1183	1997	Office	1242	-	1183	-	-	yes
167	4	10064	2516	2004	Other	3480	-	2516	-	-	-
167A	2	1116	558	2004	Other	600	-	558	-	-	-
168	7	21091	3013	2000	Residential	7560	-	0	-	yes	yes
170	9	25515	2835	2015	Residential	6615	-		-	-	-
171	7	4270	610	1994	Residential	2205	-	305	-	-	-
172	6	5532	922	1989	Residential	2196	yes	922	-	-	-
173	5	5700	1140		Residential	2550	-	1140	-	yes	yes
174	6	5826	971	2006	Office	2232	-	0	-	-	yes
175	8	6992	874	1983	Residential	3168	-	874	-	-	-
176	1	502	502	1980	Office	270	-		-	-	-
177	7	6013	859	1980	Residential	2751	-	859	-	-	-
178	5	4460	892	1989	Residential	1995	yes	892	-	-	-
179	14	6048	432	1972	Residential	6804	-	1415	-	yes	-
180	5	4380	876	1980	Residential	1980	-	876	-	-	-
181	5	4460	892	1978	Residential	2010	-	892	-	-	-
182	2	1280	640		Office	600	-	0	-	-	-
183	5	4000	800	1981	Residential	1875	yes	800	-	-	-
184	14	5796	414	1973	Residential	3444	-	0	-	-	-
185	4	1920	480	1974	Office	1092	-	480	-	-	-
186	1	365	365	1974	Office	234	-	365	-	-	yes
187	1	790	790	1974	Office	420	yes		-	-	yes
188	8	5632	704	1974	Residential	2928	-	704	-	-	-
189	14	5992	428	1973	Residential	3528	-	0	-	-	-
190	8	6208	776	1974	Residential	3024	-	776	-	-	-
191	14	7714	551	1978	Residential	4620	-	551	-	-	-
192	7	7077	1011	2002	Residential	3276	-	506	-	-	yes
193	7	5950	850	2002	Residential	2835	-	425	-	-	-

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