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DESIGN OF A METHODOLOGY, BASED ON INDICATORS ANALYSIS, TO OBTAIN A STRATEGY MAP FOR CARBON-NEUTRAL DISTRICTS PROJECTS.

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Preface

The current research study has been conducted for a master thesis in the Department of Energy Engineering at the Politechnical University of Valencia (UPV). It is based on a collaboration with the Cátedra de Transicción Energética Urbana (Catenerg) belonging to the Spanish research institute Instituto de Ingeniería Energética (IIE). The aim of the project is to investigate how to characterize the energy transition at the neighborhood scale, which is necessary to reach carbon neutrality at this scale. This thesis considers the case study of Valencia, Spain, and especially the neighborhood of El Cabañal.

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Abstract

In the wake of the Paris agreements signed in 2015, multiple initiatives are aiming at decreasing greenhouse gases emissions to meet net zero emissions by 2050 and hope to contain global warming below the target of +1.5°C. The United Nations adopted the 2030 Agenda for Sustainable development composed of of 17 Sustainable Development Goals (SDG) to promote prosperity while protecting the planet. The decarbonization of cities' districts is crucial for reaching those goals. Climate emergency and energy transition must be tackled by cities. Although they contribute to only 3% of global land occupation, more than two-thirds of the total population will live in an urban area by 2050. Besides, cities are responsible for more than 70% of greenhouse gas emissions. Nevertheless, achieving carbon neutrality in cities is highly complex. Projects must overcome four main challenges: improving the quality of life of its inhabitants, improving resource efficiency, building a green economy, and involving citizens and local governance. The city of Valencia in Spain is aiming at climate neutrality and is planning to transform three districts into carbon-neutral districts by 2030 to achieve this goal. This project is still at an embryonic stage and the main challenge of city stakeholders is to execute measures that have a positive impact on the environment, society, and economy. The neighborhood of Cabañal is one of the oldest neighborhoods in Valencia and has a high potential for energy savings and carbon neutrality. Additionally to a carbon-neutrality road map for the project, there is a strong need to provide the city council with a toolkit to assess its impact and compare it with defined targets to optimize time and investments. The review of the existing literature highlights the lack of indicators toolkit to follow-up a carbon-neutral district project.

The purpose of the present project is to provide to the city council of Valencia a set of indicators to assess carbon-neutral districts projects and accelerate the development of these projects. To answer this research question, the thesis is divided into 4 main aims: 1. Understand the main energy and environmental challenges of a carbon-neutral district, 2. Review of the literature on carbon-neutral district projects in Europe associated with the proposed indicators for such actions. 3. Develop a tool for selecting performance indicators, including key performance indicators, for carbon-neutral districts, useful for city energy transition projects. 4. Apply the results to the case study: Carbon neutral El Cabañal and develop a list of both indicators and targets for this project.

Firstly, a deep review of European projects is carried out on the understanding the stakes and challenges of carbon-neutral districts as intended by the EU's program "100 Carbon Neutral Cities by 2030". This part constitutes the project's foundation as it allows to obtain a list of objectives necessary for a carbon-neutral district. Based on this list, a literature survey was performed to analyze the existing toolkits to assess carbon neutrality and energy transition and identify the research gap. The most relevant methodologies were then aggregated, and each indicator is classified by purpose, type, scope, and category. A multicriteria decision-making procedure was applied to rank each indicator and obtain a tool to determine the more fitting list for a given project. In parallel, the objectives to achieve energy transition for a carbon-neutral project could be identified using an adapted Balanced Scorecard methodology divided into 4 axes: City's starting knowledge and background, city's processes and resources, city citizens, and greenhouse gas emissions. This general methodology was then applied to a theoretical scenario to reach carbon neutrality in El Cabañal by 2030. The outcome of this project is a strategy map, and all the related indicators, including the Key Performance ones, to support the city council in the transformation of El Cabañal into a carbon-neutral neighborhood.

Resumen

A raíz de los acuerdos de París firmados en 2015, son múltiples las iniciativas que pretenden reducir las emisiones de gases de efecto invernadero para alcanzar la neutralidad de carbono en 2050 y esperan contener el calentamiento global por debajo del objetivo de +1,5 °C. Las Naciones Unidas adoptaron la Agenda 2030 para el Desarrollo Sostenible, compuesta por 17 Objetivos de Desarrollo Sostenible (ODS) para promover la prosperidad y proteger el planeta. La descarbonización de los barrios de las ciudades es crucial para la consecución de esos objetivos. La emergencia climática y la transición energética deben ser abordadas por las ciudades. Aunque solo contribuyen al 3% de la ocupación global del suelo, más de dos tercios de la población total vivirán en una zona urbana en 2050. Además, las ciudades son responsables de más del 70% de las emisiones de gases de efecto invernadero. Lograr la neutralidad de carbono en las ciudades es muy complejo. Los proyectos deben superar cuatro retos principales: mejorar la calidad de vida de sus habitantes, mejorar la eficiencia de los recursos, construir una economía verde e implicar a los ciudadanos y a la gobernanza local. La ciudad de Valencia, en España, aspira a la neutralidad climática y, para ello, tiene previsto transformar tres distritos en distritos neutros en carbono de aquí a 2030. Este proyecto está aún en fase embrionaria y el principal reto de los agentes de la ciudad es ejecutar medidas que tengan un impacto positivo en el medio ambiente, la sociedad y la economía. El barrio del Cabañal es uno de los más antiguos de Valencia y tiene un alto potencial de ahorro energético y de neutralidad de carbono. Además, para conseguir una hoja de ruta hacia la neutralidad en carbono, es muy necesario proporcionar al ayuntamiento un conjunto de herramientas para evaluar su impacto y compararlo con los objetivos definidos para optimizar el tiempo y las inversiones. La revisión de la bibliografía existente pone de manifiesto la falta de un conjunto de herramientas de indicadores para el seguimiento de un proyecto de distrito neutro en carbono. El objetivo del presente proyecto es proporcionar al ayuntamiento de Valencia un conjunto de indicadores para evaluar los proyectos de distritos neutros en carbono y acelerar el desarrollo de estos proyectos. Para responder a esta pregunta de investigación, la tesis se divide en 4 objetivos principales: 1. Entender los principales retos energéticos y medioambientales de un distrito neutro en carbono, 2. 2. Revisar la literatura sobre los proyectos de distritos neutros en carbono en Europa junto con los indicadores propuestos para dichas acciones. 3. Desarrollar una herramienta para seleccionar los indicadores de rendimiento, incluidos los indicadores clave de rendimiento, para los distritos neutros en carbono, útiles para los proyectos de transición energética de las ciudades. 4. Aplicar los resultados al caso de estudio: El Cabañal neutro en carbono y desarrollar una lista de indicadores y objetivos para este proyecto.

En primer lugar, se lleva a cabo una profunda revisión de los proyectos europeos para comprender los retos y desafíos de los distritos neutros en carbono, tal y como pretende el programa de la UE "100 ciudades neutras en carbono para 2030". Esta parte constituye la base del proyecto, ya que permite obtener una lista de objetivos necesarios para un distrito neutro en carbono. A partir de esta lista, se realiza un estudio bibliográfico para analizar los conjuntos de herramientas existentes para evaluar la neutralidad del carbono y la transición energética e identificar las lagunas en la investigación. A continuación, se agregan las metodologías más relevantes y se clasifica cada indicador por objetivo, tipo, ámbito y categoría. Se aplica un procedimiento de toma de decisiones multicriterio para clasificar cada indicador y obtener una herramienta que permita elegir la lista más adecuada para un proyecto determinado. Paralelamente, los objetivos específicos para lograr la transición energética de un proyecto neutro en carbono pueden identificarse mediante una metodología adaptada de Balanced Score Card

dividida en 4 ejes: Conocimiento inicial y antecedentes de la ciudad, procesos y recursos de la ciudad, ciudadanos de la ciudad y emisiones de gases de efecto invernadero. Esta metodología general se aplica a continuación a un escenario teórico para alcanzar la neutralidad de carbono en El Cabañal en 2030. El resultado de este proyecto es un mapa estratégico y todos los indicadores relacionados, incluidos los de rendimiento clave, para apoyar al ayuntamiento en la transformación de El Cabañal en un barrio neutro en carbono.

Resum

Arran dels acords de París signats el 2015, són múltiples les iniciatives que pretenen reduir les emissions de gasos amb efecte d'hivernacle per assolir la neutralitat de carboni el 2050 i esperen contenir l'escalfament global per sota de l'objectiu de +1,5 °C. . Les Nacions Unides van adoptar l'Agenda 2030 per al Desenvolupament Sostenible, composta per 17 Objectius de Desenvolupament Sostenible (ODS) per promoure la prosperitat i protegir el planeta. La descarbonització dels barris de les ciutats és crucial per aconseguir aquests objectius. Les ciutats han d'abordar l'emergència climàtica i la transició energètica. Tot i que només contribueixen al 3% de l'ocupació global del sòl, més de dos terços de la població total viuran en una zona urbana el 2050. A més, les ciutats són responsables de més del 70% de les emissions de gasos amb efecte d'hivernacle. Assolir la neutralitat de carboni a les ciutats és molt complex. Els projectes han de superar quatre reptes principals: millorar la qualitat de vida dels seus habitants, millorar l'eficiència dels recursos, construir una economia verda i implicar els ciutadans i la governança local. La ciutat de València, a Espanya, aspira a la neutralitat climàtica i, per això, té previst transformar tres districtes en districtes neutres en carboni d'aquí al 2030. Aquest projecte encara està en fase embrionària i el principal repte dels agents de la ciutat és executar mesures que tinguin un impacte positiu al medi ambient, la societat i l'economia. El barri del Cabanyal és un dels més antics de València i té un potencial alt d'estalvi energètic i de neutralitat de carboni. A més, per aconseguir un full de ruta cap a la neutralitat en carboni, és molt necessari proporcionar a l'ajuntament un conjunt d'eines per avaluar-ne l'impacte i comparar-lo amb els objectius definits per optimitzar el temps i les inversions. La revisió de la bibliografia existent posa de manifest la manca dun conjunt deines dindicadors per al seguiment dun projecte de districte neutre en carboni.

L'objectiu del present projecte és proporcionar a l'ajuntament de València un conjunt d'indicadors per avaluar els projectes de districtes neutres en carboni i accelerar-ne el desenvolupament. Per respondre aquesta pregunta de recerca, la tesi es divideix en 4 objectius principals: 1. Entendre els principals reptes energètics i mediambientals d'un districte neutre en carboni, 2. 2. Revisar la literatura sobre els projectes de districtes neutres en carboni a Europa juntament amb els indicadors proposats per a aquestes accions. 3. Desenvolupar una eina per seleccionar els indicadors de rendiment, inclosos els indicadors clau de rendiment, per als districtes neutres en carboni, útils per als projectes de transició energètica de les ciutats. 4. Aplicar els resultats al cas destudi: El Cabanyal neutre en carboni i desenvolupar una llista dindicadors i objectius per a aquest projecte.

En primer lloc, es duu a terme una profunda revisió dels projectes europeus per comprendre els reptes i desafiaments dels districtes neutres en carboni, tal com pretén el programa de la UE "100 ciutats neutres en carboni per al 2030". Aquesta part constitueix la base del projecte, ja que permet obtenir una llista dobjectius necessaris per a un districte neutre en carboni. A partir d'aquesta llista, es fa un estudi bibliogràfic per analitzar els conjunts d'eines existents per avaluar la neutralitat del carboni i la transició energètica i identificar les llacunes a la recerca. A continuació, s'hi afegeixen les metodologies més rellevants i es classifica cada indicador per objectiu, tipus, àmbit i categoria. S'aplica un procediment de presa de decisions multicriteri per classificar cada indicador i obtenir una eina que permeti triar la llista més adequada per a un projecte determinat. Paral·lelament, els objectius específics per assolir la transició energètica d'un projecte neutre en carboni es poden identificar mitjançant una metodologia adaptada de Balanced Score Card dividida en 4 eixos: Coneixement inicial i antecedents de la ciutat, processos i recursos de la ciutat, ciutadans de la ciutat i emissions de gasos amb efecte d'hivernacle. Aquesta metodologia general s'aplica a continuació a un escenari teòric per assolir la neutralitat de

carboni al Cabanyal el 2030. El resultat d'aquest projecte és un mapa estratègic i tots els indicadors relacionats, inclosos els de rendiment clau, per donar suport a l'ajuntament en la transformació del Cabanyal a un barri neutre en carboni

Nomenclature

Acronym	**Definition**
GHG	Greenhouse gases
SDG	Sustainable Development Goals
BSC	Balanced Scorecard
EU	European Union
CND	Carbon Neutral District
PED	Positive Energy District
KPI	Key Performance Indicator
ICT	Information and Communication Technology
PV	Photovoltaic
SHW	Sanitary Hot Water
DH	District Heating
DC	District Cooling
AHP	Analytical Hierarchy Process
FA	Factor Analysis
RES	Renewable Energy Systems
BAU	Business as Usual

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I | Introduction

The current research study has been conducted for a master thesis in the Department of Energy Engineering at the Politechnical University of Valencia (UPV). The current project is based on a collaboration with the Cátedra de Transicción Energética Urbana (Catenerg) belonging to the Spanish research institute Instituto de Ingeniería Energética (IIE). Its aim is to investigate how to characterize the energy transition at the neighborhood scale, which is necessary to attain carbon neutrality at this scale. This thesis considers the case study of Valencia, Spain, and especially the neighborhood of El Cabañal.
The work includes :

- Carrying out a deep European projects review to understand the significant stakes and challenges of the energy transition for carbon-neutral districts.
- Conducting an exhaustive literature survey on existing assessment methodologies and indicators for urban energy transition projects.
- Developing a tool for choosing indicators and, in particular, the key performance indicators for the energy transition in carbon-neutral districts, valid for the case study.
- Applying the outcomes to the case study: Carbon Neutral El Cabañal and developing a list of indicators and targets for this project.

I.1 Background

In the wake of the last Conference of the Parties (COP26) in Glasgow in November 2021, countries are urged to step up their decarbonization goals and road maps to keep the global temperature rise as close as possible to 1.5C. This aim was mentioned in the Paris Agreement, signed in 2015 by 195 countries [1]. The energy transition is at the heart of the countries' and cities' strategies to decrease greenhouse gas emissions and meet the Paris agreement's targets [2]. Besides, the United Nations mentions the 2030 Agenda for Sustainable development composed of 17 Sustainable Development Goals (SDG) to promote prosperity while protecting the planet. The transformation of districts into carbon-neutral districts plays a crucial role in the achievement of those goals [3]. As highlighted in the proposed mission: "100 Climate-neutral Cities by 2030" conducted by the European Union, a carbon-neutral district can have a significant contribution to 8 SDGs and is essential to SDG 11 which aims at providing sustainable cities; and 13 which concerns climate actions [4]. Climate emergency and energy transition have to be tackled together by cities.
Although they contribute to only 3% of global land occupation [4], more than two-thirds of the global population is likely to live in an urban area by the end of 2050 [5]. Additionally, cities are contributing to almost two-thirds of global primary energy demand and are responsible for more than 70% of greenhouse gas emissions [3], [6]. To tackle the previous challenges, cities have to implement measures to adapt to climate change and mitigate its impact. Action plans and projects aiming at forecasting those measures and involving cities in energy transition and carbon neutrality are being adopted by cities worldwide. As an example, [7], [4] and [8] are describing the different projects taking place among European cities. All of those projects are committed to answering four main challenges [3]:

improving the quality of life of its inhabitants, improving resource efficiency, building a green economy, and involving citizens and local governance.In that context, the city of Valencia in Spain is aiming towards climate neutrality and is planning to transform three districts into carbon-neutral districts by 2030 to achieve this goal. This project is still at an embryonic stage, and the main challenge of city stakeholders is to execute deeds that positively impact the environment, society, and economy. The district of El Cabañal is one of the oldest districts in Valencia and has a huge potential for energy savings and to become carbon-neutral. Not only do city stakeholders need to develop a road map to achieve carbon-neutrality projects, but there is a gap of frameworks of indicators, as well as a monitoring system to collect the required data to assess its impact and be able to compare it with existing initiatives, [9] to optimize time and investments.

I.2 Purpose and objectives

This research work aims to carry out four main goals :

1. Understanding the main stakes of carbon neutrality in districts by reviewing various European projects,
2. Screening the existing literature and identify the methodologies available to assess energy transition and climate neutrality and how to apply them to a carbon-neutral district project,
3. Build a tool to obtain the most adapted indicators to monitor and assess the performance of a given project,
4. Apply this tool to the case study of carbon-neutral Cabañal in the city of Valencia (Spain) relying on an adapted balanced scorecard methodology.

I.3 Methodology and outline

First, a literature survey is conducted to overview carbon-neutral districts' major stakes and current knowledge about the assessment of carbon-neutral projects. Once the research gap was identified, a methodology was developed to evaluate the characteristics of a carbon-neutral project, based on an adapted balanced scorecard approach. In this part, all the different steps to provide the evaluation methodology are detailed. Finally, this assessment methodology was applied to the case study of El Cabañal in Valencia.
All the details concerning methodology and results are presented in this document, which follows the outline below:

- **Chapter 1: Introduction** presents the background of the study, as well as a short description of the purpose, the methodology followed, and the limitations of the work.
- **Chapter 2: State of the art** presents the literature screening conducted on the stakes of carbon-neutral districts and existing assessment methodologies. All the research works included in this survey are available in the reference part.
- **Chapter 3: General methodology to assess carbon-neutral districts projects** describes the steps followed to adapt the balanced scorecard methodology to carbon-neutral districts projects. Moreover, a method to choose indicators and define targets is proposed in this part.
- **Chapter 4: A case study of El Cabañal** presents the district considered for the case study and details specific data about the location and the population. It also describes the adaptation of the general methodology for the case study and the results, discussions, and limitations of the study.

- **Chapter 5: Conclusions** matches the objectives of the project with the work accomplished. An analysis of the strengths and weaknesses of the work is presented. In addition, the last section indicates what can be done in future work to continue with the research project.

II | State of the art

II.1 Understanding the stakes of carbon-neutral districts

As mentioned in the introduction, cities will play a meaningful role in the global ecological transition. Indeed, with only 3% of the global land occupation, they are a critical agent in climate change responsible for 72% of the total greenhouse emissions. Additionally, they have a considerable social and economic impact, likely to concentrate 85% of the population by 2050 and generating 80% of the economic growth. For more than ten years, the European Union and European cities have implemented ambitious strategies to limit the climate impact of cities. For example, 10 000 cities have signed the European Covenant of Mayors for Climate and Energy [10]. Each city must develop a Sustainable Energy and Climate Action Plan (SECAP) and hereby present a detailed action plan. This SECAP aims at mitigating the effects of climate change and adapt the city to climate change effects. As an example, the city of Valencia in Spain submitted its SECAP in 2019, intending to an overall greenhouse gases emissions reduction of 40% [10]. This document describes the different measures as well as the implementation timeline associated with it. In addition, initiatives to limit the impact of cities on the environment are developed locally over Europe. [11] presents seventeen initiatives of positive-energy districts over Europe, while [12] gives seven examples of zero-energy districts. As mentioned in [12], the concepts relying on energy transition are part of a broader concept of sustainable districts and cities. Indeed, to fulfill the targets of the Paris Agreement and follow the requirements of the European Green Deal [13], cities must become carbon-neutral by 2050. The European Union suggests a guideline to transform 100 cities into carbon-neutral cities by 2030 and use them as examples for climate neutrality. The guideline [4] presents seven main objectives to achieve this goal. Several of those objectives have already been implemented in various projects detailed in [12], and [11].

1. **Involve citizens :** The mission 100 [4] highlights the importance of providing citizens with an active role. Inclusiveness is necessary so that all residents can participate in the co-creation process. All the 29 projects towards sustainable urbanization and energy transition compiled in [11] focus on the objective of social sustainability and citizen involvement. To implement a carbon-neutral district project, one of the main steps is thus to build the stakeholder maps and define the management strategy using tools like, for instance, AA1000 Stakeholder Engagement Standard [14].In the city of Nantes in France [15], a powerful mobilization was necessary to link the 100 companies of the surroundings with the university and the facilities such as theatres and schools, in order to find an agreement on energy generation processes.

2. **Secure funding and financing :** This objective highlights the necessity of the involvement of both the public and private sector. There is already an European initiative to provide grants to finance those energy transition projects. Among them, the Urban Investment Support (URBIS) [16] is helping cities with their investments in carbon-neutrality and is guiding them to find the most adapted financing solution. The part of private participation can differ between each project. In the city of Lund in Sweden, the project of Northeast is financed at 90% with private funds [11] while the refurbishment of Voru in Estonia is covered only with public grants [11].

3. **Suport economic transition :** The transition towards a sustainable and circular economy is fundamental to achieving carbon neutrality. It consists of changing the way products are designed, produced, used, and recycled. Examples of this objective are implemented through the choice of buildings materials in Nantes in France, or Elverum in Norway, using only ecological materials for new buildings and buildings refurbishment.

4. **Promote innovation :** Information and communication technology (ICT)-based solutions can lead to saving up to 15% of total global emissions [17]. Thus, [4] highlights the need to support innovation through the implementation of innovation hubs, for example.

5. **Improve energy efficiency :** This objective aims at zero emissions. As the building sector accounts for 40% of energy demand in the European Union according to the French climate council [18], actions to limit their impact on greenhouse gases emissions are required. In the existing projects, the refurbishment of buildings represents a massive part of the total investment reaching up to 30% in Bilbao, Spain.

6. **Provide renewable energy and increase the use of electricity :** Energy generation revolution is necessary to decarbonize Europe's energy supply fully. According to European studies [19] renewable sources should cover an average value of 80% of the total energy use to meet the green deal objectives. All the projects presented in [11] and [12] focus on increasing local energy production through renewable resources to generate electricity and for district heating and cooling.

7. **Decarbonize mobility :** One of the main challenges of cities is to decarbonize short-distance mobility. It can be achieved by developing carbon-free fuels, advertising public transport, developing walking and cycling paths, or promoting electric vehicles. In Eora, Portugal, promoting e-mobility is part of the decarbonization of the mobility sector.

To use the 100 chosen cities as examples to achieve carbon-neutrality in Europe, it is necessary to monitor the different projects to obtain a follow-up and assess their performance. Moreover, a communication of the results, achievements, and difficulties is required to provide feedback on the different projects and accelerate the path towards carbon-neutrality. To that extent, [12] underlines the lack of a common framework to evaluate sustainability. Indeed, as presented in [11] each project is using its own indicators set and framework. There is a strong need to provide cities with clear guidelines to assess their carbon-neutral projects and define the targets.

II.2 Assessing energy transition for carbon-neutrality at the district level

Most of the existing literature focuses on a specific aspect of the cities' transition assessment methodologies. Different studies funded by the European Union consist of reviewing different projects and proposing a methodology to implement an indicators index. The CITYkeys [3] study focuses on assessing smart city projects through the use of 99 indicators while the studies of SCIS [20], IRIS [21], SMARTENCITY [22], and CITYxCHANGE [22] are proposing lists of indicators with a focus on different categories and objectives to evaluate cities energy transition. The work of K. Angelakoglou and K. Kourtzanidis [22] goes more profound in this analysis for smart cities, proposing an optimized list of project-specific KPIs while S. Lien and K.Sørnes [7] analyze the best indicators to assess Norwegian low carbon cities.
Some articles focus on the data collection used to build those indicators.In that context, M. Fremouw and A. Bagaini [23] highlight the necessity of having reliable energy data to use energy transition decision-making tools and the issues to overcome to deal with the lack of data in the area. Besides, D. Maureea and E. Nabonib [5] propose a review of software to provide energy analysis that can be used to build indicators. Finally, through the case study of the city of Valencia in Spain, I. Munoz [6]

suggests a methodology to characterize energy profile in buildings and transports relying on the GIS model.
In addition to the data collection, several articles explain how to use those indicators at a city scale. In his work, M. Cohen presents a roadmap to apply the different sets of indicators to different categories and scales. Finally, both E. Palumbo [24] and S.Walker [25] are highlighting the need of building those indicators with a life cycle analysis scope, while A. Sharifi [21] points out to the lack of indicators assessing the resilience of cities towards climate change. Nevertheless, using a set of indicators is not the only method to assess urban energy transition. Indeed, the work of I. Munoz [6] draws up an inventory of 10 different techniques. Indeed, most existing papers target this indicator-based framework and analyze various existing projects to establish an optimized set of indicators. However, a vast majority of initiatives are meant to assess urban smartness or sustainability; among the different indicator sets analyzed in [26] only one over 70 targets energy transition, and less than a half of them mentions energy-related indicators. Hence, although energy transition is a massive challenge for cities, the subject is still being developed in the literature.

Table II.1 presents the most relevant methodologies analyzed in the state of the art that have a focus on energy transition at a city scale. It is important to note that the energy-specific indicators from smart and sustainable city assessment can also be used to assess energy transition. Table II.2 shows all the methodologies that includes a part linked to the energy transition.

Table II.1: Review of methodologies focused on energy transition

Name of the project	**Type**	**Description**	**Nb. of indicators**	**Source**
IRIS	General methodology	5 energy transition tracks : Smart renewable energy positive districts, Smart energy management, Smart e-mobility, City innovation platforms, Citizen engagement.	75	[22]
SMARTEnCITY	General methodology	Evaluate district renovation, urban mobility and citizen engagement.	149	[27]
CityxChange	General methodology	KPI framework divided into three themes : Integrated Planning and Design, Common Energy Market and public transportation.	33	[28]
Norwegian case study	Case study	Focus on low carbon cities. Description of the KPIs developed for the norwegian cases towards energy transition	11	[7]
SCIS	General methodology	Focus on the evaluation of 5 energy sectors : energy supply units and plants, buildings, e-mobility, ICT, renovation an retrofitting.	400	[20]
Fargo case study	Case study	Focus on energy evaluation towards environment, economic, social, governance, policy, water & environment, transportation	59	[29]
Saheb Y., Shnapp S., Paci D.	Case studies	Focus on the evaluation of 7 categories : energy, governance, social equity, economic efficiency, conservation and quality of life	25	[12]

Table II.2: Review of methodologies mentioning energy transition

Name of the project	**Focus**	**Description**	**Nb. of indicators energy**	**Source**
CityKEY	Smart City	Analyse of 3 main categories : People, Planet and Prosperity.	10	[3]
MATCHUP	Sustainable city	Three dimensions (environment, economy and social) and four field of activity (energy efficiency, mobility, ict and citizens). Special focus on energy indicators	26	[22]
Shen. Ochoa.	Sustainable city	Analyse of 4 dimensions : environmental, economic, social and governance	18	[29]

II.2.1 How to choose the right methodology ?

As recommended in [9], the indicator framework analyzed in this paper have been built using the same seven following steps.

1. Determine the purpose of the assessment and the final users,
2. Define the scope of the assessment,
3. Identify the elements assessed and the objectives,
4. Choose indicators,
5. Measure and collect data for the indicators,
6. Combine data and map indicators,
7. Analyse results and assess implications.

However, the various studies present slight differences in how to sort indicators and choose the relevant ones. A detailed investigation of those various methodologies has been conducted in the following part. Each methodology strives to create categories of indicators to facilitate understanding and sorting the different indicators. The groups described in the literature are :

- **Different typologies [3]:** Indicators are defined as input indicators (human, material, and financial resources), output indicators (give more information about the product of the project), outcome indicators (measure the results generated by outputs), and impact indicators (contrast the results with the city targets)[30].
- **Different sectors:** Indicators are sorted by their application sector. Most of the methodologies focus on the indicators affecting the trilemma of economics, society, and environment [26]. The identified sectors are dependent on the focus of the methodology. If a methodology aims at assessing the smartness of a city, ICT is the main category [3], [22] while if a methodology assesses sustainability, citizens' involvement is highlighted. Regarding urban energy transition, six categories have been identified by the IRIS project [21]: technical, environmental, economic, social, ICT, and legal.
- **Different projects or city objectives towards energy transition:** Some methodologies are using the targets of the projects as different categories. For example, in the Norwegian case [7] eight different categories are proposed: carbon emissions, energy consumption, energy generation, energy grid capacity, green mobility in the energy system, smart energy management, city environment and involvement. While [5] focuses on the urban area and separates the indicators into three main categories: urban built environment, urban thermal comfort, and energy systems.

Listing and considering those indicators can lead to a high number of indicators and complicate the final understanding. The different research papers use decision-making tools to rate the indicators to shorten this list and choose the most suitable indicators. The first step is to define grading criteria such as relevance, completeness, availability, measurability, or non-redundancy [3], [7], [22]. Those criteria are then ordered by importance for stakeholders [7], [9] and eventually indicators rating the most regarding those attributes are selected.
When choosing a suitable set of indicators for a given city or project, the main steps that have to be followed are detailed in [31]. The city of Fargo (USA) followed those steps to evaluate its energy transition policies [29]. The methodology should provide enough indicators to cover all the fields of energy transition but not too many to stay comprehensible by stakeholders. Moreover, a particular effort should be put into building indicators regarding the objectives set by the city. Thus, most of the indicators reviews highlight the need to involve the different stakeholders in the choice of the methodology.

II.2.2 How to obtain data to build the indicators ?

One of the main issues linked to indicator-based methodologies is collecting data to build them. The technical monitoring guide of EU Smart Cities information [20] differentiates three approaches to build indicators at a city scale :

- Bottom-up methodology: indicators are aggregated from building data. In that case, data come from sensors performing direct measurements in the buildings or theoretical models, as mentioned by [6] in work for the city of Valencia,
- Monitor at neighborhoods scale: Data come from direct measurement at district or city scale or databases of energy mapping tools as PLANHEAT [23] for example.
- Calculate by indirect means: Data come from a calculation. Examples of formulas and steps needed to calculate those indicators are detailed in the monitoring of EU Smart Cities [20], and in the IRIS project [28].

II.2.3 How to use indicators at a city level ?

To be the most effective, indicators have to be designed and adapted for the different groups of stakeholders described by the IRIS project [21]: distribution system operators (DSOs), consumers, technology and services providers, policy-making bodies and governance, citizens, representative citizen groups and citizen ambassadors. Those indicators can be used at six different ends: Instrumental use (used to take actions), Conceptual use (help user understand a problem), Tactical use (used as a delaying technique), Symbolic use (used as proof of stakeholders involvement), Political use (used to support a position of a user) [9]. One of the pieces of advice given by the analysis of [31] to use those indicators as a decision-making tool is to analyze them in a matrix-like structure. Examples of this methodology can be found in the performance and opportunity loss matrices used to assess the energy projects of 'Pricenhage' neighborhood located in the Netherlands [25]. Finally, the existing literature highlights the lack of indicators taking into account both the life cycle assessment [24] and the resilience [21] of energy systems.

II.3 Defining targets to reach carbon neutrality

As highlighted in [12], a combination of an indicator framework and targets for these indicators is necessary to evaluate sustainability. Among the energy transition assessment methodologies studied in the previous part and described in Table II.1, only the project SMARTenCITY set up targets for each indicator. The European research project for the development of positive energy district among Europe [32] highlights the fact that methodologies to define targets are projects dependant and proposes a general methodology to uniformize the targets definition. It also ease the follow-up of energy transition projects and the comparison between European districts. The analysis based on the review of 15 case studies results in an ideal target definition process for the energy transition of seven steps detailed in Figure II.1.

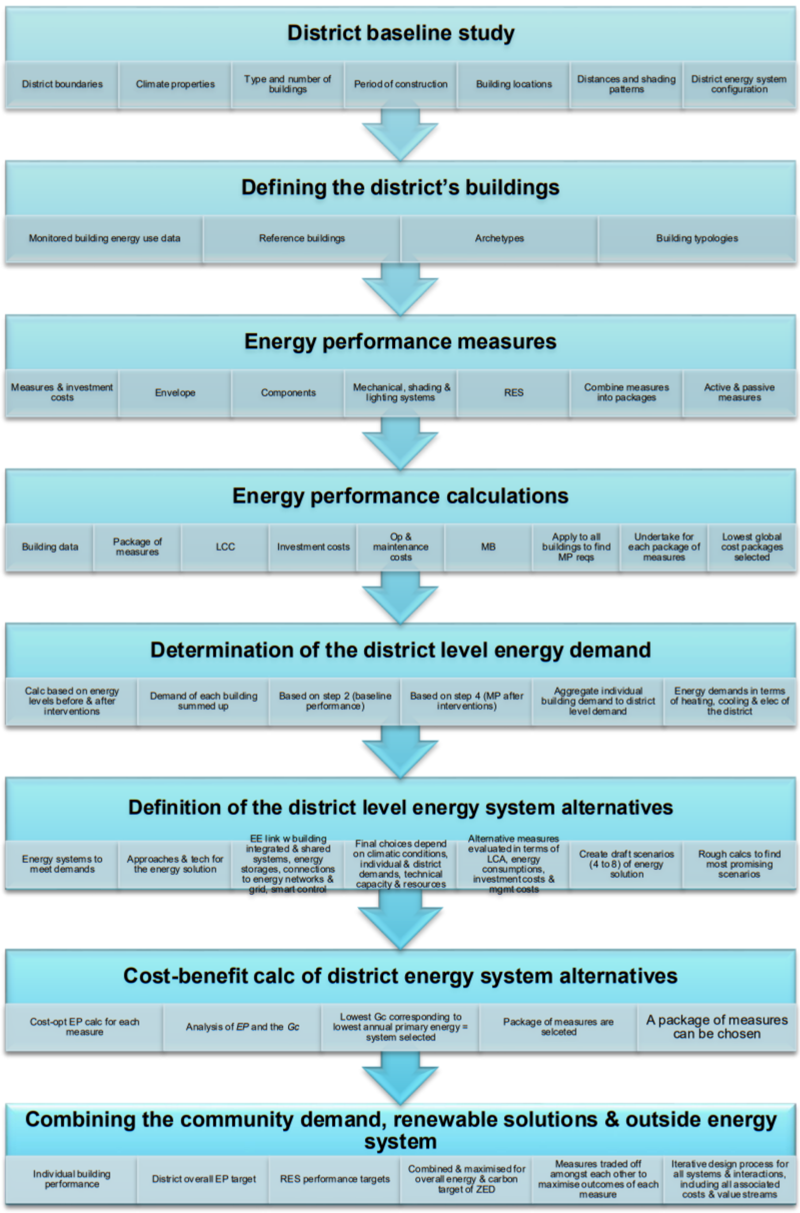


Figure II.1: Steps to develop a target for a carbon-neutral project [32]

Depending on the availability of data and monitoring systems, these steps can be adapted and divided into two different approaches. The first approach consists in defining a target at the building scale based on direct monitoring, if possible, or on a reference building. Data for reference buildings can be found in building codes.In Spain, this technical building code is the Código Técnico de la Edificación [33]. The target is then defined at a building level using simulation tools. The simulation tool used depends on the indicator considered. For example, simulation of energy generation can be performed with the software HOMER PRO [34] and simulation of energy savings can be obtained with the software ENERGY + [35]. In his work, D. Mauree [5] provides a list of simulation tool for different energy-related models. This list and the compatibility of each software is presented in Table II.3. The results of the simulation tools can then be optimized through a cost-optimized methodology detailed in [32] consisting of finding the optimal target in terms of minimal cost and minimal emissions for a carbon-neutral district. The targets at the building level are then aggregated for each building type in the district to obtain the target at the district level. The second approach consists of performing the same methodology directly at the district level. As mentioned in [32] this approach is possible only to build energy generation and energy efficiency targets.

Tool	Outdoor Thermal Comfort	urban environmental conditions	Energy demand	Renewable productions	Energy systems	Yearly simulation	Neighbourhood / City scale simulation
Microclimate							
ENVI-met	X	X					X
CIM		X				X	X
UWG		X				X	X
CAT		X					X
SOLWEIG	X	X				X	X
Comfort							
RayMan	X	X				X	
OTC Model	X					X	
UTCI calculator	X					X	
Energy demand							
Ladybug and Honeybee	X	X	X	X		X	X
CitySim	X	X	X	X	X	X	X
CESAR		X	X			X	X
EnergyPlus			X			X	
UMI			X			X	X
CEA			X	X	X	X	X
Urban Solve			X			X	X
Energy System							
Homer				X	X	X	X
Perera et al.,				X	X	X	X
Energy hub				X	X	X	X

Table II.3: Simulation tools for energy modelling [5]

The literature analysis concerning targets definition highlights a gap in the definition of the targets related to the transportation area, as well as non-technical targets. However, as highlighted in the first part of this state-of-the-art, energy transition to achieve carbon neutrality goes beyond technical consideration, involving economic, social, legal, and environmental dimensions.

II.4 Contribution to the existing literature

The first part of this literature survey highlights the complex and multidisciplinary aspects of carbon-neutral districts projects. Moreover, it sheds light on the lack of a common framework to evaluate sustainability at a district scale. The second part of this state-of-the-art analyzes the different existing methodologies to evaluate energy transition and underlines that only a tiny fraction of the indicators lists focus on urban energy transition evaluation. Moreover, taken individually, those methodologies do not allow to treat all the fields of this urban energy transition and carbon neutrality. Besides, most of the existing assessment frameworks are incomplete and do not propose targets for each indicator, which is necessary to follow-up each objective. This project aims at proposing a follow-up methodology for carbon-neutral districts projects relying on the identification of the most suitable indicators for a given project and the definition of adapted targets, while considering all the objectives of carbon-neutrality. The methodology presented in this report descibes the different criteria, hypothesis, and characteristics used to create this follow-up tool. Lastly, the methodology has been used in the case study of the neighborhood of El Cabañal in Valencia, as the city is aiming at transforming three districts into carbon-neutral districts by 2030.

III | General methodology proposed to assess a carbon-neutral district project

As highlighted in the literature review, a carbon-neutral district project is a complex and multi-dimensional subject. To assess these projects, it is necessary to provide indicators and KPIs covering every dimension and compare them with a defined target. The solution considered in this thesis is the adaptation of the Balanced Scorecard methodology. This part descibes the particularities of the methodology and how it has been adapted and improved to match with a carbon-neutral district project and to provide an assessment tool for local project managers.

III.1 The balanced scorecard methodology

The balanced scorecard is a performance analysis tool for companies developed by R. Kaplan and D. Norton (Harvard University). The additional value of this methodology presented in [36] is to not only take into account the financial outcome, but to have an overall view of the project or company's strategy. By applying the principles and practices of BSC, organizations are more likely to :

- Get their project done on time and within budget.
- Deliver a quality product or service that will satisfy clients and end users.
- Ensure that project team members will finish the project with improved capacities, sense of personal achievement and satisfaction.

Thus, the balanced scorecard is a table divided into four main axes :

- **Financial:** This part concerns the costs, the profitability, and the turnover of the project or the company;
- **Customer:** This part deals with customers satisfaction, information, and involvement;
- **Internal processes:** This part refers to the efficiency of the internal processes of the company or the project;
- **Organizational capacity:** This part underlines the need to improve tools and technology together with the knowledge and skills of the project team or the company.

Each category contains objectives that can be linked together in a strategy map to indicate how the final value of the company is created. Moreover, a key indicator performance informs the user of the state of each objective. This value is correlated with the target defined to determine the gap between the targeted performance and the current situation illustrated by the indicator.

III.2 The adapted balanced scorecard methodology

The balanced scorecard methodology described previously can be used to follow up a multidimensional and complex project as a carbon-neutral district project. To do that, it is necessary to adapt the axes, the objectives, the indicators, and the targets to the stakes of carbon neutrality. The analysis of the literature resulted in the identification of objectives and axes for the carbon-neutral district, presented in Figure III.1 and detailed in Table III.1. The methodology to identify the indicators is detailed in part 3.4. Finally part 3.5 and 3.6 present the methodology followed to identify the targets and thresholds corresponding to the indicators.

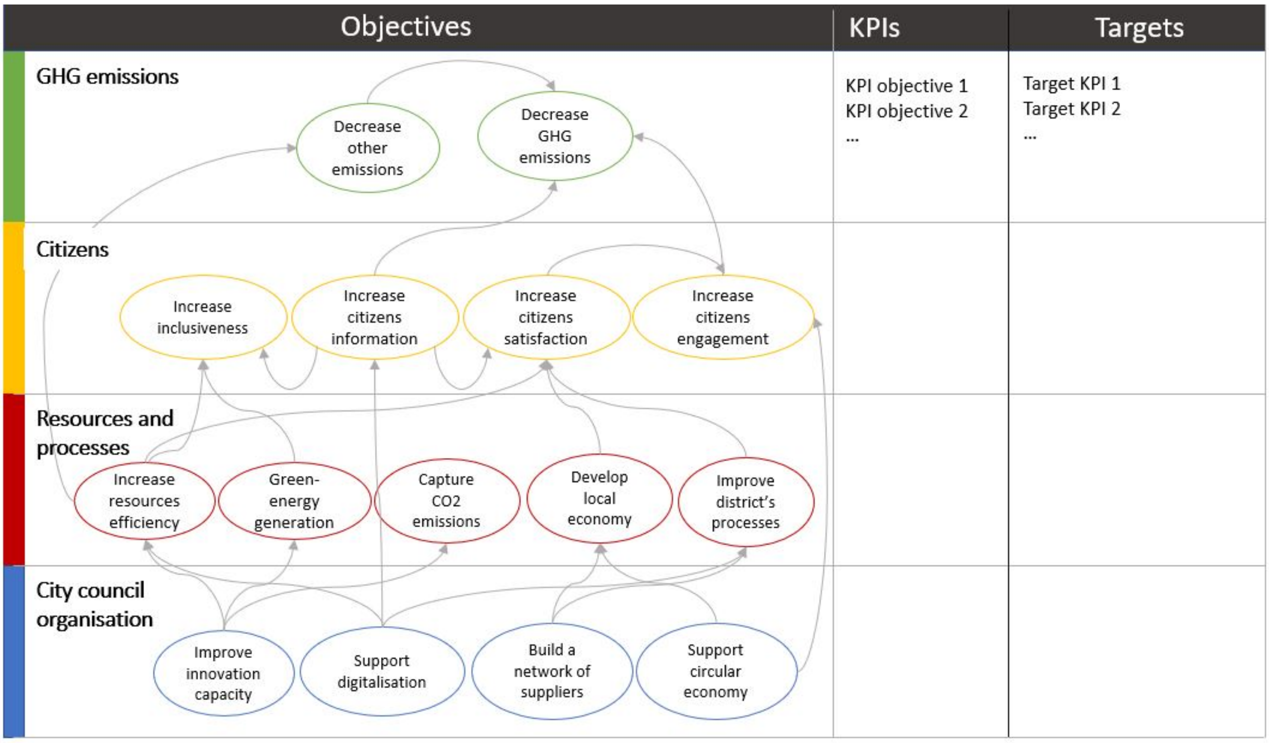


Figure III.1: Adapted balanced scorecard methodology

III.3 Adaptation of the objectives to carbon-neutral district project

To identify the main objectives for carbon-neutral districts and neighbourhood, a screen of the literature presented in the state-of-the-art has been performed. A detailed analysis of the following documents has been conducted :

- the guideline given by the mission 100 [4] aiming at transforming 100 cities into carbon-neutral areas by 2030,
- the objectives aiming at building a positive energy district highlighted in the European review [12],
- a benchmarking of the projects towards sustainable urbanization and the energy transition described in [37].

To simplify the understanding of the methodology, a graphical presentation of the steps followed is presented in Figure III.2.

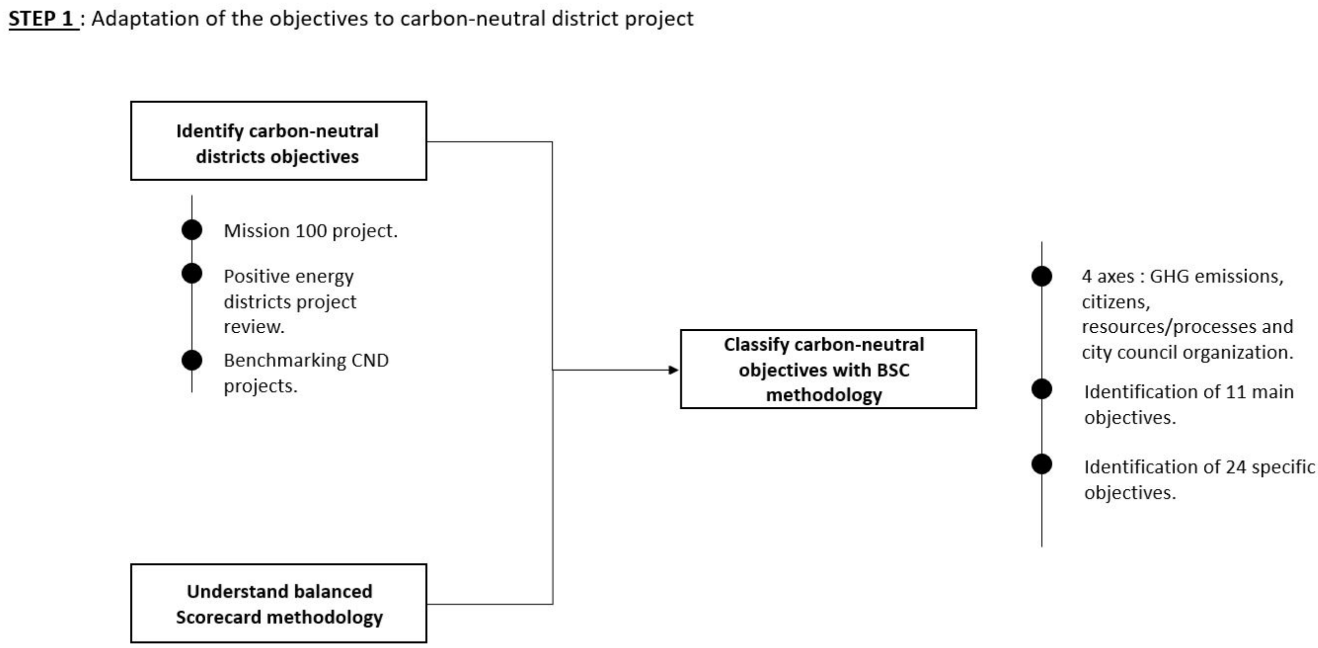


Figure III.2: Graphical methodology to identify the objectives to achieve the energy transition in a carbon-neutral district project

This analysis led to the identification of 4 categories and 40 objectives for a carbon-neutral district. The categories identified are presented in III.1. Only the first three categories: GHG emissions, citizens, and resources and processes have been included in the scope of this master thesis. Indeed, it has been considered that the city council organization is an internal subject and goes beyond the competencies and knowledge linked to the master's degree MUTEDS.
To simplify the use of the adapted balanced scorecard, those objectives have been classified into main objectives presented in III.1 and specific objectives corresponding to the main objectives detailed in Table III.1.

Table III.1: Main objectives and specific objectives identified for a carbon-neutral district

Main objectives	Number of specific objectives	Details of specific objectives
Decrease GHG emissions	3	Decarbonize energy generation Decarbonize buildings : residential, commercial and industrial sectors Decarbonize transportation
Decrease other pollution	1	Reduce other pollution
Increase citizens' engagement	1	Increase involvement towards energy transition
Increase citizens' information	1	Inform the citizens
Increase citizens' satisfaction	2	Develop advantages for citizens Increase citizens' satisfaction
Increase inclusiveness	3	Develop inclusive projets Favorize neighbourhood diversity Increase involvement of minorities
Increase resources efficiency	4	Increase efficiency in the buildings sector (residential, commercial and industrial) Increase efficiency in transportation Net zero waste Net zero water
Green energy generation	3	Develop renewable energy Increase energy storage Increase quality of supply
Capture GHG emissions	1	Increase green-areas
Optimize internal processes	3	Develop a legal framework for energy transition projects Increase quality of data and monitoring system Promote energy transition projects
Develop local economy	2	Decrease energy costs Develop new economic opportunities

III.4 Definition of the indicators for energy transition to achieve a carbon-neutral district project

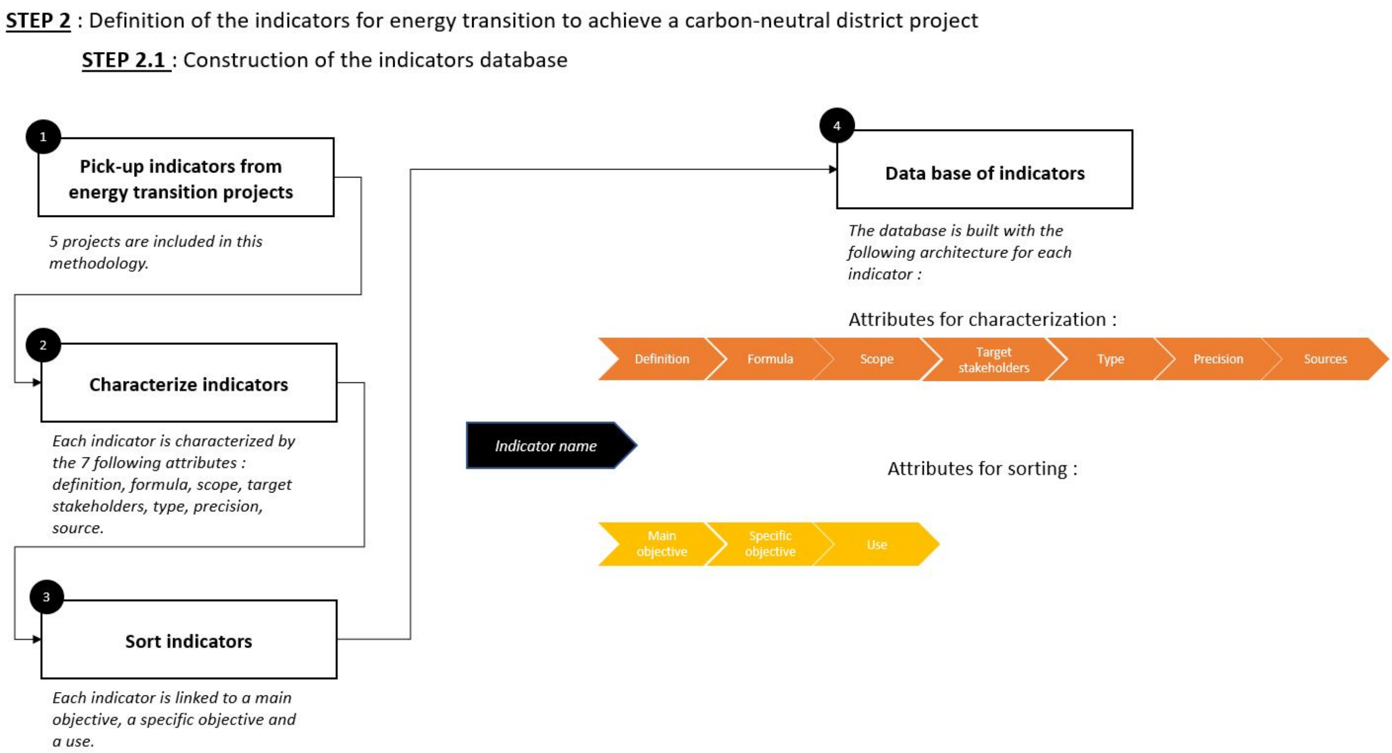
The following step to adapt the balanced scorecard methodology to a carbon-neutral district project is to build a list of indicators allowing the monitoring of each main objective and specific objectives. As highlighted in the literature survey, there is a lack of an efficient toolkit of indicators to assess a carbon-neutral district's project. This part presents the methodology followed to build up a tool to provide a list of indicators to evaluate a carbon-neutral project, depending on the project's or city's characteristics.
The methodology followed to build the tool is divided into three parts:

1. Construction of an indicator pool by identifying the relevant list of indicators to be aggregated and description of the characteristics of the indicators (targeted stakeholders, scope, accuracy...);

2. Definition of a sorting methodology for the different indicators relying on various categories, main objectives, and specific objectives;

3. Definition of a rating methodology to optimize the list depending on the project and stakeholders using criteria and scaling them in order to obtain a shortened but complete list of indicators easily usable to follow-up the energy transition for a carbon-neutrality project.

To simplify the understanding of the methodology, Figure III.3 presents a graphical explanation of the two main steps to identify the most suitable indicators detailed in the following paragraphs.



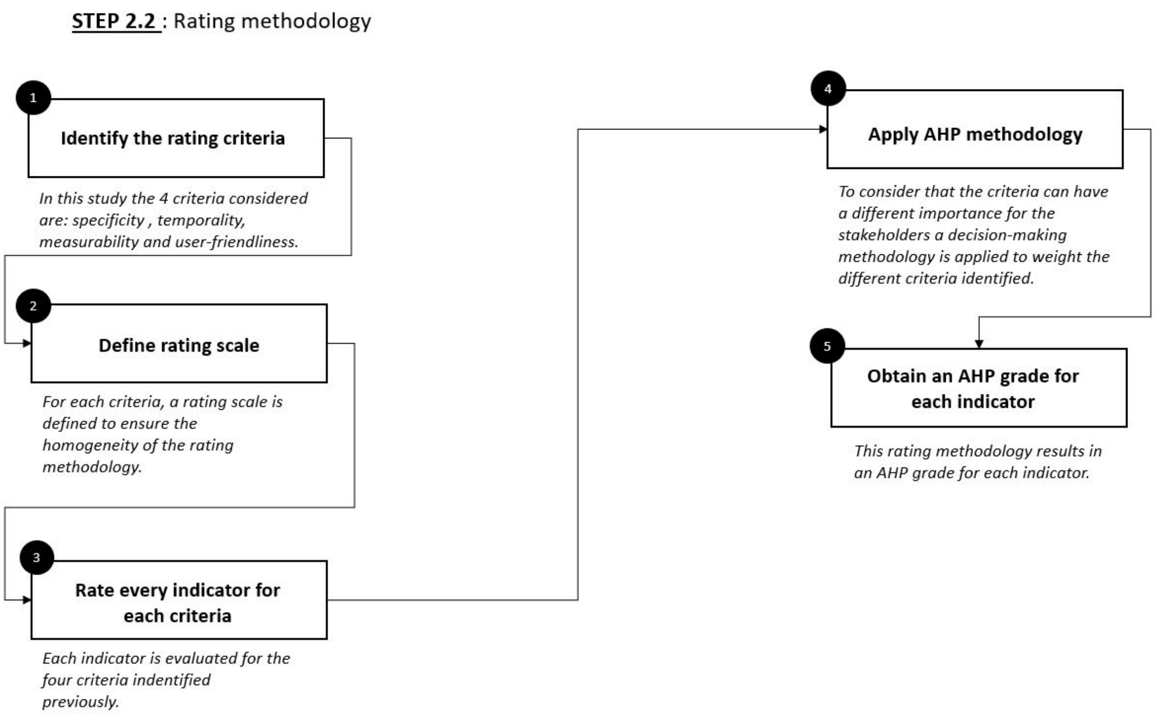


Figure III.3: Graphical methodology to identify indicators for energy transition in carbon-neutral districts projects

III.4.1 Construction of the indicators database

Five of the fourteen indicator lists analysed in the state-of-the-art have been integrated into the tool. Only the methodologies focusing on energy transition assessment have been included in the scope of this study. Table III.2 details the different sources of the indicators lists used in the tool.
A quantitative analysis of the completeness of each indicator lists towards each category to assess energy transition identified in the literature (technical, environment, economy, society, ICT and governance) have been conducted in Table III.3 and highlights that each methodology taken individually does not allow to have an overview of all the categories. The five lists have first been aggregated to provide a toolkit covering all the identified categories. As the methodologies evaluated are meant to assess energy transition, indicators to evaluate carbon capture have been added to cover carbon neutrality as well. Those 4 indicators have been built relying on the carbon capture solutions at the district level proposed by [38].

Table III.2: Research projects integrated to the tool

Name of the project	**Description**	**Year**	**Type**	**Content**	**Nb. of indicators**
IRIS [21]	Identify energy transition tracks : project funded by European Union's Horizon 2020 research and innovation program	2018	Project specific methodology	5 energy transition tracks : Smart renewable energy positive discrits, Smart energy management, Smart e-mobility, City innovation platforms, Citizen engagement.	75
SMARTEnCITY [27]	Building smart zero CO2 city across Europe, funded by European Union	2017	Project specific methodology	Evaluate district renovation, urban mobility and citizen engagement.	149
CityxChange [28]	Project member of SCIS, funded by European Union	2019	Project specific methodology	KPI framework divided into three themes : Integrated Planning and Design, Common Energy Market and public transportation.	33
Indicators framework by SCIS [20]	List of projects mostly cofunded with European commision	2018	General methodology	Focus on the evaluation of 5 energy sectors : energy supply units and plants, buildings, e-mobility, ICT, renovation an retrofitting.	40
Saheb Y., Shnapp S., Paci D. [12]	Report presenting lessons learned from existing positive energy districts	2019	General methodology	Focus on the evaluation of 7 categories energy, governance, social equity, economic efficiency, conservation and quality of life	25

Table III.3: Completeness of the methodologies included in the tool

	IRIS	**SCIS**	**CityxChange**	**Smartencity**	**Saheb Y., Shnapp S., Paci D.**
Number of indicators linked to energy transition	52	29	25	46	25
Technical	29%	48%	40%	48%	12%
Environment	13%	10%	8%	15%	44%
Economy	21%	17%	20%	0%	12%
Social	23%	3%	24%	13%	32%
ICT	10%	21%	0%	13%	0%
Governance	4%	0%	8%	11%	0%

Characterization of the indicators

Each indicator presented in Appendix G is described with the following characteristics:

- **Name:** This field describe the name of the indicator in an efficient and understandable way. Some indicators names of the included frameworks have been adapted to increase the accuracy and specificity of the indicator.
- **The definition:** This field gives a quick description of the indicator and the scope considered,
- **Formula:** If applicable, this field details the mathematical formula used to build the indicator.
- **Scope:** This field contains only two categories depending on whether the indicators can be applied at a city level or are designed to be used at a project level,
- **Target stakeholders:** The literature [21] describes different groups of stakeholders detailed in the Table III.4.

Table III.4: Target stakeholders in the scope of the tool

Target stakeholders :	
Governance	This category represents the project's governance. At a city level, government is city council.
DSO	DSO stands for Distribution System Operators and is responsible for the management and operation of the distribution network of electricity.
TSP	TSP stands Technology and Services Providers and includes the private sector composed of industry, technological companies and service providers.
End users	The end users are the customers impacted by the project or the decisions.

- **Type:** The literature [39] describes five types of indicators: input, process, output, outcome, and impact indicators. The Table III.5 gives a definition for each of them.

Table III.5: Indicators types definitions

Type of indicators	Details
Input indicators	Resources needed for the implementation of an activity (ex : policies, human resources, materials, financial resources)
Process indicators	Measure whether planned activities took place or not (ex: holding of meetings, training courses, distribution of smart meters)
Output indicators	In relation with the product of the activity (e.g. number of smart meters distributed, area of roof isolated, number of electric busses)
Outcome indicators	Measure intermediate results generated by outputs. Quantity and quality information. (e.g. : number of well isolated dwellings as a percentage of the total number of dwellings)
Impact indicators	Measure the quality and quantity of long-term results generated by program outputs (change in quality of life, reduction of energy use)

- **Precision:** This parameter indicates whether the indicator is quantitative or qualitative.
- **Source:** This parameter describes the source of the indicator. When indicators are identical in the different sources, all the sources are mentioned in this section.

Sorting of indicators

Each indicator has been attached to one of the previously detailed categories (technical, environment, economy, social, ICT, and governance), to make sure that every category of carbon neutrality is covered by the tool.
Moreover, to use this tool for a carbon-neutrality project, each indicator has been linked to one of the 11 main objectives and the 24 specific objectives detailed in Table III.1. The indicators that did not match with those objectives have been considered out of the scope of the study. Table III.3 presents the number of indicators for each objective and specific objective.
Finally, each indicator has been sorted by its intended use: each indicator can be a core, a specific, or a background indicator. Table III.6 describes the specificity of each use.

Table III.6: Use of the different indicators

Use of the indicator	Details
Core	The indicator can be used as a KPI for the main objective it refers to.
Specific	The indicator can be used to follow-up the specific objective it refers, to but does not describe the whole main objective.
Background	The indicator can be used as a detail for the specific objective, but does not describe the whole specific objective.

This process led to 141 indicators. To facilitate the understanding of the balanced scorecard, it is necessary to reduce this number through a rating methodology while still covering all the objectives and categories. The following part proposes a rating methodology for those indicators.

III.4.2 Rating methodology

Criteria identification

The tool's objective is to use this indicator pool to propose the most adapted list of indicators for a given city or project. To achieve this optimization, a possibility is to analyse each indicator through comparative criteria. The choice of the criteria is district and project-dependent and has to be made in collaboration with local stakeholders. A non-exhaustive list of criteria is given in part II.2.1. Relying on the analysis of the papers based on criteria ratings used in the literature review, it appears that 4 criteria are particularly relevant to rate indicators: Specificity, Temporality, Measurability, and User-friendlines. This list of criteria has been validated in collaboration with the Chair of Urban Energy Transition of Valencia. Table III.7 details these criteria and the scales used to rate each indicator for each criterion.

Table III.7: Rating criteria and scales

Criteria	**Description**	**Scale**
Specificity	this criterion evaluates if the indicator is gives precise information on the objective considered	1- The indicator does not have a direct link with a given objective 3- The indicator is interesting for the evaluation but does not have a direct link with the objective 5 - The indicator gives clear and specific information about the objective.
Temporality	This criterion describes the period of validity of the indicator	1- The period of validity of the indicator is short (one measure at a given moment) 3- The period of validity of the indicator is medium (one measure not changing at a short timescale) 5- The period of validity of the indicator is long (can be measured continually).
Measurability	This criterion analyses if the indicator is easy to measure, build, or aggregate.	1- Only indicator information, no information concerning how to build it or collect data, aggregation difficult. 3- Some information about how to build the indicators and collect data 5- Detailed information about how to collect data, build the indicator, analyse it.
User-friendliness	This criterion indicates if the indicator is easy to understand and to use by the different stakeholders using the tool.	1- Indicators very technical and difficult to understand for final users 3- Indicators that can be easily understood by someone with a background in transition subject 5- Indicators very easy to understand by everyone.

Multi-criteria decision-making methodology : Analytical Hierarchy Process

The previous criteria do not have the same importance for the project manager or the city council. To provide an accurate grade for each indicator, it is important to take into account those differences. To be able to select the best indicators for a given city or project, the different grades obtained in the previous part have been analysed through an Analytic Hierarchy Process (AHP) which is a multi-criteria decision-making methodologies [40]. The application of the methodology consists of finding the relative weights to be associated to each criterion to calculate the final grade as a pondered average value of the different criteria. This part presents the different steps of the AHP methodology applied to the pool of indicators included in the tool. A detailed description of the methodology and the justification of the calculation is presented in Appendix A. This step has to be performed with the stakeholders of the project considered.

III.4.3 Use of the indicators-choice tool

Indicator choice tool presentation

The indicator choice tool obtained with this methodology contains 141 indicators divided into 6 categories: technical, environmental, economic, social, ICT, and legal. The complete list of indicators, as well as the characteristics of each of them, are detailed in Appendix G.
To allow the follow-up of a carbon-neutral district project and match with the adapted balanced scorecard methodology, the list of indicators obtained should cover all the identified categories, objectives and specific objectives and be composed of different types to provide to city stakeholders a precise overview of the measures' evaluation. The following results present the completeness of the tool towards the different categories and types of indicators described in the methodology. As highlighted by Figure III.4 the list of indicators covered the totality of the categories, although the technical category remains the majority with 34% of the total indicators. An explanation for that can be that energy transition projects require a lot of technical improvements. Moreover, regarding the balanced scorecard axes, Figure III.5 underlines the fact that the list of indicators covered the totality of the axes, although the resources and processes category remains the majority with 73% of the total indicators. An explanation for that, can be that the technical improvements concern majority resources management and processes. Concerning the type of indicators proposed, Figure III.6 illustrates that outcome and output indicators are highly represented, while impact and process indicators are both counting for less than 10% of the total. Moreover, Table III.8 presents the number of indicators for each main objective and specific objectives. The result shows that each objective and specific objective included in the scope of the analysis is covered by at least one indicator (considering all use of indicators: core, specific, and background indicators).

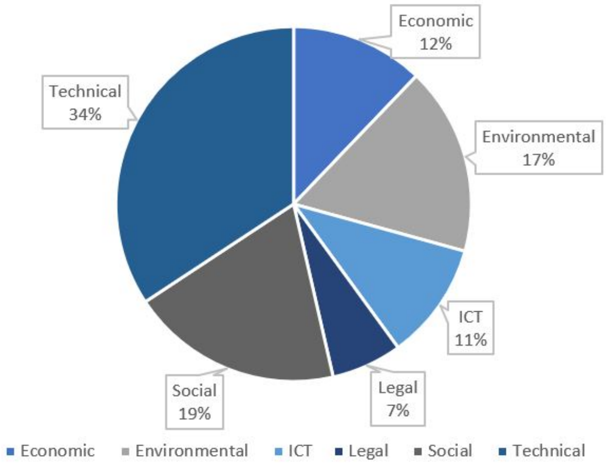


Figure III.4: Distribution of indicators per energy transition category

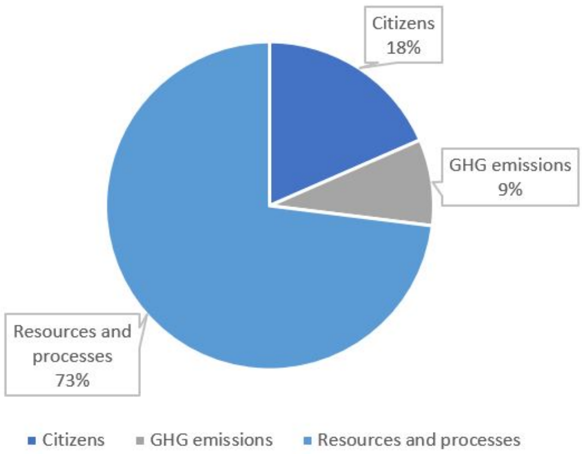


Figure III.5: Distribution of indicators per adapted balanced scorecard axis

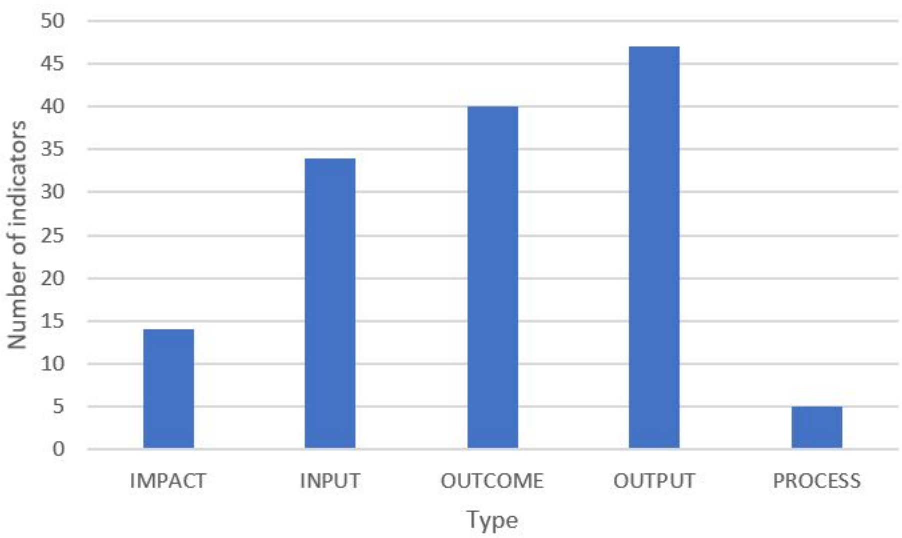


Figure III.6: Distribution of indicators per type

Table III.8: Number of indicators per main objective and specific objective

Main objectives and specific objectives	Number of indicators included
Decrease GHG emissions	**10**
Decarbonize energy generation	2
Decarbonize residential sector	3
Decarbonize transportation	2
Decrease other pollution	**3**
Reduce other pollution	3
Increase citizens engagement	**10**
Increase involvement towards energy transition	10
Increase citizens information	**5**
Inform the citizens	5
Increase citizens satisfaction	**4**
Develop advantages for citizens	2
Develop inclusive projets	1
Increase citizens satisfaction	1
Increase inclusiveness	**8**
Develop inclusive projets	4
Favorize neighbourhood diversity	2
Increase involvment of minorities	2
Increase resources efficiency	**40**
Increase efficiency in the residential sector	14
Increase efficiency in transportation	18
Net zero waste	4
Net zero water	4
Green energy generation	**21**
Develop renewable energy	8
Increase energy storage	3
Increase quality of supply	10
Optimize internal processes	**29**
Develop a legal framework for energy transition projects	5
Increase quality of data and monitoring system	7
Promote energy transition projects	17
Develop local economy	**8**
Decrease energy costs	5
Develop new jobs	3

Added value of the tool

The added value of this indicators-choice tool is to give the possibility to adapt this list of indicators to the carbon-neutrality project assessed. The user can thus choose the following parameters defined in the methodology as illustrated in Figure III.7: category, scope, objectives, specific objective, source, target stakeholders, type, and precision.

Category	All
Scope	All
Objective	All
Source	All
Target stakeholder	All
Type	All
Accuracy	All

Figure III.7: Parameters of the tool

Depending on the parameters selected, the tool is providing a list of indicators as well as the following information for each of them: type of indicator, precision, number of sources, details, rating value for each criterion, AHP value. This list can then be sorted by the highest AHP value, and the user can choose how many indicators he wants to analyse at that point.

III.5 Indicators selection for the adapted balanced scorecard methodology

To simplify the understanding of the methodology, a graphical explanation is described in Figure III.8.

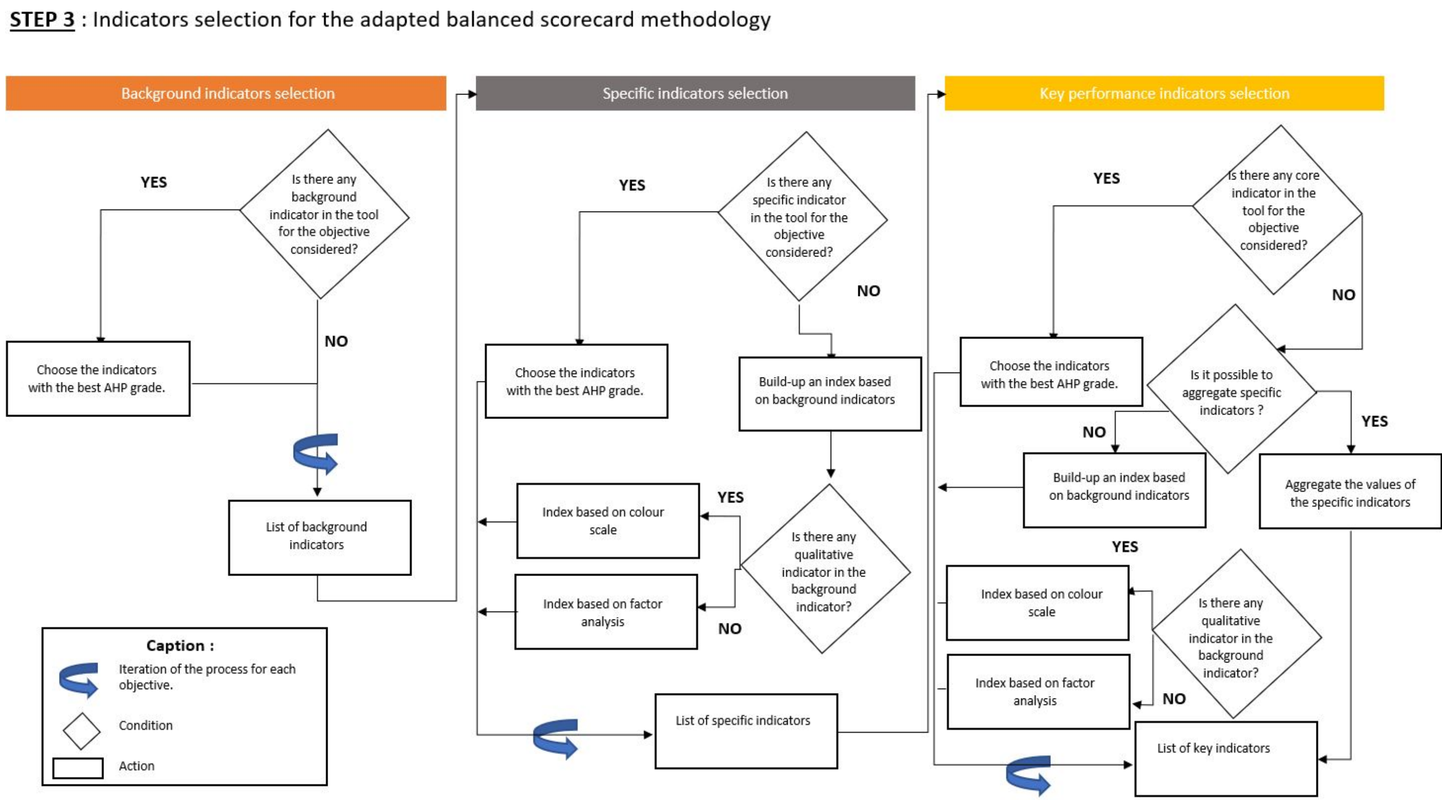


Figure III.8: Indicators selection for the adapted balanced scorecard methodology

The idea of using an adapted balanced scorecard methodology to follow-up carbon-neutral districts projects is to simplify the understanding for projects managers and city stakeholders. Thus, levels of indicators has been defined relying on the use of indicators presented in Table III.6 to ease the understanding of the dashboard. The first level of indicators contains the key performance indicators (referred to as core indicators in the previous list of indicators), and corresponds to the follow-up of the main objectives detailed in Table III.1. The second level of indicators contains specific indicators and corresponds to the follow-up of the specific objectives detailed in Table III.1. Finally, the third level of indicators is background indicators, which are used to build specific indicators and can give details in case of an alert highlighted by KPIs or specific indicators. A graphical summary of those threes level is presented in Figure III.9.

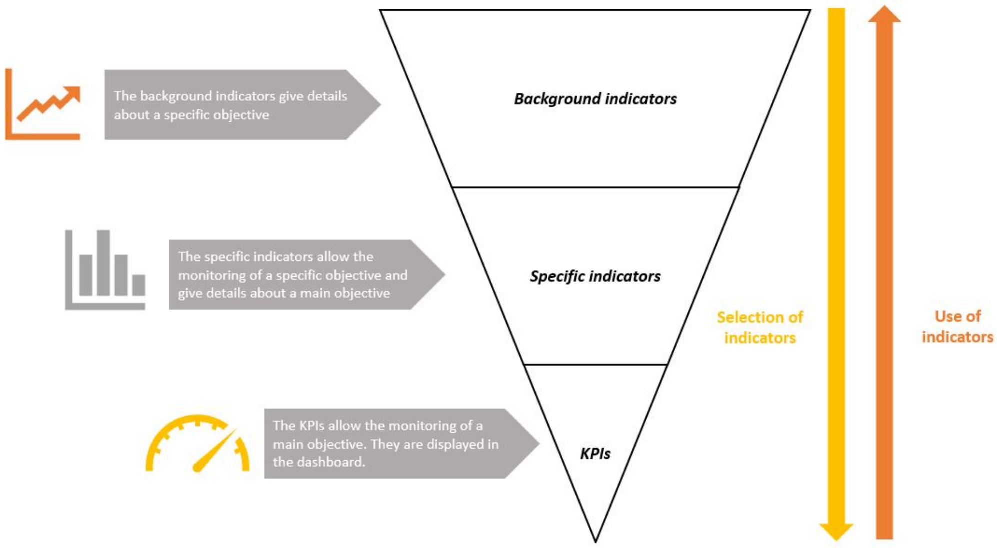


Figure III.9: Three levels of indicators

This part describes the methodology followed to choose the best indicators for each level. Figure III.3 summarizes the process.

III.5.1 Background indicators choice

The first step is to identify the background indicators for each specific objective. As background indicators are only meant to give details about a specific objective, it is not mandatory to build background indicators for each specific objective.
There are two different scenarios :

1. There is no background indicator for the specific objective considered: in that case, it means that the specific indicators relies on direct measurement and cannot be detailed with background indicators,
2. There is more than one background indicator for the specific objective considered: in that case, only the background indicator with the top AHP grade is selected for the project. If there are several with the same AHP grade, all of them are included.

III.5.2 Specific indicators choice

The second step is to identify the specific indicators for each specific objective. As specific indicators are meant to be used to follow up the achievement of targets and are necessary to build the key performance indicators, each specific objective must have at least a specific indicator. There are two different scenarios :

1. The indicators-choice tool built previously contains at least one specific indicator for the specific objective considered: in that case, the same methodology with the highest AHP grade is applied for the selection of the specific indicator. The formulation of the indicator can be slightly modified to meet the particularities of the case study.

2. The indicators-choice tool built previously does not contain any specific indicator for the specific objective considered: in that case, it is necessary to build an index based on the background indicators results. The method to build this index is detailed in the part III.5.4.

III.5.3 Key performance indicators choice

The last step is to build the key performance indicators, which will appear directly in the dashboard of the user to follow up the carbon-neutral district project. As highlighted in the screened literature, a KPI should meet the following criteria [3]. It has to be specific, measurable, achievable, relevant, and time-defined. So that the adapted balanced scorecard methodology could be efficient, it is mandatory to keep a shortlist of indicators. Thus, a minimum of one KPI and a maximum of two KPIs per main objective is settled in this methodology. There are three scenarios :

1. The indicators-choice tool built previously contains a core indicator for the main objective considered: in that case, the core indicator can be used as a KPI for the objective considered. The formulation of the KPI can be slightly modified to meet the particularities of the case study.

2. The indicators-choice tool built previously does not contain any core indicator for the main objective considered, but the KPI can be obtained through the aggregation of the specific indicators: In that case, a KPI based on this aggregation can be built up.

3. The indicators-choice tool built previously does not contain any core indicator for the main objective considered, and it is impossible to aggregate the specific indicators (e.g : not the same unit or qualitative indicators) : in that case, it is necessary to build an index based on the results of the specific indicator. The method to build this index is detailed in the part III.5.4.

III.5.4 Index construction

As mentioned previously, it is necessary to build up indexes to obtain some specific indicators or KPIs. Depending on the precision of the background indicators in the case of specific indicators indexes or of specific indicators in the case of key performance indicators indexes, the type of index built is different. There are two different scenarios:

1. There is at least one qualitative (based on Likert Scale) indicator in the list of the indicators considered for the index: in that case the index will be a colour scale (for example: green, yellow and red). The value of each indicator will be transformed to match with this colour scale, and the final result of the index will depend on the weight attributed to each indicator. Although the colour scale index is project and district-specific, the indicator with the highest AHP grade will be considered as the most important for the index,

2. There are only quantitative indicators: in that case, the index will be a numerical index taking into account the weight (wi) of each indicator considered. For instance, if the index relies on three different variables (vi), it can be built with the following formula :

$$I = \frac{v_{1,t} \times w_{v_1} + v_{2,t} \times w_{v_2} + v_{3,t} \times w_{v_3}}{v_{1,0} \times w_{v_1} + v_{2,0} \times w_{v_2} + v_{3,0} \times w_{v_3}}$$

Where t represents the value of the variable at the time of the measure, and 0 is the comparison base that have to be parameters by the project manager. At the beginning of the project, when no monitoring data are available, the weight of each indicator can be defined as the weighted average based on the AHP grade.

$$w_{v_i} = \frac{AHP_i}{\sum_{j=1}^{n} AHP_j} \tag{III.1}$$

If monitored data for the indicators considered are already available, the calculation of the weight (wi) of each indicator can be performed with a mathematical model like factor analysis, which determines the contribution of each variable to a given factor.

III.6 Choice of targets for the indicators of carbon-neutral district projects

To use the adapted balanced scorecard methodology as a dashboard to follow up the carbon-neutral district project, it is important to define targets for each indicator identified previously. Targets are defined yearly and differ with projects' specificity and timeline to achieve carbon-neutrality. The methodology to define targets is different whether the indicator is qualitative or quantitative, and is highly dependent on the data availability in the district or city considered for the energy transition project.
Figure III.10 presents a graphical process used to obtain a target depending on the type of indicator considered.

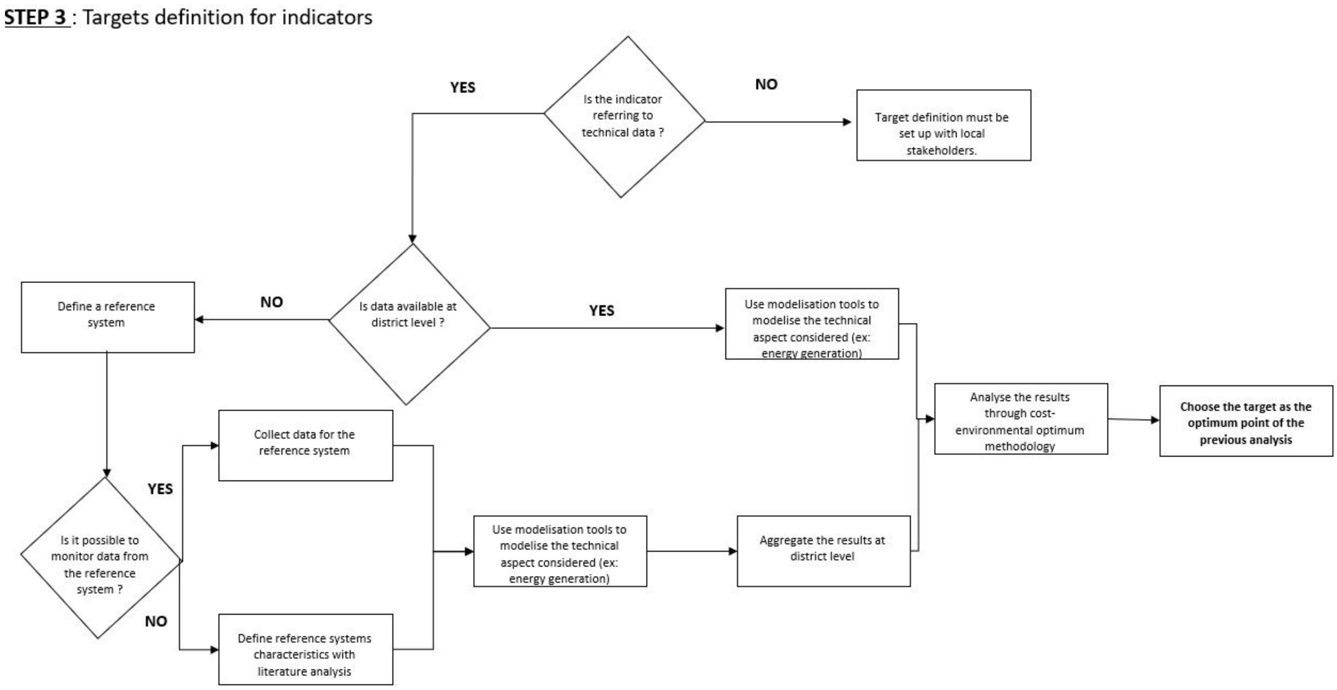


Figure III.10: Graphical methodology to obtain the targets for energy transition in carbon-neutral districts projects

III.7 Choice of thresholds for the indicators of carbon-neutral district projects

To use the adapted balanced scorecard methodology as a dashboard to follow up the carbon-neutral district project, it is important to define thresholds for each indicator identified previously. When the indicator falls below this threshold, an alert will appear on the dashboard and the user will be able to use the three levels of indicators to find the source of the problem. To facilitate the follow-up, two levels of thresholds can be defined, the first one as a warning and the second one as an alert.
The definition of these thresholds is highly location and project dependant, but the method to follow can be divided into 4 scenarios, depending on the type of indicator :

1. The indicator is a numerical value : in that case the two thresholds can be defined relying on either numerical simulations or from benchmarking in the absence of data ;
2. The indicator is a Likert scale: in that case the thresholds will consist of the Likert scale;
3. The indicator is a numerical index : in that case the index built with the factor analysis methodology relies on the comparison between the current value and the average annual value. Thus, if the indicator falls below 1 a warning can be sent. The alert threshold can be defined with the project stakeholders;
4. The indicator is a colour scale index: in that case the thresholds will rely on the different colours of the index.

III.7.1 General discussion

The proposed methodology results in an follow-up dashboard presenting the most fitting indicators, when considering a city or project specificity and covering all categories of the energy transition to achieve carbon-neutrality. The final dashboard organized in the three level hierarchy of indicators fill up the lack of a common framework to evaluate energy transition in cities. Indeed, it gives the possibility to the user to have an overview of the project but also to obtain details and quickly react if a key performance indicator indicates an alert. However, this study does not address the literature gap highlighted in the introduction considering the lack of indicators to characterize life cycle assessment and energy resilience. Finally, there are two main limits to this research. Firstly, the indicator data base relies only on five methodologies and needs to be completed to be used at a large scale and cover all types of projects or cities. Secondly, the list of criteria to rate the indicators has been chosen relying on the study of 9 frameworks of indicators used for the literature review. Thus, to be sure that this list of criteria can cover all kind of project and city specificity, the number of studies included in this review must be increased.

IV | Case study of the neighborhood El Cabañal in Valencia

The case study of El Cabañal in Valencia has been conducted to validate the previous general methodology. This section is divided into three parts:

1. The first part presents the characteristics of the neighborhood and details the reasons for its choice as a case study;
2. The second part analyses the possible scenarios to reach carbon-neutrality in the neighborhood by 2030;
3. Finally, the last part describes the results of applying the general methodology to the chosen scenario.

IV.1 Presentation of El Cabañal

IV.1.1 General description

Cabanyal-Canyamelar is a neighborhood located in Poblats Maritims district in Valencia, rounded in red in Figure IV.1. The district is one of the most famous seaside neighborhoods in Valencia. It is one of the densest neighborhoods in Valencia with a density of 14 351 inhabitants [41] per square kilometers, which is more than two times the average value for the city of Valencia. The general data of the district are represented in Table IV.1.

Table IV.1: General data of El Cabañal

Surface [km²]	1.35
Number of inhabitants	19 359
Density of population [inhab/km²]	14 351

IV.1.2 Key figures

It is necessary to analyze the neighborhood's critical data,to understand its particularities, and be able to adapt the methodology to the characteristics of El Cabañal, and to transform the district into a carbon-neutral district.

Social situation

The first set of data analyzed is the social aspect. The age distribution presented in Figure IV.2 shows that two third of the population is below 55 years old [42]. The active part of the population (from 20 years old to 64 years old) represents 60% of the total population. Regarding the educational background, 62% of the working-age inhabitants have a degree below or equivalent to high school graduation [41]. The distribution of educational background is presented in Figure IV.3.

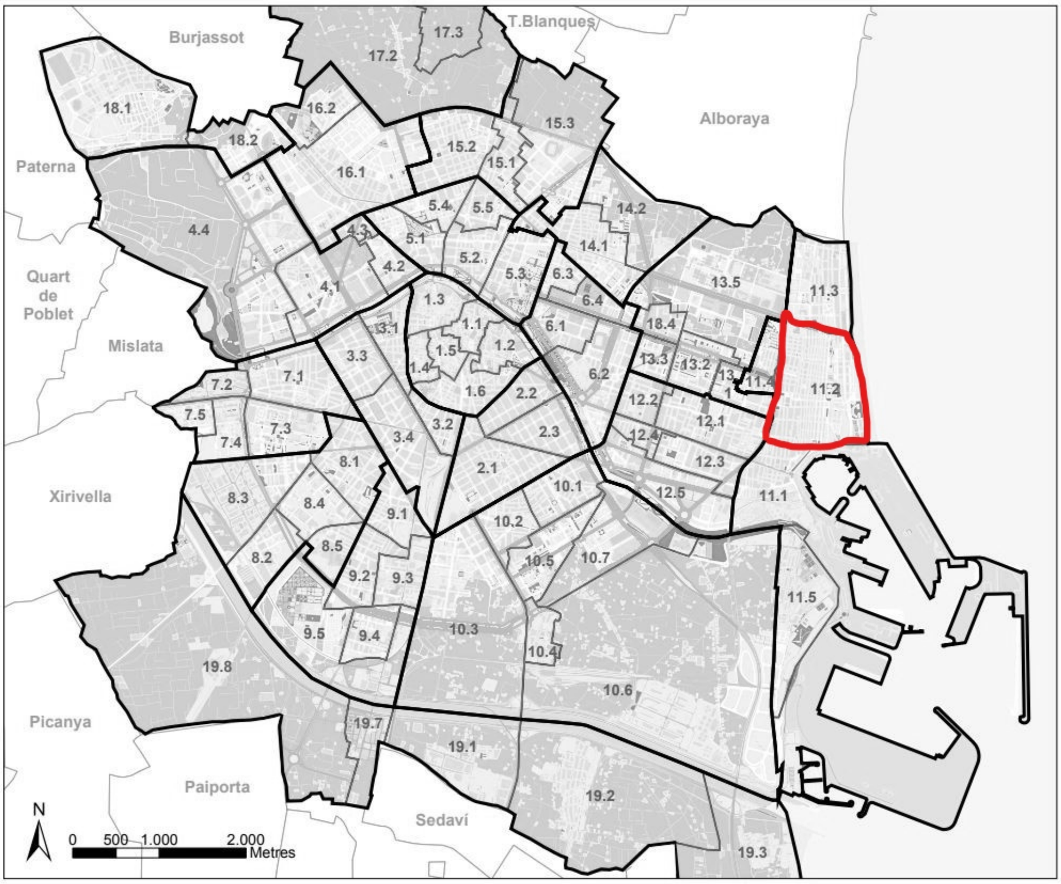


Figure IV.1: Geographical description of El Cabañal

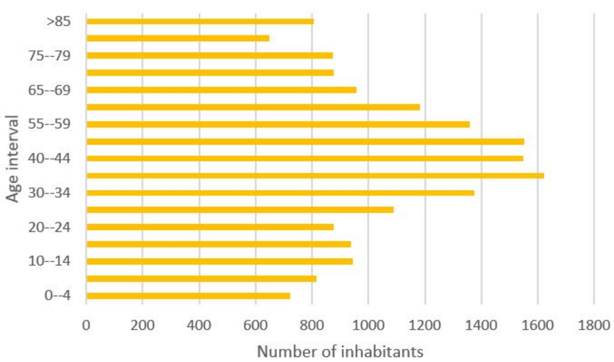


Figure IV.2: Age distribution in Cabañal

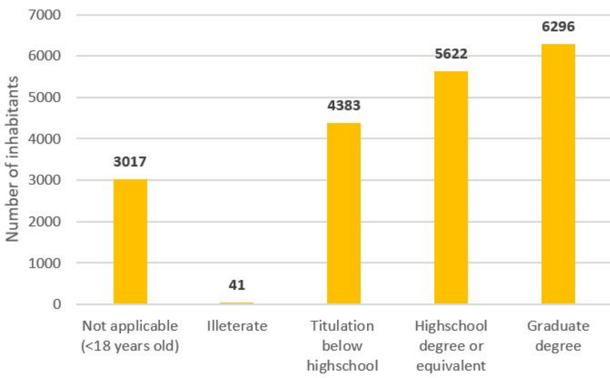


Figure IV.3: Educational background distribution in Cabañal

Economic situation

As highlighted in Figure IV.4, the neighborhood economy relies mainly on the service sector. Indeed, 79% of the working force is working in the service area whereas only 9% is working in the industrial sector [42].

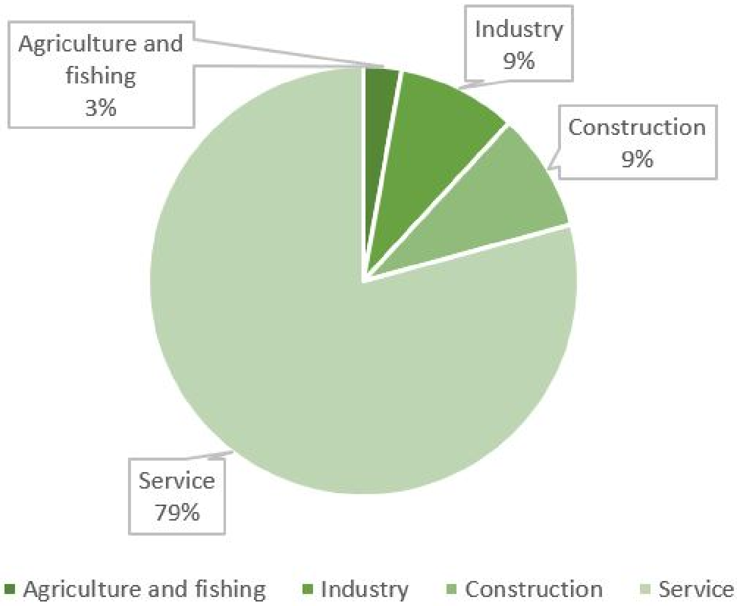


Figure IV.4: Economic activities in Cabañal

Energy related figures

El Cabañal is one of the oldest neighborhoods in Valencia. Indeed, as shown in Figure IV.5 more than a quarter of the residential buildings have been built before 1940, and 85% of the buildings have more than 40 years [42]. Those old buildings require special attention regarding energy efficiency. Concerning the vehicles' distribution, Figure IV.6 underlines the prevalence of tourism vehicles, representing 71% of the total number of vehicles owned in the district [42].

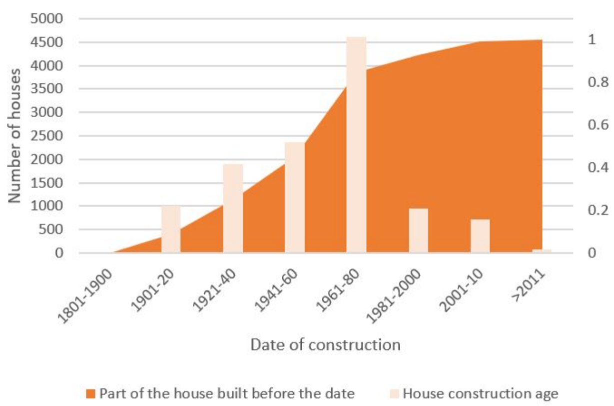


Figure IV.5: Distribution of houses by year of construction in Cabañal

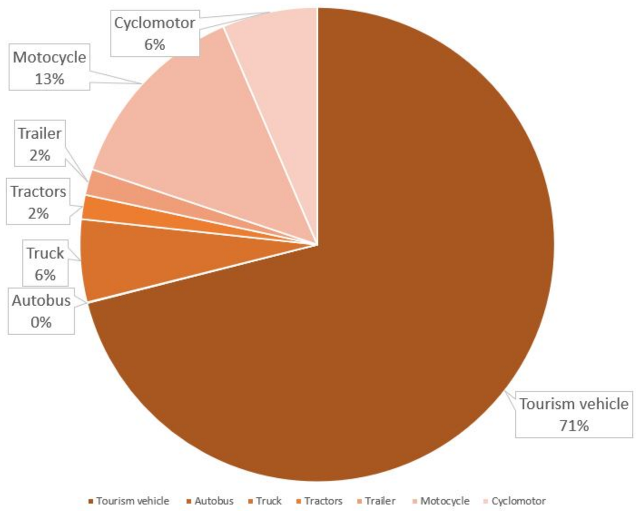


Figure IV.6: Distribution of vehicles by type in Cabañal

The energy consumption data are not available per district. The data for the whole city has been divided by the number of inhabitants in the district of Cabañal to calculate a value for Cabañal.

Considering this assumption and the calculations presented in Appendix B based on the open data in [41], the total annual energy consumption in Cabañal is considered to be of 159.8 GWh. Table IV.2 presents the consumption per energy vector, and Figure IV.7 describes the energy consumption per sector. Those Figures show that 39% of the energy consumption is covered with electricity and that the transportation area is the biggest energy consumer and represents 47% of the total yearly energy consumption in the district.

Table IV.2: Consumption per energy vector in Cabañal

Energy vector	**Consumption [GWh/y]**
Electricity	62.5
Natural gas	22.5
Gasoline	38.2
Diesel	36.6
Total	**159.8**

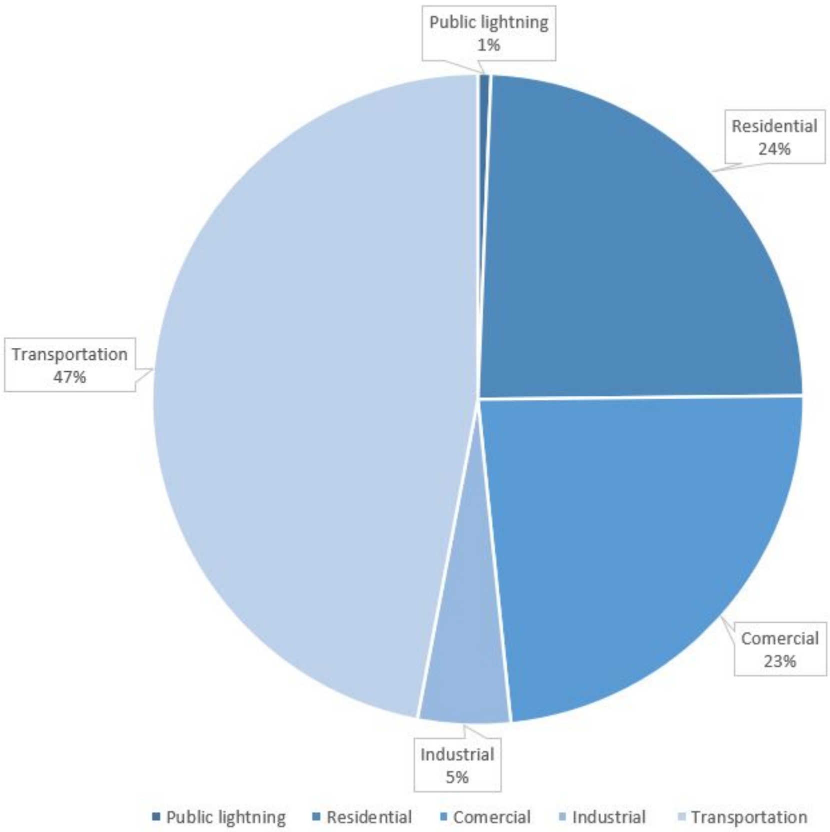


Figure IV.7: Energy consumption in Cabañal

The greenhouse gases emissions data are not available in the open data of the city of Valencia. Thus, an estimation has been calculated relying on the energy consumption of El Cabañal. In that case, only scopes 1, concerning direct emissions, and 2, concerning indirect emissions from energy use, are considered for the neighborhood's carbon footprint. The annual total CO_2 emissions of the neighborhood concerning scope 1 and 2 for public lightings, residential, industrial, commercial, and transportation sectors are equal to 32 889 ton of CO_2. The details and sources used for the calculation are presented in Appendix B. Figure IV.8 presents the distribution of CO_2 emissions per category.

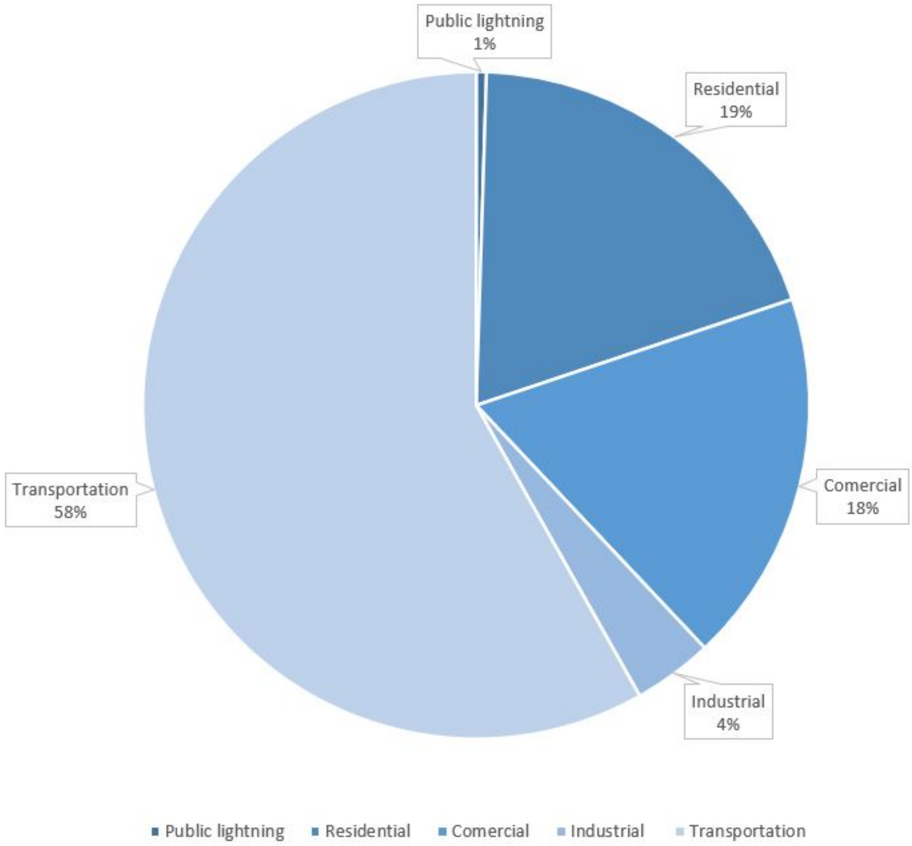


Figure IV.8: Distribution of greenhouse gases emissions per sector in Cabañal

IV.1.3 Resources available

It is essential to perform the inventory of the energy resources available to analyze the neighborhood's potential to become carbon-neutral. Due to the district's location, three energy sources have been analyzed for this characterization: water, wind, and sun.

Water resources

The neighborhood is located directly next to the coast line. Hence the location is particularly suitable for water based technologies for district heating and cooling systems.

Wind resources

The wind data of the location can be extracted from PVGIS [43] database. Figure IV.9 represents the distribution of yearly wind speeds in the neighborhood, as well as the power generated by a small wind turbine [44] at different wind speeds. The analysis of this figure shows that there are only a few hours in the whole year with a suitable wind speed to produce electricity with this type of windmill.

Solar resources

The district is located in a mainly sunny area. The figure IV.10 represents the global daily horizontal irradiance evolution over the year in El Cabañal [43]. The yearly average value of this irradiance comes up to 4 741 W/m^2 is higher than the average European value (3 400 W/m^2 [45]). Hence, the location is auspicious for energy production using solar systems.

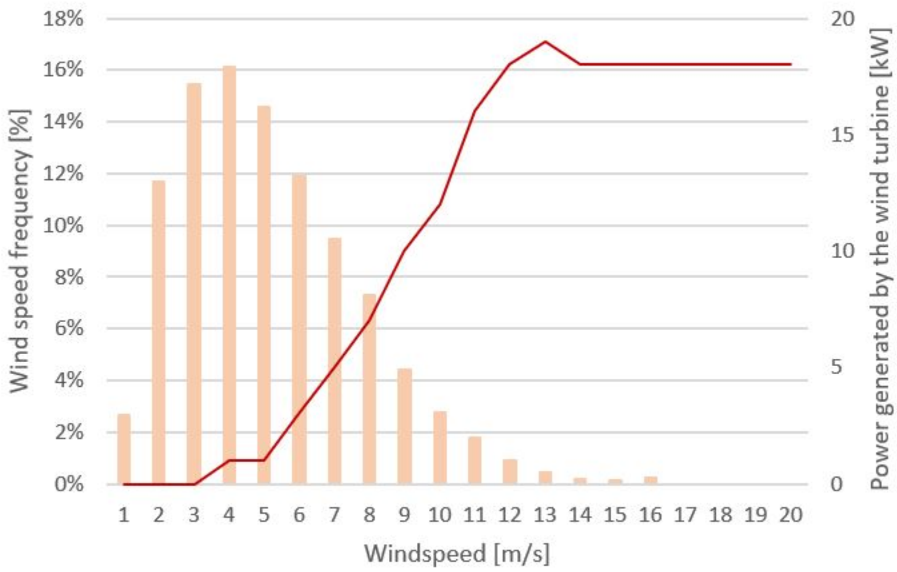


Figure IV.9: Wind speed distribution in El Cabañal

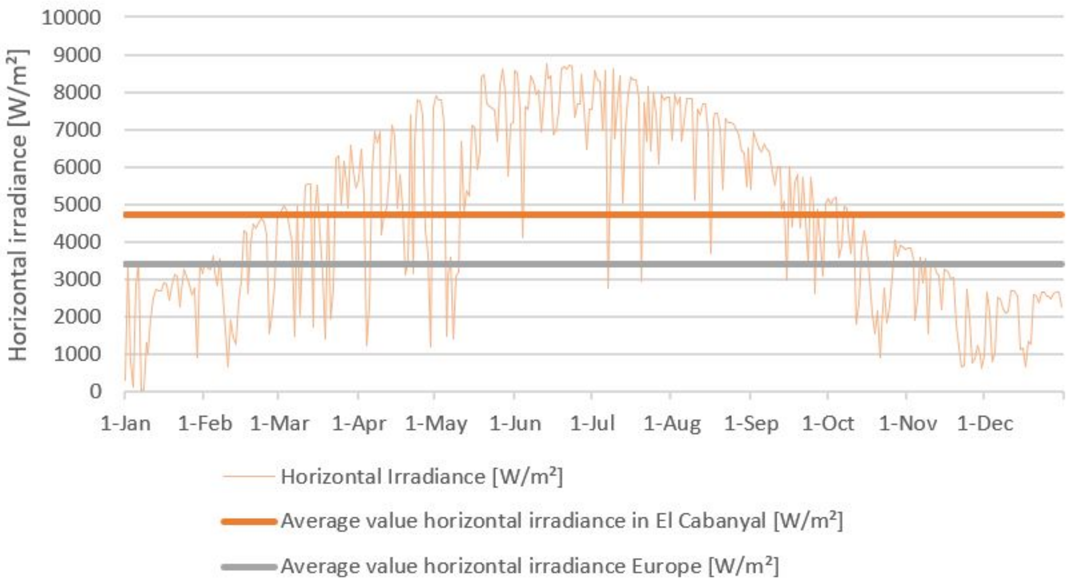


Figure IV.10: Horizontal irradiance in El Cabañal

IV.2 Justification of the interest for the neighbourhood

As presented in the previous part, El Cabañal is one of the oldest neighborhoods in Valencia. As a result, most houses were built more than 50 years ago and did not respect the current energy efficiency standards [33]. Due to low incomes only a few houses have been rehabilitated, hence there is a considerable margin for improvement in this regard. Moreover, regarding the resources available in the location, El Cabañal is blessed with much sun and direct access to the sea-water, making it particularly suitable for renewable energy production. Besides, the socio-economical context of the neighborhood constitutes both a challenge and a chance to build an inclusive energy transition project. Finally, the neighborhood appears to be an excellent candidate for energy transition and, as a result, has the potential to be transformed into a carbon-neutral district by 2030 within the scope of the commitment of Valencia through the "Missions VLC2030" [4].

IV.3 Scenarios analysis for a carbon-neutral El Cabañal

This part presents the comparison of nine technical scenarios in El Cabañal and determines whether they will result technically in carbon-neutrality by 2030. Moreover, an analysis of the social actions and economic investments necessary to reach carbon neutrality in this district has been conducted. The objective is to choose the most suitable scenario that can be used as an application example for the adapted balanced scorecard methodology. Thus, this analysis gives a realistic overview of how to reach carbon-neutrality in El Cabañal, but a deep dive study out of the scope of this master thesis is necessary to obtain a precise and detailed actions roadmap.

IV.3.1 Technical scenarios presentation

The technical analysis has been conducted by comparing a business-as-usual scenario with an ideal scenario for the four main drivers to achieve the carbon-neutrality in a district:

- Energy efficiency and electrification
- Energy production
- Energy storage
- CO_2 removal

The details of the hypothesis, data, and calculations performed are available in appendix C.

Energy efficiency

Energy efficiency must be improved to limit energy consumption and reduce the peak power demand to favor the implementation of renewable energy systems by decreasing the dependency on the grid. For each energy consumption area (residential, transportation, commerce and industry), different energy efficiency improvement measures have been proposed:

- Residential area
  - Housing's refurbishment: As seen in the previous analysis, Cabañal is a historical neighborhood composed of many old houses that are not energy efficient. In these scenarios, houses are renovated to meet the standards of Passiv Haus [46]. The number of houses refurbished is different in the two scenarios.
  - Replacement of gas and oil-based heaters: Combining the fact that houses are old and that a considerable part of the population relies on low incomes, many houses are still heated by fossil-fuels-based heaters which are emitting greenhouse gases. In these scenarios, those heaters are replaced by an electric and more efficient alternative (e.g.: heat pumps). The percentage of heaters replaced is different in the two scenarios.

- Transport
  - Electric vehicles: As Spain is behind the European average regarding electric cars penetration (less than 1% of cars are electric in Spain against 6% in Europe [47]), the number of electric cars must increase to achieve carbon-neutrality. The percentage of yearly increase is different in the two scenarios.
- Commerce and industry
  - Processes efficiency: In the industrial sector, factories are submitted to an energy audit to improve energy efficiency for the ideal scenario.
  - Shops: As for the residential houses, the shops in Cabañal are located in old houses and need to be refurbished.

For all those measures, the two following scenarios have been compared:

Table IV.3: Scenarios regarding energy efficiency EE

SCENARIOS Energy Efficiency	BAU EE1	Ideal EE2
Target renovation of the houses towards passiv	60%	100%
Houses standards by 2030		
Taget number of thermal energy heater replaced by electric heaters	60%	100%
Part of electric vehicles targeted in 2030	14%	100%
Energy efficiency improvements in commercial area and industry	0%	30%

Energy production

The second driver of the energy transition to meet the target of carbon-neutrality by 2030 is to produce green energy. Different clean energy production measures have been proposed:

- Installation of PV panels: Regarding the solar resources available, it has been decided to focus the renewable energy production mainly on photovoltaic panels. The percentage of the electricity demand covered by the installation depends on the scenario.
- Construction of a district heating and cooling system using the seawater: a district heating and cooling system will cover the heating, cooling, and SHW demand. The percentage of the heating and cooling demand covered by this system depends on the scenario.

Table IV.4: Scenario regarding energy generation EG

SCENARIOS Energy Generation	BAU EG1	Ideal EG2
Minimal target in renewable energy generation by 2030	70%	120%
Surface available PV pannels [m2]	567000	945000
District heating and cooling demand coverage	60%	100%

Energy storage

Due to the choice of a PV panel system to cover the electricity demand, electricity production occurs only during the day. There are two different solutions to cover the electricity demand of the neighborhood at every hour of the day:

- Buying the electricity from the grid when the solar panels are not producing electricity and selling the electricity to the grid when the production of electricity in the neighborhood is higher than the demand;

- Include an energy storage system in the neighborhood.

Two scenarios have been compared for the energy storage: a business-as-usual scenario, where the grid is used as storage (SS1), and an ideal scenario (SS2), where the neighborhood has its energy storage system with batteries, with a target of storage capacity of 1 day of electricity demand by 2030.

CO_2 removal

Minimizing the CO_2 emissions as much as possible is necessary to achieve the energy transition. However, the residual emissions that cannot be avoided need to be compensated with CO_2 removal installations. In that case, the measure proposed for the CO_2 removal is to increase the green zones by planting trees which capture CO_2 naturally. It has been assumed that the free surface to plant a tree in Cabañal represents 2% of the surface of the neighborhood.

IV.3.2 Technical scenarios analysis

The two different scenarios for each area have been combined and led to 8 different scenarios listed in Table IV.5

Table IV.5: Scenarios analysed

Scenario number	Combination
1	EE1 - EG1 - SS1
2	EE1 - EG1 - SS2
3	EE1 - EG2 - SS1
4	EE1 - EG2 - SS2
5	EE2 - EG1 - SS1
6	EE2 - EG1 - SS2
7	EE2 - EG2 - SS1
8	EE2 - EG2 - SS2

These scenarios have been compared through four-axis: technical assessment, environmental assessment, economic assessment, and social assessment.

Technical assessment

The nine combinations of the previous scenarios have been compared through three different technical axes: calculation of the energy demand to cover, sizing of the PV system, and sizing of the storage system. This part presents the main results of the calculations. The details of the calculations and the hypothesis used are presented in the appendix D.
Results:

- Yearly energy demand to cover: The yearly energy demand has been calculated for the two different scenarios and is presented in Figure IV.11 and Figure IV.12.

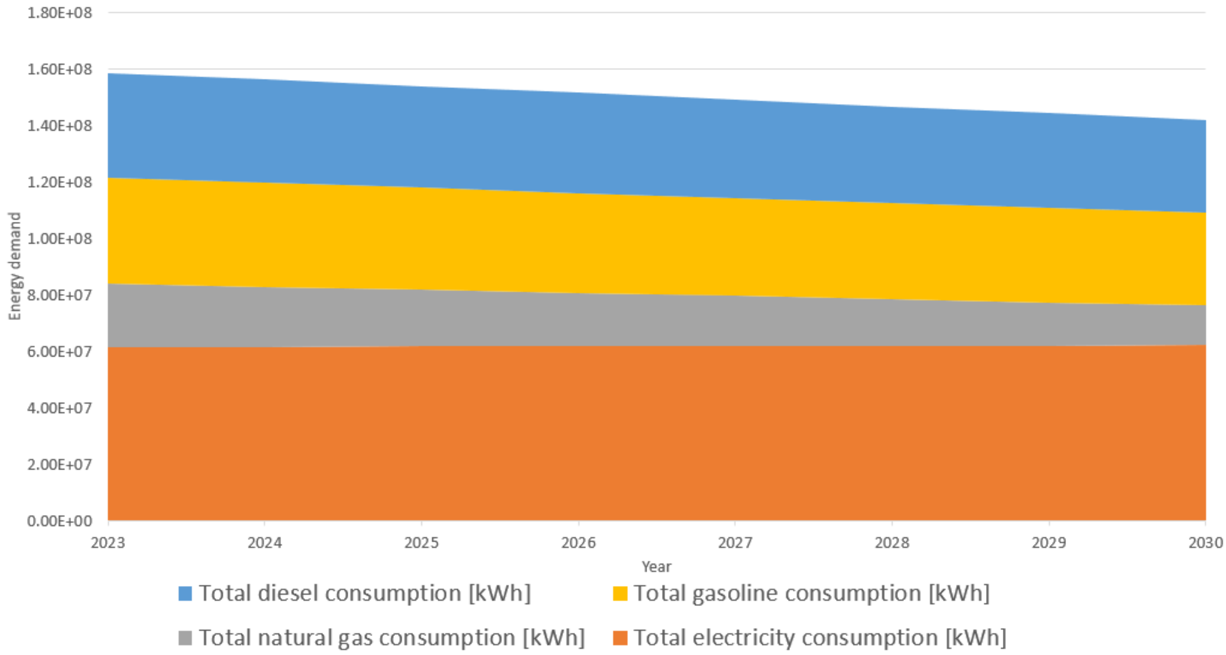


Figure IV.11: Yearly energy demand (BAU scenario)

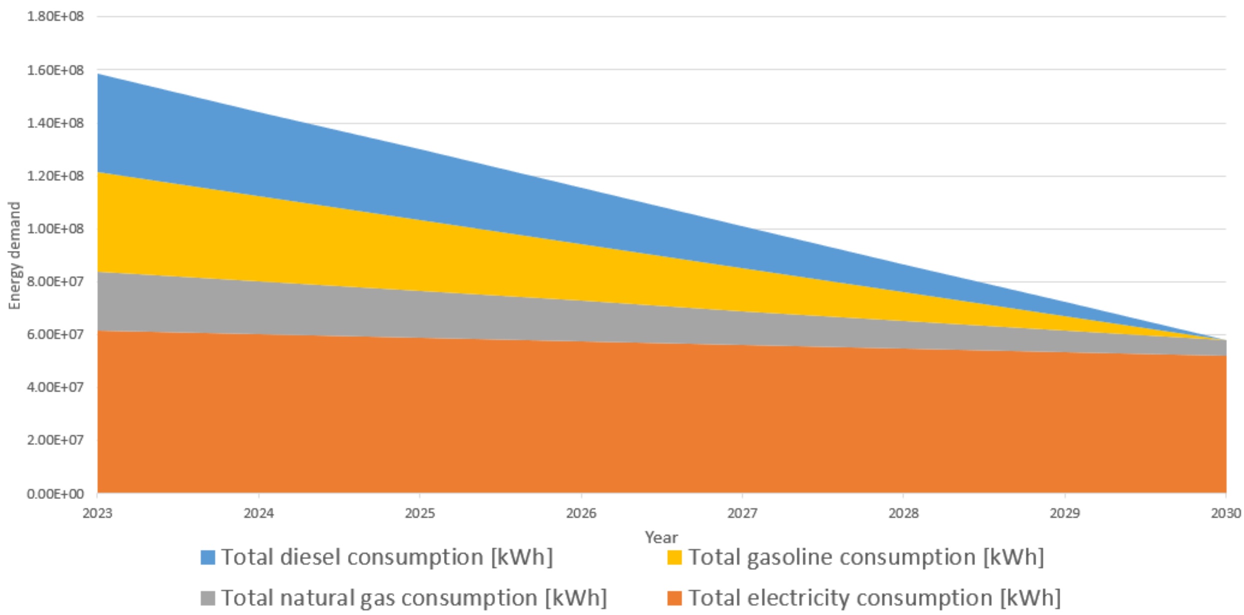


Figure IV.12: Yearly energy demand (IDEAL scenario)

- Sizing of the PV system:

  Considering the energy demand to cover, the sizing of the photovoltaic system has been performed for each scenario. The results are presented in Table IV.6 and Figure IV.13.

Table IV.6: Sizing of the PV system

SCENARIOS	Minimum peak power to cover with PV in 2030 [kW]	Surface of PV necessary [m2]	Number of PV	Number of inverters
1,2	28191	233552	70479	783
3,4	48328	400370	120820	1342
5,6	25856	214202	64640	718
7,8	44324	367203	110811	1231

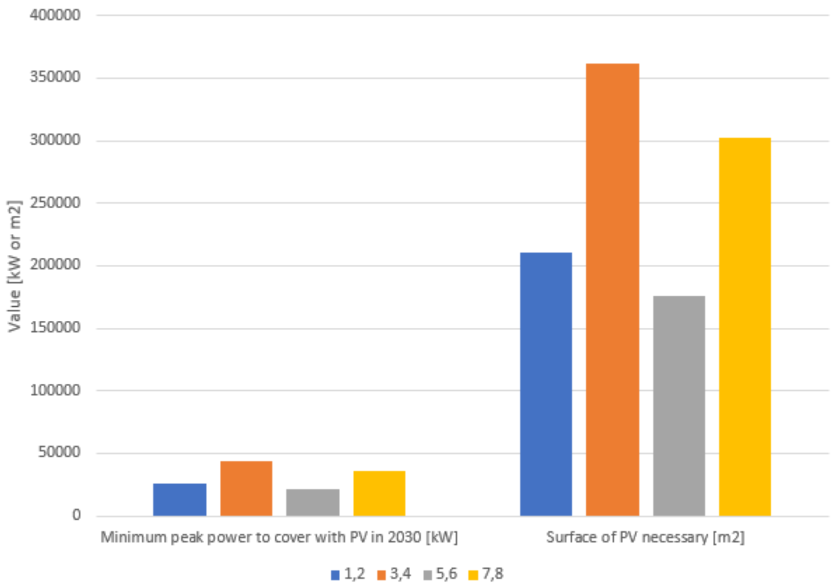


Figure IV.13: Sizing of the PV system

- Sizing of the storage system: Table IV.7 presents the sizing of the storage system with Lithium-ion batteries with a nominal capacity of 300W.

Table IV.7: Sizing of the storage system

SCENARIOS	Capacity of the storage system in 2030 [kWh]	Number of batteries
1,3,5,7	0	0
2,4	100058	416909
6,8	96097	400403

Interpretation of the results:
From a technical point of view, it has been supposed that the only incompatibility of a scenario occurs if the surface necessary to install PV panels exceeds the surface available in the neighborhood. All the scenarios are compatible with the surface available for the PV panels installation. By hypothesis, this number equals:

- 70% of the roofs in the business-as-usual energy generation scenario,
- 100% of the roofs in the ideal energy generation scenario

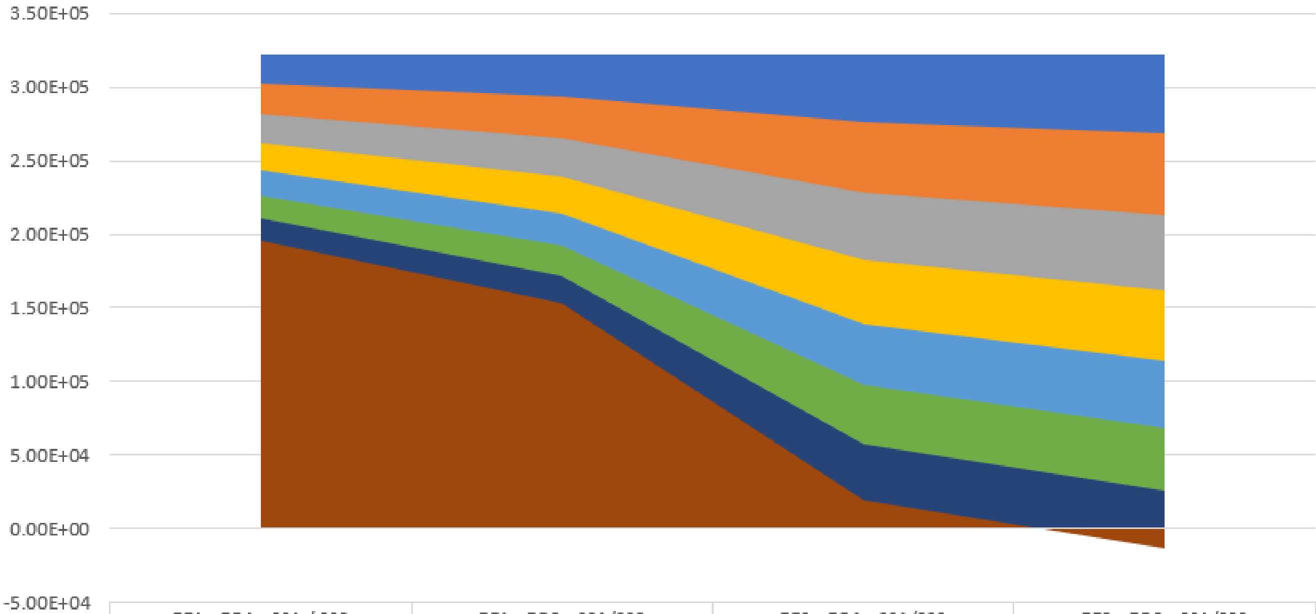
Environmental analysis

Environmental analysis has been conducted for each of the nine scenario combinations to determine the yearly CO_2 emissions linked to the energy consumption in the following sectors: residential, transport, commercial and industrial. The goal of this analysis is to determine if all the scenarios lead to carbon-neutrality by 2030. This environmental analysis is based on the amount of electricity to purchase from the grid, the consumption of natural gas, and the consumption of gasoline and diesel. Considering the technical analysis and the calculation of the daily electricity balance in batteries detailed in appendix D, it has been determined:

- The amount of electricity to be purchased from the grid yearly;
- The amount of natural gas necessary to cover the heating needs yearly;
- The amount of diesel and gasoline necessary to cover the transportation needs yearly.

The yearly CO_2 emissions for each scenario can be calculated using the CO_2 contents of those energy vectors.
Moreover, by relying on the calculation of the maximum number of trees that can be planted yearly, the maximal CO_2 capture can be calculated for each year. As a result, the CO_2 balanced can be calculated as the CO_2 emissions minus the CO_2 capture yearly for each scenario.

Results:
The details of the hypothesis, data, and calculations performed are available in Appendix D.



	EE1 - EG1 - SS1 / SS2 1,2	EE1 - EG2 - SS1/SS2 3,4	EE2 - EG1 - SS1/SS2 5,6	EE2 - EG2 - SS1/SS2 7,8
2023	3.22E+05	3.22E+05	3.22E+05	3.22E+05
2024	3.02E+05	2.94E+05	2.77E+05	2.68E+05
2025	2.82E+05	2.66E+05	2.29E+05	2.13E+05
2026	2.62E+05	2.39E+05	1.83E+05	1.62E+05
2027	2.44E+05	2.15E+05	1.39E+05	1.14E+05
2028	2.26E+05	1.92E+05	9.74E+04	6.85E+04
2029	2.10E+05	1.72E+05	5.74E+04	2.64E+04
2030	1.95E+05	1.53E+05	1.93E+04	-1.27E+04

2023 2024 2025 2026 2027 2028 2029 2030

Figure IV.14: Environmental Analysis (CO_2 balance)

Interpretation of the results:
This environmental analysis shows that considering the hypothesis used for this case study, only two scenarios lead to carbon neutrality by 2030.

- The combination of the ideal scenario for energy efficiency and energy generation with a storage system with batteries in the neighborhood: scenario 8;
- The combination of the ideal scenario for energy efficiency and energy generation without energy storage in the neighborhood: scenario 7.

Although it is possible to achieve carbon-neutrality by using the grid as a storage system, this solution is not suitable if carbon-neutrality is extended to all the districts. Indeed, physical energy storage in the district is necessary to not overload the grid and limit the risk of blackouts. To this extent, scenario seven is considered non-compatible with the carbon-neutral El Cabañal project. In that case, if the storage system do not cover the electricity demand, the difference will be purchased from the national grid.

Economic analysis

A simplified economic assessment of the investment required for scenario eight has been performed to estimate the economic investment necessary to fund a carbon-neutral project in the neighborhood. The details of the hypothesis, data, and calculations performed are available in Appendix D.

Results:

Table IV.8: Investment breakdown for scenario 8

Investment break down [m€]	Scenario 8
Investment energy efficiency	**98.6**
Investment energy efficiency - Refurbishment	*92.5*
Investment energy efficiency - Electric vehicles	*3.6*
Investment energy efficiency - Heaters	*2.5*
Investment energy generation	**60.1**
Investment energy generation - PV pannels	*58.3*
Investment energy generation - DH/DC	*1.8*
Investment storage system	**77.2**
Investment CO_2 removal	**11.4**
Total investment	**247.3**

Interpretation of the results

In total, the project of carbon-neutral El Cabañal for 2030 will require an investment of 247.3 million euros. The increase of energy efficiency is the most significant source of investment, accounting for 40% of the total investment, followed by the storage system accounting for 31% of the total investment. Both public and private sectors must subsidize the project to cover this investment.

Social analysis

A simplified stakeholders analysis for scenario eight has been performed based on author estimations to estimate the social actions to be implemented to develop a carbon-neutral project in the neighborhood
Results

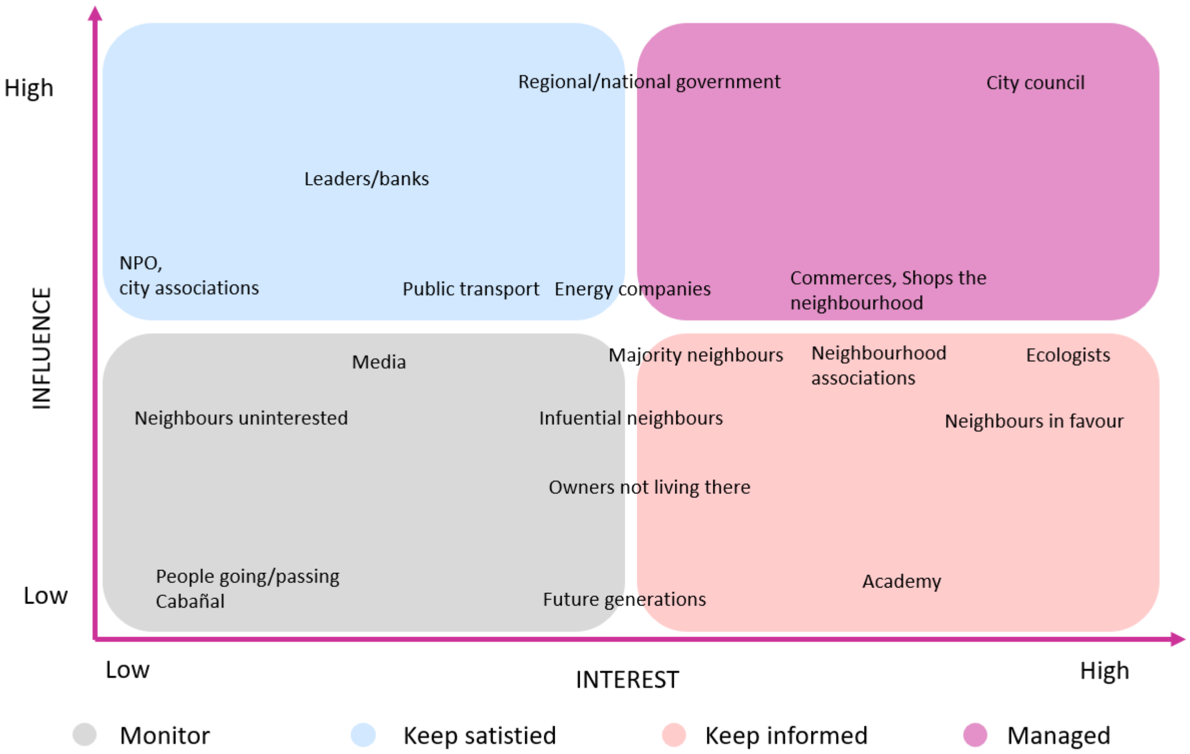


Figure IV.15: Stakeholders map

Intepretation of the results:

- If the stakeholders have a low to medium interest and low to medium influence, the team project needs to monitor it to claim that this group does not change the plans of the project. No special action is required for this group of stakeholders;
- If the stakeholders have a low to medium interest and a medium to big influence, the management strategy is to keep this group satisfied because they can change or finish the project due to their influence. In that case, this means, for example, meeting all the deadlines and engagements defined;
- If the stakeholders have a high to medium interest and a low to medium influence, the management strategy is to keep them informed to confirm their support to the project by inviting them to an information meeting and milestones presentations;
- If the stakeholder has a medium to high interest and medium to big influence, the team needs to manage this group closely; they are the key stakeholders. An example of actions is to imply them into decision-making strategy as well as the definition of the project objectives and actions road map from the very beginning.

IV.3.3 Scenario choice

Considering the four-axis analysis: technical, environmental, economic, and social conduct, scenario 8 is the most adapted to reach carbon-neutrality in El Cabañal in 2030. This scenario has been used to illustrate the adapted balanced scorecard methodology and how to apply it to the follow-up of a carbon-neutrality project.

IV.4 Application of the adapted Balance Scorecard Methodology to El Cabañal

The general methodology presented beforehand is intended to be adapted to El Cabañal, depending on the data available and in collaboration with the local stakeholders. This part presents a proposal of the application of the methodology for El Cabañal relying on the scenario chosen.

IV.4.1 Objectives and specific objectives included in the analysis

This part presents the objectives and specific objectives included in the analysis performed for the case study. All the main objectives of the axes GHG emissions, citizens, and resources and processes identified in the scope of the general methodology have been included. The specific objectives of the axis "city council organization" have been considered out of the scope of the study.

IV.4.2 Analytical Hierarchy Process for El Cabañal

As mentioned in the part III, the criteria selected may not have the same importance depending on the project and the neighborhood considered. To select the indicators which take into consideration the particularities of El Cabañal, an AHP should be conducted directly with the city stakeholders. In this master thesis, because of a lack of time to conduct the study, the author performed this AHP methodology. The pairwise comparison matrix, based on the comparison the criteria pairwise, is presented in Table IV.9. In this matrix, for instance, a number of 5 in the line measurability and column user-friendliness means that measurability is 5 times more important for stakeholders than user-friendliness. This evaluation relies on a subjective analysis from the author based on a carbon-neutral projects review. The consistency of the matrix is valid as it is equal to 1.6%, which is below the required limit of 10% [40].

Table IV.9: Pairwise comparison matrix for the AHP methodology

	User friendliness	Measurability	Temporality	Specificity
User friendliness	1	1/5	1/3	1/3
Measurability	5	1	3	3
Temporality	3	1/3	1	1
Specificity	3	1/3	1	1

The calculation detailed in Appendix A results in the weight distribution presented in Table IV.10. The results are rounded to tenth.
The pondered average value is calculated based on the following formula to obtain the AHP grade for each indicator, :

$$AHPvalue = \sum_{i=1}^{4} (C_i * W_i) \tag{IV.1}$$

Where Ci = grade of the indicator for the criterion i,
and Wi = weight of the criterion i

Table IV.10: Criteria weight distribution for AHP methodology

User friendliness	**8%**
Measurability	**52%**
Temporality	**20%**
Specificity	**20%**

The grade of each indicator in this case study is presented in Appendix E.

IV.4.3 Indicators selection

The indicator selection followed the same process as presented in figure III.3 of part III. Regarding the results of the AHP methodology for this case study, it has been decided that if there is only one indicator with the highest AHP grade, the second highest is selected as well to have a complete overview of the specific objective. Concerning the numerical index building presented in the general methodology, it has been assumed that the weight of each indicator will be calculated using the pondered average with their AHP grade (Equation IV.1).

IV.4.4 Targets definition

In this case, all the targets calculated refer to technical indicators. Following the target definition process presented in figure IV.16 and because almost no data are available at the moment, references systems presented in Appendix D have been used for the calculation. In that case, the social, technical, and environmental optimizations have already been performed for the scenario selection. Thus, when relying on the scenario chosen in part IV.3, the yearly targets for each indicator selected can be calculated. Indicators among the technical ones have been chosen and their yearly targets to meet carbon neutrality by 2030 have been estimated for this master thesis. The calculation of these targets will show how the adapted balanced scorecard methodology can work to follow up a carbon-neutrality project. Social and economic targets must be defined with the stakeholders and experts of the subject. A total of 20 targets have been calculated yearly for the neighborhood, relying on the simulations performed for the chosen scenario presented in the last part. Appendix F details the calculations and hypothesis used to calculate these targets.

IV.4.5 Thresholds definition

Similar to the definition of the targets, three thresholds have been calculated for selected indicators to illustrate the use of the adapted balanced scorecard methodology. Thresholds must be defined for each indicator by the project managers, to perform the follow-up of the project,
The following thresholds have been calculated for three indicators:

1. Greenhouse gas emissions in energy supply: It has been supposed that the first threshold is reached when the yearly emissions reduction target is half reached, the second threshold is reached when the target value is reached;

2. Thermal energy savings in residential: It has been supposed that the first threshold is met when the thermal energy savings target is reached at 70%, the second threshold is met when this target is entirely reached;

3. Capacity of energy storage: It has been supposed that the first threshold is met when the storage capacity is higher than the target of the previous year, the second threshold is met when the storage capacity is equal to the yearly target.

IV.5 Results and discussion

This part presents the results obtained by relying on the methodology presented and the hypotheses assumed for the case study of El Cabañal. The part is divided into three sections. The first section describes the three levels of indicators to build to assess the carbon-neutrality of the neighborhood, El Cabañal. The second section presents examples of targets for specific indicators to transform the district into a carbon-neutral district. The last part details how to use the adapted balanced scorecard methodology for the follow-up of the project. Each part contains a discussion of the results and the hypothesis made.

IV.5.1 Indicators of the project carbon-neutral el Cabañal

This result part presents the identification of the three levels of indicators for the case study and the thresholds identified. Tables IV.11 and IV.12 presents the background indicators for each specific objective, Table IV.13 presents the specific indicators identified for each specific objective, and Table IV.15 presents the key performance indicators identified for each main objective. Descriptions about every indicator included in these figures can be found in Appendix E. Overall a total of 111 indicators distributed over the three hierarchy levels are obtained with the methodology.

a) Background indicators

Tables IV.11 and IV.12 detail the background indicators obtained with the previous methodology for the specific objectives considered. A total of 63 background indicators have been identified. Nine of the specific objectives do not contain background indicators; in this case, the table refers as "only specific indicators."

b) Specific indicators

The application of the methodology to the case study led to the selection of 36 specific indicators presented in Table IV.13. Each specific objective is covered by at least one specific indicator and at maximum by four specific indicators.

Objective	Specific objective	Background indicator with the best AHP grade	Unit
Decrease other pollution	*Reduce other pollution*	Only specific indicators	-
Decrease GHG emissions	*Decarbonize energy generation*	Only specific indicators	-
	Decarbonize residential sector	Only specific indicators	-
	Decarbonize transportation	Only specific indicators	-
Increase citizens satisfaction	*Increase thermal confort*	Only specific indicators	-
	Develop advantages for citizens	Number of customers that are positive about how energy systems are controlled (Nc)	number
		Number of people using ICT related platform (Nict)	number
		Advantages for stakeholders (A)	Likert scale
Increase inclusiveness	*Develop inclusive projets*	Only specific indicators	-
	Favorize neighbourhood diversity	Only specific indicators	-
	Increase involvment of minorities	Only specific indicators	-
Increase citizens engagement	*Increase citizens involvement*	Only specific indicators	-
Increase citizens information	*Inform citizens*	Only specific indicators	-
Increase ressources efficiency	*Increase efficiency in the residential sector*	Distribution of energy source for buildings heating and cooling	GWh/Year
		Distribution of residential energy use (SHW, conditioning, heating...)	%
		Energy consumption of public buildings	kWh/m²
		Energy use from district heating	kWh/year
		Final energy consumption	kWh/m²
		Primary energy demand and consumption	kWh/m²
	Increase effiency in commercial and indutrial sector	Distribution of commercial and industrial energy use (SHW, conditioning, heating, industrial processes...)	%
	Increase efficiency in transportation	Carpooling location	number
		Clean mobillity utilisation	number/km
		Passenger-km public transport and private vehicle	km
		Number of efficient vehicles deployed in the area	number
		Yearly km made through e-car sharing systems	km
		Kilometres of high capacity public transport system per 10000 population	km/ 100 000 inh
		km of bycicle paths and lines per 100 000 population	km/100 000inh
		Cost of monthly ticket for public transport in relation with averge wage	€
		Number of personal auto per capita	number/capita
		Daily average lenght by each transport type	km/vehicle/day
		Percentage of electric vehicles	%
		Daily average time by trip	years
		Distribution of vehicles in the city	number

Table IV.11: Background indicators for the case study- Table 1

Objective	Specific objective	Background indicator with the best AHP grade	Unit
	Net zero water	% of water re-used on site	%
		Water surface per capita	m²
	Net zero waste	% of waste recycled on-site and nearby	%
		% of low-GHG emission contruction material	%
		% of recycled construction material	%
		% of reused construction material	%
Green-energy generation	*Develop renewable energy*	energy use (PV, biomass, solar thermal, hydraulic, minieolic, geothermal)	kWh/year
		Increase in local renewable energy generation	%
		Degree of energetic self-supply by RES	%
	Increase enegy storage	Storage energy losses	%
		Battery degradation	%
	Increase quality of supply	Energy curtailment of RES (EC)	kWh
		Peak load (P)	kW
		Average default correction time (CT)	h/month
		Number of unexpected stops (reliability) (Ns)	number/day
Capture GHG emission	*Increase public green-area*	Increased % of green facades	%
		Increased % of green roofs	%
		Vegetable garden per dwelling	m²
Optimize internal processes	*Promote energy transition projects*	Payback period	years
		Total annual costs	€/year
		Return on investment	%
		Financial benefit for the end-user	€/household/year
		Total investments	€
		Grants	%
		% of the project contribution to the municipal budget	%
	Increase quality of data and monitoring systems	Datasafety (Ds)	number/day
		Quality of open data (Q)	%
		Expiration date of open data (Ed)	%
		Number of sensors deployed in the city (Nse)	number
	Develop a legal framework for energy transition projects	Signature of covenent of mayor (Sc)	binary
		Existence of regulations for development of energy efficient districts (Re)	number
		Existence of local/ national energy performance certificate (Rp)	number
		Existence of regulations for development of sustainable mobitily (Rs)	number
Develop local economy	*Decrease energy costs*	CO2 reduction cost efficiency	€/tonCO2
		Reduction of energy price by ICT related technology	%
		Fuel poverty	%
	Develop new jobs	Number of sustainable jobs created locally	number
		Stimulating an innovative environment	no unit

Table IV.12: Background indicators for the case study- Table 2

Objective	Specific objective	Specific indicator with the best AHP grade	Unit
Decrease other pollution	*Reduce other pollution*	Air quality index	ppm or g/m3
		Decreased emissions of oxides (NOx)	%
		Decreased emissions of particulate matter	%
Decrease GHG emissions	*Decarbonize energy generation*	Greenhouse gas emissions in energy generation	gCO2eq/kWh
	Decarbonize residential sector	Greenhouse gas emissions in residential buildings	gCO2eq/kWh
	Decarbonize commercial and industrial sector	Greenhouse gas emissions in commerce and industry	gCO2eq/kWh
	Decarbonize transportation	Greenhouse gas emissions in transportation	gCO2eq/kWh
Increase citizens satisfaction	*Increase thermal confort*	Number of hours per year where the inside temperature is higher (summer) or lower (winter) than the set point temperature	h
	Develop advantages for citizens	Index based on colour scale	colour (green,yellow or red)
Increase inclusiveness	*Develop inclusive projets*	% of social housing	%
	Encourage neighbourhood diversity	Repartition of incomes categories	%
	Increase involvment of vulnerable groups	Participation of vulnerable groups	Likert scale
		People reached in each target groups indentified	%
Increase citizens engagement	*Increase citizens involvement*	% of citizens environmental-friendly	%
		% of inhabitants involved in the project of the neighborhood	%
		Consumers engagement	number
		Professional stakeholders involvement	Likert scale
Increase citizens information	*Inform citizens*	Training of citizens on environmental behaviour	Likert scale
		Environmental education	number
		Number of awareness campaigns	number
Increase ressources efficiency	*Increase efficiency in the residential sector*	Total energy demand in residential area in the neighborhood.	kWh/day
		Total energy consumption in the residential area in the neighbourhood.	kWh/day
		Thermal energy savings	kWh/year
	Increase efficiency of the commercial and industr	Total energy demand in the neighborhood.	kWh/day
	Increase efficiency in transportation	Total energy consumption in the transportation area in the neighbourhood.	kWh/day
	Net zero waste	Quantity of waste produced per activity and per inhabitants.	kg/hab/day
	Net zero water	Water consumption per activity and per inhabitants	L/hab/day or m3/hab/day
Green-energy generation	*Develop renewable energy*	Daily total renewable energy generation.	MWh/day
	Increase enegy storage	Capacity of energy storage	% of energy produced / year
	Increase quality of supply	Weight-based index (IQ)	Number between 0 and 1
Capture GHG emission	*Increase public green-area*	Greenspace per inhabitant (parks, urban trees, places...)	m²/inh
Optimize internal processes	*Promote energy transition projects*	% of the project financed by the municipal budget	%
	Increase quality of data and monitoring systems	Weight-based index (IQd)	Number between 0 and 1
	Develop a legal framework for energy transition p	Weight-based index (IL)	Number between 0 and 1
Develop local economy	*Decrease energy costs*	Energy cost	€/kWh
	Develop new jobs	Local job creation	number

Table IV.13: Specific indicators for the case study

Formula and details for index calculation Weight-based indexes
The formulas to build the index indicators presented in the previous tables are detailed in this part. The variable names refer to the background indicators presented in Table IV.11. In that case:

- I_Q= Increase quality of supply index
- $I_Q d$= Increase quality of data and monitoring systems index
- I_L= Legal framework development index

The indice t corresponds to the current value of the variable while the indice 0 refers to the comparison basis chosen for each variable, to be set by the dashboard user.
The weight of each background indicator is not calculated in this thesis but can be calculated thanks to AHP rates and weighted average.

$$I_Q = \frac{Ec_t \times W_{Ec} + P_t \times W_P + Ct_t \times W_{Ct} + Ns_t \times W_{Ns}}{Ec_0 \times W_{Ec} + P_0 \times W_P + Ct_0 \times W_{Ct} + Ns_t \times W_{Ns}} \tag{IV.2}$$

$$I_{Qd} = \frac{Ds_t \times W_{Ds} + Q_t \times W_Q + Ed_t \times W_{Ed} + Nse_t \times W_{Nse}}{Ds_t \times W_{Ds} + Q_t \times W_Q + Ed_t \times W_{Ed} + Nse_t \times W_{Nse}} \tag{IV.3}$$

$$I_L = \frac{Sc_t \times W_{Sc} + Re_t \times W_{Re} + Rs_t \times W_{Rs}}{Sc_0 \times W_{Sc} + Re_0 \times W_{Re} + Rs_0 \times W_{Rs}} \tag{IV.4}$$

Color scale indexes
Regarding the color scale indexes, the approach presented in the general methodology is to assign the highest weight to the indicator with the highest AHP grade. For example, the index based on a color scale for the specific objective "develop advantages for citizens" relies on three indicators: Number of customers that are positive about how energy systems are controlled (Nc), Number of people using ICT related platform (Nict), and advantages for stakeholders (A). The value of these background indicators need to be converted to color scale based on discussion with projects stakeholders, and the index can be built following Table IV.14.
An indicator in green does not require any action, an indicator in orange is an alert, while an indicator in red indicated a problem.

Table IV.14: Example colour index building

Colour index	Combination Nc-Nict-A
	GGG, GGY, GGR, GYG, GYY, GYR
	GRG, GRY, GRR, YGG, YGY, YGR, YYG, YYY, YYR
	YRG, YRY, YRR, RGG,RGY,RGR,GYG,RYY,RYR,RRG, RRY, RRR

c) Key performance indicators

The application of the methodology to the case study led to the selection of 11 key performance indicators presented in Table IV.15. Each main objective corresponds to one key performance indicator.

Formula and details for index calculation

Factor analysis-based and color-scale-based indexes are obtained in the same way as for specific indicators.

Objective	Key performance indicators (KPIs)	Unit
Decrease other pollution	*Air pollution index taking into account the Nox and the particulate matter emitted instantaneously*	ppp or g/m3
Decrease GHG emissions	*Daily average greenhouse gas emissions per capita*	tCO2eq/day
Increase citizens satisfaction	*Colour-scale based index*	colour (green,yellow or red)
Increase inclusiveness	*Colour-scale based index*	colour (green,yellow or red)
Increase citizens engagement	*Colour-scale based index*	colour (green,yellow or red)
Increase citizens information	*Colour-scale based index*	colour (green,yellow or red)
Increase ressources efficiency	*Weight-based index*	Number between 0 and 1
Green-energy generation	*Weight-based index*	Number between 0 and 1
Capture GHG emission	*Daily quantity of CO2 captured divided by the district's CO2 emissions compared to average value of the last month.*	%
Optimize internal processes	*Weight-based index*	Number between 0 and 1
Develop local economy	*Colour-scale based index*	colour (green,yellow or red)

Table IV.15: Key performance indicators for the case study

Discussions

The final number of indicators appears to be quite high regarding the study's objective to make the follow-up of indicators easier for the project stakeholders. However, even though this case study presents a complete framework necessary to analyze energy transition in a carbon-neutral district, part of it can also be used depending on the project's complexity and time frame. Moreover, additionally to the discussion concerning the general methodology, optimizing the indicators list for a given case study, necessary to obtain the final adapted balanced scorecard, relies on the estimation of grades for each indicator regarding each identified criterion. Those grades are put using a Likert Scale defined in Table III.7, which means that this analysis remains subjective and dependent on the author's interpretation. The optimization of the indicator list for each hierarchy level and the indexes construction is highly dependent on the result of the AHP methodology performed; in this case study, the AHP methodology has been conducted by the author relying on personal knowledge and benchmarking of carbon-neutral projects. Thus, the process remains subjective.

IV.5.2 Targets of the project carbon-neutral el Cabañal

Figure IV.16 presents the yearly targets calculated for a list of chosen indicators. The targets estimation relies most of the time on direct calculations on the results presented in appendix C and D. Appendix F details the calculation for the targets that are not direct calculation.

Yearly targets chosen scenario KPIs

Axes	Objective	Specific objective	KPI	Unit	2023	2024	2025	2026	2027	2028	2029	2030
GHG emissions	Decrease GHG emissions	-	Daily average greenhouse gas emisisons	kgCO2/d/inh ab.	45.7	38.1	30.4	23.1	16.3	10.0	4.1	-1.4
	Decrease other pollution	-	Air pollution index	number	50	43	36	29	21	14	7	0

Yearly targets chosen scenario specific indicators

Axes	Objective	Specific objective	Specific indicator	Unit	2023	2024	2025	2026	2027	2028	2029	2030
GHG emissions	Decrease GHG emissions	Decarbonize energy generation	Greenhouse gas emissions in energy supply	gCO2eq/kWh	142	134	125	115	103	89	71	46
		Decarbonize residential sector	Greenhouse gas emissions in residential	gCO2eq/kWh	160	136	105	76	48	23	0	-20
		Decarbonize commercial and industrial sector	Greenhouse gas emissions in commercial and industrial sector	gCO2eq/kWh	155	128	100	73	48	25	4	-16
		Decarbonize transportation sector	Greenhouse gas emissions transportation	gCO2eq/kWh	254	254	254	253	251	248	239	-20
Resources and processes	Increase resources efficiency	Increase efficiency in the residential sector	Total energy demand in the neighborhood	kWh/day	105850	100784	95719	90653	85587	80522	75456	70390
			Total energy consumption in the neighborhood	kWh/day	105850	100784	95719	90653	85587	80522	75456	70390
			Thermal energy savings residential	kWh/year	0	1991309	1991309	1991309	1991309	1991309	1991309	1991309
		Increase efficiency in the commercial and industrial sector	Total energy demand in the neighborhood	kWh/day	123239	117957	112675	107394	102112	96830	91549	86267
		Increase efficiency in the transportation sector	Thermal energy savings transportation	kWh/year	0	10680097	10680097	10680097	10680097	10680097	10680097	10680097
	Green energy generation	Develop renewable energy	Daily total renewable energy generation	kWh/day	0	16462	32178	47145	61365	74838	87564	99542
		Increase energy strorage	Capacity of energy storage	% of elec. Prod./d	0%	75%	78%	81%	85%	88%	92%	97%
	Capture GHG emissions	Increase public green area	Greenspace per inhabitant	m²/inh	1.4	2.4	3.4	4.4	5.4	6.4	7.4	8.4

Yearly targets chosen scenario background indicators

Axes	Objective	Specific objective	Background indicator	Unit	2023	2024	2025	2026	2027	2028	2029	2030
Resources and processes	Increase resources efficiency	Increase efficiency in the residential sector	Part of the heating and cooling demand covered by natural gas	%	100%	96%	81%	66%	51%	35%	18%	0%
			Energy use from district heating	kWh/y	0	1305613	3495841	5108373	6138480	6577272	6405850	5575665
		Increase efficiency in transportation	Number of efficient vehicles deployed in the area	number	171	171	171	171	171	171	171	0
	Green energy generation	Develop renewable energy	Increase in renewable energy generation	%	0%	100%	54%	33%	23%	17%	13%	10%
			Degree of energetic self-supply by RES	%	0%	15%	35%	54%	75%	96%	119%	142%
	Promote energy transition projects	-	Total investments	m€/y	42.2	41.3	41.0	40.7	40.3	40.0	39.7	0.0

Figure IV.16: Targets calculations for chosen indicators - Case study

Discussion

As mentioned in the methodology in part III, the targets have been defined only for a list of chosen indicators to illustrate the adapted balanced scorecard methodology. The list of targets obtained yearly answer to the objectives of having an overview of targets calculation for the case study to test the general methodology. However, to enable a complete project follow-up, it will be necessary to define the remaining targets together with the project's stakeholders. Moreover, the numbers used for the calculations of these targets relies on the scenario analysis performed. This scenario gives a technically realistic overview of the steps to transform the neighborhood into a carbon-neutral place by 2030 but still constitutes simplified engineering of the energy systems, which is not considering for example:

1. Comparison of scenario with other renewable energy sources: biomass boilers, wind turbines, thermal solar systems, or burning wastes;
2. Variation of variable's sensitivity: for the calculation, the sensitivity of each variable has not been included in this simplified model. Moreover, the equipment considered have been selected are examples, and further benchmarking is necessary to find the adapted equipment for the neighborhood. This sensitivity can be obtained, for instance, with a simulation with the software Homer;
3. Analysis based on monitored data: the electric and thermal demand have been calculated relying on consumption data for the year 2020 and assumptions. These data must be collected and monitored directly in the neighborhood to increase the accuracy of the analysis;
4. Deeper environmental, economic and social analysis: the calculation performed for this analysis gives an overview, but further analysis need to be conducted upstream of the project; for example, the environmental analysis will need to include environmental impact analysis of the new renewable energy generation system, and the economic analysis will need to include a calculation of the Net Present Value of the project and not only the investment.

IV.5.3 Adapted balanced scorecard of carbon-neutral El Cabañal

To apply the adapted balanced scorecard to the neighborhood, a strong implication of local stakeholders is necessary. However, to validate the balanced scorecard methodology, an example of use is presented in this part.

Thresholds calculations

The two thresholds calculated yearly for key performance indicators and the three selected specific indicators are presented in Table IV.16 and Table IV.17.

KPI	Value	Unit	Condition	2023	2024	2025	2026	2027	2028	2029	2030
Daily average greenhouse gas emissions	Target	kgCO2/d/inhab.		45.7	38.1	30.4	23.1	16.3	10.0	4.1	-1.4
	Threshold 1	kgCO2/d/inhab.	The target GHG emissions reduction between two years is half achieved	-	41.9	34.2	26.7	19.7	13.2	7.0	1.3
	Threshold 2	kgCO2/d/inhab.	The target GHG emissions reduction between two years is achieved	45.7	38.1	30.4	23.1	16.3	10.0	4.1	-1.4

Table IV.16: Thresholds KPI example

Specific indicator	Value	Unit	Condition	2023	2024	2025	2026	2027	2028	2029	2030
Greenhouse gas emissions in energy supply	Target	gCO2eq/kWh		142	134	125	115	103	89	71	46
	Threshold 1	gCO2eq/kWh	The target GHG emissions reduction between two years is half achieved	-	138	130	120	109	96	80	59
	Threshold 2	gCO2eq/kWh	The target GHG emissions reduction between two years is achieved	142	134	125	115	103	89	71	46
Thermal energy savings residential	Target	kWh/year		0	1991309	1991309	1991309	1991309	1991309	1991309	1991309
	Threshold 1	kWh/year	The thermal energy savings target is achieved at 70%	0	1393916	1393916	1393916	1393916	1393916	1393916	1393916
	Threshold 2	kWh/year	The thermal energy savings target is achieved	0	1991309	1991309	1991309	1991309	1991309	1991309	1991309
Capacity of energy storage	Target	% of elec. Prod./d		0%	75%	78%	81%	85%	88%	92%	97%
	Threshold 1	% of elec. Prod./d	The capacity of energy storage is at least equal to the target of the previous year	0	60%	75%	78%	81%	85%	88%	92%
	Threshold 2	% of elec. Prod./d	The capacity of energy storage target is met	0%	75%	78%	81%	85%	88%	92%	97%

Table IV.17: Thresholds specific indicators examples

The thresholds will determine the alerts sent to the user. When an indicator is below the first threshold, an alert is sent, went it is below the second one, a warning is sent. A time frame for the comparison can be defined to avoid overloading the user with alerts. For example: if the indicator "daily greenhouse gas emissions per capita" is below the threshold on average for more than one month, then an alert is sent to the user. The settings must be done directly by the user.

Use case description

This part describes two use cases for the balanced scorecard dashboard relying on the indicators, targets and thresholds obtained.

Use case 1

The user sees that the index-based key performance indicator for green-energy generation is not meeting the target: the indicator is red or yellow. To understand the reason, the user can analyze the corresponding specific indicators. In that case, the specific indicators are: Develop renewable energy, Increase energy storage, Increase quality of supply.
For example, if the indicator "capacity of energy storage" is red, the user directly understands that this is the main problem with green energy production. There can be several reasons why the storage system target is not met:

1. If the indicator is yellow, this means that the first threshold is met, knowing that the first threshold corresponds to the target of the previous year, it means that the yearly increase of the installed storage system capacity is not met: the interpretation will then be different if the analysis is performed in January or in December. If the indicator is not turning green at the end of the year, it means it will turn red at the beginning of the following one, and the targets will not be met.

2. If the indicator is red, it can mean that the installed capacity of the storage system is well below the target as mentioned previously. Alternatively, if the indicator suddenly turns red in the middle of the year, it can comes from a problem with the storage system. In that case, the user can check the corresponding background indicators that give information on the energy losses because of the battery system and on the degradation state of the batteries.

Use case 2
The user sees that the key performance indicator for "daily average greenhouse gas emissions" is red, which means its value is below the first threshold. To understand the reason, the user can analyze the corresponding specific indicators. In that case, the specific indicators are

- Greenhouse gas emissions in energy supply;
- Greenhouse gas emissions in residential buildings;
- Greenhouse gas emissions in the commercial and industrial sector,
- Greenhouse gas emissions in transportation.

The user can see if one is below the first or the second threshold to identify the origin of the problem. For example, if the greenhouse gas emissions in residential buildings are above the first threshold, the corresponding indicator will be red, and the user can assume that it is because a considerable part of the heating and cooling needs are covered by natural gas. It refers to resource efficiency; thus, to confirm his assumption, the user can go through the balanced scorecard dashboard and check the indicators for the specific objective "Increase resource efficiency in the residential sector," if the thermal energy savings indicator is below the first threshold, it confirms his assumption.
However, if he wants to understand the reason, he can check the corresponding background indicators: the indicator "Distribution of energy source" will help him quantify the problem. If the share of natural gas is not meeting the target, it can be because:

1. The consumption of energy is higher than the demand, and consumption of gas is higher. To confirm this, he can check the indicator "final energy consumption" if this is higher than expected, the user can check the indicator "thermal comfort" to see if the problem comes from a lack of efficiency of buildings or rather misbehavior in energy use. If the problem comes from misbehavior in energy use, the user can check for example, the social indicators for the specific objective "inform citizens";
2. The transformation of the heating systems is not achieved:
   (a) If the share of district heating is not meeting the target, it can mean that the consumption of natural gas is higher because the objective of energy produced by district heating is not met. It can also be verified by checking the indicator "energy use for district heating" or by analyzing the indicators for the specific objective "renewable energy generation";
   (b) If the share of electricity is not meeting the target, it can be because the share of heating systems replaced to the efficient electric system is too low.

The same analysis can be performed if problems arise from a higher CO_2 intensity in transportation, industry, or energy generation.

Discussion

The adapted balanced scorecard methodology applied to the case study of El Cabañal meets the objective to provide a decision-making tool for projects manager by giving an overview of all the project's aspects with relevant indicators analysis. However, so that the analysis is accurate, an important work upstream of the project is necessary:

1. A robust monitoring system is necessary upstream from the project implementation: this requires not only the installation of captors and sensors to monitor the different variables but also the development of a data network to integrate the variables coming from external service providers;

2. A phase of settings with local stakeholders: As mentioned several times in the description of the methodology, the involvement of projects stakeholders, and especially working closely with the city council responsible for the project is necessary to: perform the AHP methodology, rate the indicators, set the targets and the thresholds: this implies strong coordination between the projects managers and the local stakeholders;

3. A meticulous update process: the additional value of the balanced scorecard methodology is to provide the user with real-time alerts. A data update process must be set for the non-monitored data.

V Conclusions

Cities must adapt and reinvent the urban area to mitigate the effects and adapt to the challenges of climate change as well as prevent the increasing energy demand from resulting in a rise in natural resources consumption. The climate action policies and the energy planning initiatives worldwide would be a pivotal point to help cities solve those problems. Numerous cities are already beginning worldwide to set carbon-neutrality goals. Therefore, it is crucial to provide tools to assess the strategies and the measures they are taking. Assessing the energy transition at a city level is challenging and results in many frameworks in a narrowed focus on the energy performance of the cities infrastructures. However, technical adaptation alone will not be enough to make cities more sustainable. Cities must view the global transition, which relies on the measures of environmental, economic, and social impacts. Cities should have a specific analysis and follow-up of their actions and compare them with comparable projects to optimize urban energy transition measures and results, This research study presents a general methodology to build a dashboard of indicators and targets to follow-up energy transition projects to achieve carbon-neutrality. This study aims at providing cities with an easily understandable but complete tool to simplify carbon-neutral districts projects. The resulting dashboard is city-specific and gives a comprehensive overview of all the energy transition objectives to achieve carbon-neutrality for a given project. To this extent, this dashboard contains:

1. The objectives of energy transition for carbon-neutrality projects that have been identified through a literature review and benchmarking on existing projects. Not only technical but also environmental, social, and economic objectives have been included in the scope of the study;
2. An optimized three-level set of indicators to facilitate the navigation from a complete overview of the project to objective's specific details. The methodology to build this indicator set relies on aggregating five existing frameworks and developing a procedure to grade and select the most adapted indicators for a given city or project. The strength of this tool is to provide a general list of indicators, thus it can be easily used and reproduced by different cities. This work presents the set of indicators obtained for the case study of El Cabañal, in Valencia (Spain);
3. A project-specific list of targets and thresholds for each indicator to monitor the project. This work presents the set of indicators obtained for the case study of El Cabañal in Valencia (Spain).

While the key findings of the case study clearly show the validity and completeness of the general methodology, it also raises the question of the subjectivity of the indicators rating procedure. Moreover, it highlights the complexity of shortening the list of indicators when it comes to covering all the objectives.
Finally, future work should address the main drawbacks and gaps identified in the methodology and focus on:

1. Increasing the reliability of the indicators selection tool by adding the analysis of other methodologies or indicators frameworks to the scope of the tool;
2. Finding a more selective and non-subjective way to rate the different indicators for the identified criteria;
3. Elaborating a system allowing to assess a different project or city-specific criteria,

4. Developing a mathematical model to build index-based indicators based on factor analysis.

To conclude, this work addresses the carbon-neutral district assessment framework gap identified in the literature. The presented methodology constitutes a basis for developing a follow-up dashboard to assess energy transition projects to achieve carbon-neutrality in European cities.

VI | Budget

This part aims at presenting an estimation of the budget necessary to perform this study in the industry or with a consultancy firm.
The calculation of the budget is divided into three axis: human resources costs, equipment costs and general costs.

VI.1 Human resources costs

This project has been led for a Master Thesis counting for 30 ECTS, which is equivalent to 900 hours of work for the author. This time schedule is divided into 4 parts: the literature review, the general methodology proposal, the case study simulation and the writing of the report.
The support of the doctoral student helping with the project has been estimated to 30 hours, and the support of the supervisor to 50 hours. Table VI.1 presents the induced costs due to human resources:

Table VI.1: Estimated budget human resources

Task	**Responsible**	**Nb. of hours [h]**	**Cost per hour [€/h]**	**Total cost [€]**
Litterature review	Junior Engineer	150	30	4500
General methodology	Junior Engineer	400	30	12000
Case study simulation	Junior Engineer	200	30	6000
Writing	Junior Engineer	150	30	4500
Review and Guidance	Doctoral Student	30	50	1500
Review and Guidance	Professor	50	70	3500
			Total cost	**32000**

VI.2 Equipment

For this study, no particular technical equipment has been used, only the computer use is included in the cost calculation. The cost allocated to the project has been calculated by dividing the number of hours of use for the project by the estimated total hours of life of the devide. Table VI.2 details the costs linked to the equipments.

Table VI.2: Estimated budget equipment

Equipment	**Price [€]**	**Amortisation period [y]**	**Use period [h]**	**Cost [€]**
Laptop Junior Engineer	1000	5	900	20.5
Laptop Doctoral Student	1000	5	100	2.3
Laptop Professor	1500	5	200	6.8
			Total cost	**29.7**

VI.3 General Costs

Finally, the general bills linked to the project (internet and electricity) have been included in the budget. The price per month has been calculated proportionally to the number of people living in the author apartment. Table VI.3 presents the costs linked to these bills.

Table VI.3: Estimated budget General Costs

Bill	**Unit cost [€/month]**	**Cost [€]**
Shared internet bill	20	120
Shared electricity bill	50	300
	Total cost	**420**

VI.4 General Budget

The three previous parts have been aggregated to obtain the gross execution budget. To this budget, a margin of 10% for the executive company and a IVA of 21% have been applied, leading to a final contractual budget of 42 509 € for the project.

Table VI.4: Total budget for the project

Category	**Cost [€]**
Budget Human Resources	32000
Budget Equipment	30
Budget General Cost	420
Industrial profit (10%)	3245
Taxes (IVA 21%)	6814
Contractual budget	**42509**

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Appendices

A | Analytical Hierarchy Process

This appendix details the calculation performed through the AHP methodology to obtain the weight of each criterion in the indicators' selection process. This methodology relies on three main steps : binary comparison matrix, calculation of the eigenvalues, analysis of the consistency.

A.1 Binary comparison matrix

The binary comparison matrix consists of comparing all criteria two by two. Thus, for all column and line :

$$a_{ji} = a_{ij}^{-1}$$

The criteria are compared based on the scale presented in the following table.

Table A.1: Scale for comparison matrix

Numerical scale	Verbal scale
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importances
2,4,6,8	Intermediate values

A.2 Calculation of the eigenvalues

The final weight of each criterion is calculated through the eigenvalue of the binary comparison matrix. To calculate the eigenvalue, the following process is iterated until the convergence of Sn at 10E-3. Table A.2 presents the calculations for the master thesis, where:

- A = Binary comparison matrix
- S = Vector with the sum of each column of A
- Sn = Normalized vector with the values of S divided by the vector norm.

Table A.2: Eigenvalues calculation

1st iteration					
A^2				S	Sn
4.0	0.6	1.6	1.6	7.8	0.0769
28.0	4.0	10.7	10.7	53.3	0.5245
10.7	1.6	4.0	4.0	20.3	0.1993
10.7	1.6	4.0	4.0	20.3	0.1993
2nd iteration					
A^2				S	Sn
67.6	10.1	25.8	25.8	129.3	0.0781
451.6	67.6	172.8	172.8	864.7	0.5222
172.8	25.8	66.1	66.1	330.9	0.1998
172.8	25.8	66.1	66.1	330.9	0.1998
3rd iteration					
A^2				S	Sn
18052.7	2699.4	6907.7	6907.7	34567.6	0.0781
120729.9	18052.7	46196.1	46196.1	231174.9	0.5222
46196.1	6907.7	17676.5	17676.5	88456.9	0.1998
46196.1	6907.7	17676.5	17676.5	88456.9	0.1998
4th iteration					
A^2				S	Sn
1.3E+09	1.9E+08	4.9E+08	4.9E+08	2470148334.3	**0.0781**
8.6E+09	1.3E+09	3.3E+09	3.3E+09	16519412083.1	**0.5222**
3.3E+09	4.9E+08	1.3E+09	1.3E+09	6320996832.2	**0.1998**
3.3E+09	4.9E+08	1.3E+09	1.3E+09	6320996832.2	**0.1998**

A.3 Consistency check

To validate the consistency of the methodology and the evaluation of the criteria, the consistency ratio (CR) must be calculated. With 4 criteria, this consistency ratio should be below or equal 0.08. The consistency ratio is calculated by dividing the consistency index (CI), depending on the dimension of the matrix n with the random consistency index (RI) equal to 0.89 for 4 criteria. The consistency index (CI) relies on the calculation of the eigenvalues (lambda), the identification of the maximal eigenvalues and the dimension of the matrix.

$$CR = \frac{CI}{RI}$$

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

In this thesis, CR = 0.015 which means the criteria assessment is consistent.

B | Calculation of energy consumption and greenhouse gases emissions in El Cabañal

B.1 Energy consumption

The calculation of the energy consumption has been performed for the following category : public lighting, residential sector, commercial sector, industrial sector and transportation. For those categories only the following energy vectors have been considered : electricity, natural gas, petrol and diesel.

B.1.1 Energy consumption public lighting, residential sector and industrial sector

For public lighting, residential sector, commercial sector and industrial the data for electricity consumption and natural gas consumption are available in the open data of the city of Valencia and detailed in figure B.1.

H1 = **All the districts have the same weight in the energy consumption**
With this hypothesis the energy consumption in El Cabañal, is obtained by diving the value of the Anuari with the number of inhabitants in the city of Valencia, and multiply this second value by the number of inhabitants in the neighbourhood. This calculation is presented in table B.2 and table B.3.

Table B.1: Energy consumption in Valencia

	Public lightning	**Residential**	**Comercial**	**Industrial**
Electricity [kWh]	4.33E+07	1.03E+09	1.42E+09	9.13E+07
Natural gas [kWh]		5.81E+08	1.43E+08	2.15E+08

Table B.2: Part of inhabitants in El Cabañal

Number of inhabitants in Cabanal	19359
Number of inhabitants in Valencia	801545
Part of the population living in Cabanal	2.42%

Table B.3: Energy consumption data for El Cabañal

	Public lightning	**Residential**	**Comercial**	**Industrial**
Electricity [kWh]	1.04E+06	2.47E+07	3.42E+07	2.19E+06
Gas natural [kWh]	0	1.39E+07	3.43E+06	5.16E+06

B.1.2 Energy consumption in transportation

The data are not available for this sector. Thus, several hypotheses have been assumed to calculate the part of transportation in the energy consumption of El Cabañal.

H2 = **All the districts have the same weight in the car owning**
It has been assumed that the number of cars in El Cabañal can be calculated by multiplying the total number of cars in Valencia and multiplying it by the ratio of the Valencian population living in the neighbourhood, as highlighted in table B.4. Moreover, the repartition of each type of engine (electricity, petrol and diesel) is assumed the same for the whole Valencia and El Cabañal and presented in table B.5. The consumption of each kind of car is presented in table B.6.

Table B.4: Number of cars in El Cabañal

Number of cars in Valencia	352151
Number of cars in Valencia per inhabitants	0.44
Number of cars in Cabanal (n)	8505

Table B.5: Distribution of cars in El Cabañal

Part of petrol engine (Pp)	53%
Part of diesel engine (Pd)	45%
Part of electrical cars (Pe)	2%

Table B.6: Cars consumption

Thermal car consumption (Ct) [L/km]	0.07
Electric car consumption (Ce) [kWh/km]	0.19

H3 = **Transportation consumption calculated in the border of the neighbourhood**
It has been chosen that the transportation consumption concerns only the energy consumed inside the physical borders of El Cabañal. Moreover, the average daily distance considered is equal to two roundtrips in the maximum length of the district (in that case the diagonal because the district is a rectangle).

Table B.7: Daily distance for each car

Surface [km²]	1.341
Daily maximum distance (D) [km/d/car]	6.55

The yearly transportation energy consumption is equal to 1.36E+07 kWh and can then be calculated using the following formula :

$$E = n * D * 365 * [Pp * Ct * LHV_{petrol} + Pd * Ct * LHV_{diesel} * + Pe * Ce]$$

B.2 Greenhouse gases emissions calculation

The calculation for the greenhouse gases emissions in the neighbourhood refers to emissions due to energy consumption in the following sectors : public lightnings, residential sector, industrial sector and transportation sector.
The scope 3 of emissions corresponding to the life-cycle emissions of each sector is out of the scope of

this analysis. Moreover, different sector like wastes treatment have not been included in the analysis because of the lack of data related to this part and the complexity of modelling.

Thus, the emissions' calculation relies on the energy calculation performed. The following hypothesis has been assumed:
H4 = **The GHG emissions for each vector of energy is equal to the quantity of energy necessary times the content of CO2 of one kWh** The data chosen for the CO2 content of each energy vector are presented in table B.8.

Table B.8: CO2 content of each energy vector

GHG emissions electricity in Spain [gCO2eq/kWh]	163
GHG emissions gas natural [gCO2eq/kWh]	180
GHG emissions petrol [gCO2/kWh]	260
GHG emissions Diesel [gCO2/kWh]	250

B.3 Data and hypotheses

The sources of data used in these calculations are presented in table B.9. The hypothesis assumed to calculate the energy consumption of the neighbourhood are summed up in table B.10.

Table B.9: Data used in the energy consumption calculation

Data	**Source**
Electricity public lighting	Annuari CAP8 2.3
Electricity residental comercial and industrial	Anuari CAP8 2.7
Natural gas residential comercial and industrial	Anuari CAP8 2.8
Number of inhabitants in Valencia and Cabanal	Anuari CAP1 1.3
Surface of Cabanal	Anuari CAP1 1.2
Part of each kind of engine	Anuari CAP3 1.7
LHV values	Engineering Toolbox
Electric car consumption	https://ev-database.uk/
CO2 contents of fuels	Engineering Toolbox
CO2 content of electricity for Spain	https://app.electricitymap.org/

Table B.10: Hypotheses made for energy consumption calculations

Hypothesis	**Details**
H1	All the districts have the same weight in the energy consumption.
H2	All the districts have the same weight in the car owning.
H3	Transportation consumption is calculated in the borders of the neighbourhood.
H4	The GHG emissions for each vector of energy is equal to the quantity of energy necessary times the content of CO2 of one kWh.

C Calculation and hypothesis carbon-neutral scenarios

This appendix details the assumptions and data used to calculate the different characteristics of the 9 scenarios analysed in the case study.

C.1 Energy efficiency

Table C.1: Data energy efficiency calculation

Data	Value	Source
Primary Energy Demand for passiv House [kWh/m2] - SHW/Heating/Cooling/Electricity	60	https://passiv.de/
Nb. Of houses in El Cabanal	8509	Ayutamiento Valencia Estatistica - Districte_11_Barri_2
Average surface of houses [m2]	45	Ayutamiento Valencia Estatistica - Districte_11_Barri_3
Electricity consumption residential [kWh/y]	2.5E+07	Author calculation based on Anuari CAP8
Thermal energy consumption residential [kWh/y]	1.4E+07	Author calculation based on Anuari CAP8
Part of electric vehicles in Spain in 2020	0.20%	https://passiv.de/
Target electric vehicles in Spain in 2030	20%	Ayutamiento Valencia Estatistica - Districte_11_Barri_2
Electricity consumption transportation [kWh/y]	3.7E+05	Author calculation based on Anuari CAP8 - 2020 (Appendix B)
Thermal energy consumption transportation [kWh/y]	7.5E+07	Author calculation based on Anuari CAP8 - 2020 (Appendix B)
Electricity consumption commercial + industry [kWh/y]	4E+07	Author calculation based on Anuari CAP8 - 2020 (Appendix B)
Thermal energy consumption commercial + industry [kWh/y]	9E+06	Author calculation based on Anuari CAP8 - 2020 (Appendix B)

Table C.2: Hypothesis energy efficiency calculations

Hypothesis	**Details**
H1	The gas natural consumption in the residential area is only due to heating and cooling
H2	The energy and electricity consumption in 2023 is supposed equal to the one calculated for 2020 in residential, transportation, commercial and industry
H3	The distribution of cars (thermal and electricity) in 2023 is supposed equal to the one calculated for 2020
H4	The consumption of the electric heater is considered equal to the natural gas heater.
H5	The consumption of the electric car is considered equal to the thermal car
H6	The target is achieved linearly, which means the increase in efficiency (in %) is the same every year

Table C.3: Formula used energy efficiency calculations

Calculation	**Details**
Electricity consumption houses	Electricity consumption in 2023 - (nb. Houses renovated * passiv house consumption) + (nb. Heaters replaced * electricity consumption heaters)
Electricity consumption transportation	Electricity consumption in 2023 - nb. of cars replaced * electricity consumption
Electricity consumption commercial + industry	Electricity consumption in 2023 * (1- % yearly improvement)
Thermal energy consumption houses	Thermal consumption 2023 * (1-% of heater replaced)
Thermal energy consumption transportation	Thermal consumption 2023 * (1-% cars replaced)
Thermal energy consumption commercial + industry	Thermal consumption 2023 * (1-% yearly improvement)

C.2 Energy generation

Table C.4: Data used energy generation

Data	Value	Source
Spanish target renewable energy generation by 2030	70%	IEA - Spain
Total surface roof in Cabanal (70% of the total neighborhood surface)	945000	Ayutamiento Valencia Estatistica - Districte_11_Barri_3

Table C.5: Equipment selected for energy generation : PV pannels

Brand	Techno Sun
Model	Panel solar 440W monocristalino PERC
Vmpp (V)	41.0
Impp (A)	10.7
Ppeak (Wp)	440.0
Voc (V)	49.6
Isc (A)	11.4
Cost per panel (€)	124.2
Surface one panel [m²]	2.2
Total surface necessary (inc. Inverser)	3.3

Table C.6: Equipment selected for energy generation : Inverters

Brand	ABB
Model	TRIO-20.0-TL-OUTD-S2X-400
Power (W)	24000
Minimum voltage MPP (V)	400
Maximum voltage MPP (V)	800
Maximum open circuit voltage (V)	-
Maximum current MPP (A)	50
Maximum short circuit current (A)	-
Number of MPP trackers	2
Cost per inverter (€)	2 981

Table C.7: Hypothesis energy generation

Hypothesis	**Details**
H1	The energy production is covered only by PV pannels

Table C.8: Calculations energy generation

Calculation	**Details**
Quantity of electricity to generate with renewable energy	Yearly electricity consumption * Yearly improvement in RE generation
Minimum power to cover with PV	Yearly electricity demand / (ESH*PV pannels efficiency)
Number of PV	Minimum power to cover/ max power with one PV pannel
Maximum number of PV per inverter	(Vmpp_inv/Vmpp_Pvpannel)*(Impp_inv/Impp_Pvpannel)
Number of inverter	Number of PV/Max number of PV per inverter
Surface of PV necessary	Number of PV * Surface necessary per PV pannel
Total thermal energy to cover with natural gas	Yearly gas consumption * (1-% covered by DH)

C.3 Storage system

Table C.9: Equipment selected storage system

Brand	Victro energy
Model	LFP smart - 12
Technology	Li-ion
Energy per battery [kWh]	0.3
DoD	80%

Table C.10: Calculation storage system

Calculation	**Details**
Capacitity of storage system	Daily electricity demand * yearly % of improvement
Number of batteries	Capacity of storage system / Dod * capacity of one battery

D | Scenarios analysis

This appendix presents the calculations performed to choose the most suitable scenario.

D.1 Environmental analysis

The environmental analysis include the emissions of the scope 1 and 2, which means direct emissions from fossil fuels burning and emissions linked to the electricity consumption in the neighborhood.

D.1.1 Electricity emissions

To calculate the emission linked to the electricity consumption, a net balance diary electricity has been calculated for each scenario, it results in the amount of electricity purchased or sold to the national grid for a typical day. For this calculation, an estimation of the hourly electricity production with the PV pannels system, an estimation of the hourly demand have been performed.

Electricity production

For the electricity production, the data of the amount of electricity produced in El Cabanal with an installation of 1kWp has been extracted from PVGIS (Optimized angle and slope, efficiency of the system of 82%). Figure D.1 presents the power produced with an installation of 1kWp.
For each scenario and each year, the hourly electricity production capacity for a typical day has been performed.

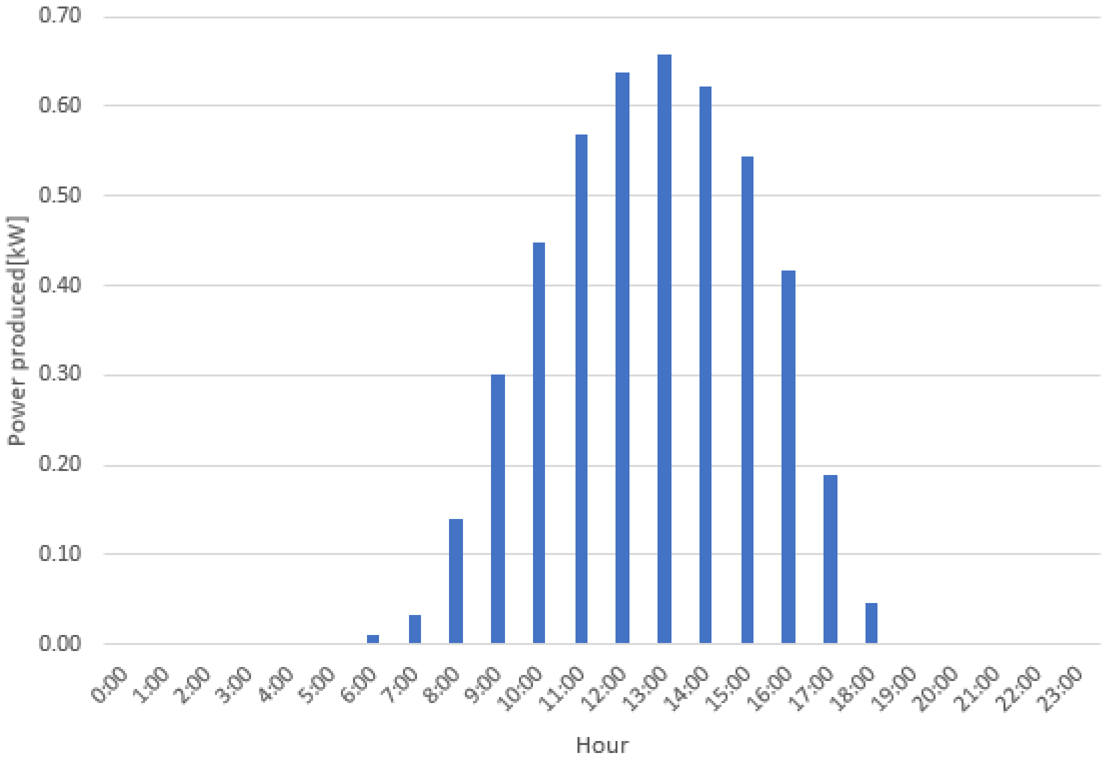


Figure D.1: PV pannel production for 1kWp installed

Electricity demand

Monthly demand estimation

Relying on the monthly distribution of the electricity consumption presented for the year 2020 in ANNUARI CAP8, the monthly electricity consumption for each sector (residential, transport, commercial and industrial) has been calculated for each scenario and each year. The monthly average daily value of electricity consumption for each sector has then been calculated. An example of the table obtained for each scenario and each year is presented in table D.2

Month	Contribution in the annual electrical consumption	Residential	*Average daily consumption residential*	Commercial	*Average daily consumption commercial*	Industrial	*Average daily consumption industrial*	Transport	*Average daily consumption*
January	10%	3544937	*114353*	1222967	*39451*	1222967	*39451*	61824	*2033*
February	9%	3157173	*112756*	1089192	*38900*	1089192	*38900*	61824	*2033*
March	8%	2901135	*93585*	1000861	*32286*	1000861	*32286*	61824	*2033*
April	7%	2741027	*91368*	945626	*31521*	945626	*31521*	61824	*2033*
May	8%	2870374	*92593*	990249	*31944*	990249	*31944*	61824	*2033*
June	7%	2625934	*87531*	905920	*30197*	905920	*30197*	61824	*2033*
July	8%	3114615	*100471*	1074510	*34662*	1074510	*34662*	61824	*2033*
August	10%	3693151	*119134*	1274099	*41100*	1274099	*41100*	61824	*2033*
September	9%	3255762	*108525*	1123204	*37440*	1123204	*37440*	61824	*2033*
October	8%	3053272	*98493*	1053347	*33979*	1053347	*33979*	61824	*2033*
November	8%	3019194	*100640*	1041591	*34720*	1041591	*34720*	61824	*2033*
December	8%	2936889	*94738*	1013197	*32684*	1013197	*32684*	61824	*2033*

Figure D.2: Monthly electricity demand per sector

Daily demand estimation

An estimation of the daily total electricity demand can be calculated with the following steps:

1. Estimation of the contribution of the consumption for each hour of the day as a percentage of the peak demand : relying on the estimation of the monthly demand and the electricity demand curves per day presented in figure D.3 extracted from the study "Optimal Voltage Control Using an Equivalent Model of a Low-Voltage Network Accommodating InverterInterfaced Distributed Generators".

2. Estimation of the daily peak demand can be calculated with the following formula:

$$Dpeak = dailyconsumption/Sum(hourlycontribution)$$

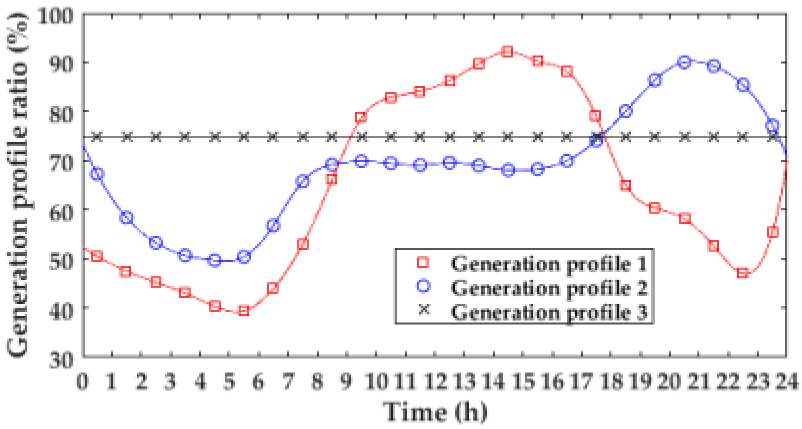


Figure D.3: Load profiles for commercial, residential and industrial sectors

For each scenario and each year a table with the hourly electricity demand for a typical day in the month can be calculated. The average value gives the hourly electricity demand for a typical day in the year. Table D.4 presents an example of hourly electricity demand for a given scenario and year.

	Hour	Demand curve EV (% of peak consumption)	Demand curve residential (% of demand)	Consumption curve commercial (% of peak demand)	Consumption curve industrial (% of peak demand)	January	February	March	April	May	June	July	August	September	October	November	December	Average day
Peak demand residential						8934	8809	7311	7138	7234	6838	7849	9307	8479	7695	7862	7401	
Peak demand commercial						3808	3755	3116	3043	3083	2915	3346	3967	3614	3280	3351	3155	
Peak demand industrial						2838	2799	2323	2268	2298	2172	2494	2957	2694	2445	2498	2351	
Peak demand Ev charging						146	146	146	146	146	146	146	146	146	146	146	146	
	0:00	0.33	0.5	0.15	0.4	6222	6136	5101	4981	5047	4774	5473	6480	5908	5366	5482	5163	**5511**
	1:00	0.30	0.5	0.15	0.4	6217	6131	5096	4976	5043	4769	5468	6475	5903	5361	5477	5158	**5506**
	2:00	0.23	0.35	0.15	0.4	4867	4800	3990	3896	3948	3734	4281	5069	4621	4197	4288	4038	**4311**
	3:00	0.17	0.35	0.15	0.2	4290	4230	3515	3433	3478	3290	3772	4468	4073	3698	3779	3558	**3799**
	4:00	0.13	0.25	0.15	0.2	3392	3345	2779	2714	2750	2601	2982	3533	3220	2924	2987	2813	**3003**
	5:00	0.10	0.25	0.15	0.2	3387	3340	2774	2709	2745	2596	2978	3528	3215	2919	2983	2808	**2999**
	6:00	0.08	0.25	0.15	0.8	5087	5017	4166	4067	4122	3897	4471	5300	4829	4383	4479	4217	**4503**
	7:00	0.06	0.3	0.15	1	6098	6013	4992	4874	4939	4670	5359	6353	5788	5253	5368	5054	**5397**
	8:00	0.05	0.3	0.15	1	6097	6012	4991	4873	4938	4669	5358	6351	5786	5252	5367	5052	**5395**
	9:00	0.03	0.4	0.15	0.9	6704	6610	5487	5357	5429	5133	5891	6984	6363	5775	5901	5555	**5932**
	10:00	0.03	0.5	0.36	0.8	8112	7999	6639	6482	6569	6210	7128	8451	7699	6987	7140	6721	**7178**
	11:00	0.02	0.6	0.93	0.8	11175	11019	9146	8930	9049	8555	9819	11642	10606	9626	9835	9259	**9888**
	12:00	0.05	0.6	0.97	0.9	11616	11454	9507	9282	9407	8893	10207	12101	11024	10006	10224	9625	**10279**
	13:00	0.02	0.6	0.9	0.9	11345	11186	9285	9065	9187	8684	9968	11819	10767	9772	9985	9399	**10038**
	14:00	0.03	0.6	0.9	0.8	11062	10908	9054	8840	8958	8469	9720	11525	10499	9529	9736	9166	**9789**
	15:00	0.08	0.5	0.9	0.8	10176	10034	8330	8133	8242	7792	8942	10601	9658	8767	8957	8433	**9006**
	16:00	0.20	0.6	0.49	0.6	8958	8834	7337	7164	7259	6864	7874	9332	8503	7720	7888	7427	**7930**
	17:00	0.40	0.6	0.49	0.6	8988	8863	7366	7193	7288	6893	7904	9361	8533	7749	7917	7456	**7959**
	18:00	0.7	0.7	0.49	0.6	9925	9788	8141	7950	8056	7621	8732	10336	9424	8563	8747	8240	**8794**
	19:00	1.00	0.7	0.6	0.6	10388	10245	8528	8329	8439	7985	9144	10816	9866	8967	9159	8631	**9208**
	20:00	0.70	0.8	0.6	0.4	10669	10522	8750	8545	8659	8191	9387	11111	10131	9204	9402	8857	**9452**
	21:00	0.60	1	0.6	0.2	11874	11709	9733	9505	9631	9109	10443	12367	11273	10239	10461	9852	**10516**
	22:00	0.50	0.95	0.36	0.2	10499	10353	8605	8403	8515	8053	9233	10935	9967	9053	9249	8710	**9298**
	23:00	0.45	0.6	0.27	0.2	7022	6925	5759	5624	5698	5390	6177	7313	6667	6057	6188	5829	**6221**
																	ENERGY DEMAND [kWh/day]	**171912**
																	PEAK POWER (kW)	**10516**

Figure D.4: Hourly electricity demand calculation

Daily net electricity balance

Relying on the previous calculation the electricity balance for one typical day can be calculated for each scenario and each year. Figure D.5 presents the hourly electricity balance for the different scenario in 2030.

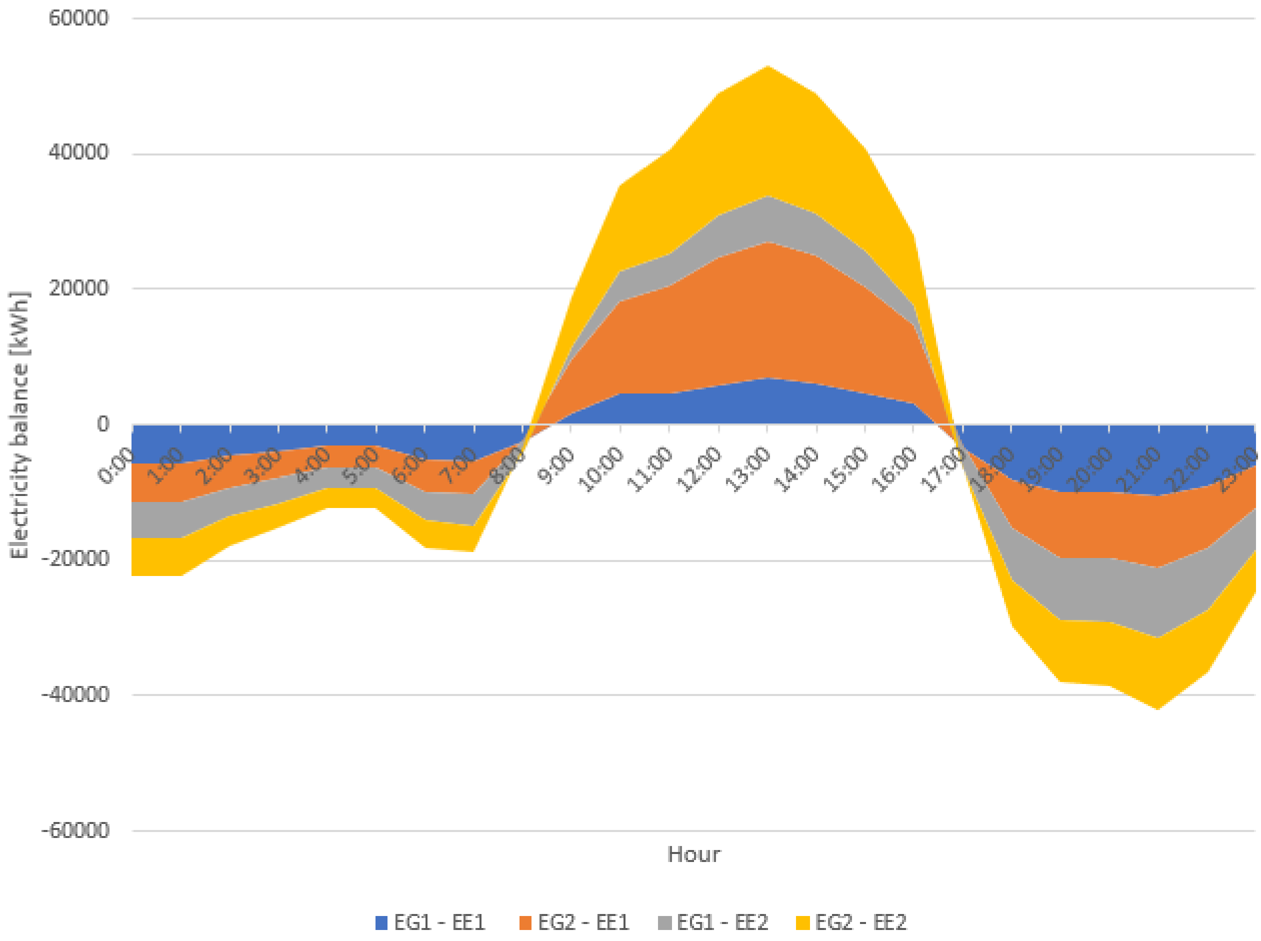


Figure D.5: Daily electricity balance for each scenario in 2030

Calculation of the electricity emissions

In the case of the BAU scenario for the electricity storage, the grid is the storage, the daily electricity defaults will then be purchased from the grid and the daily electricity excess will be sold to the grid. In the case of the ideal scenario (storage system in the neighborhood), the excess of electricity is stored and decrease the part of electricity to be purchased. However, in term of GHG emissions the two scenarios are equivalent.
Thus, for each scenario, the electricity emissions are calculated as the product of electricity to be purchased from the grid (in balance) per the CO2 content of the national grid electricity. This latest is calculated on a linear yearly basis, with a diminution following the pledge of Spain to meet 100% of renewable electricity production by 2050. Table D.1 presents this evolution.

Table D.1: Estimated CO2 content evolution of Spanish grid electricity

	2023	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
CO2 content electricity [gCO2e/kWh]	149.3	142.5	135.7	128.8	122.0	115.1	108.3	101.5

D.1.2 Natural gas, gasoline and diesel emissions

The natural gas demand is calculated for every year and every scenario on the basis of the residential area demand for heating and cooling. The results for every year and every scenario is multiplied by the CO2 content of natural gas. The gasoline and diesel demand is calculated for every year and every scenario on the basis of the transport area demand for thermal cars. The results for every year and every scenario is multiplied by the CO2 content. Table D.2 presents the value used for the CO2 content of the fossil fuels.

Table D.2: CO2 content of fossil fuels (combustion)

Fossil fuel	**Value**	**Source**
CO2 content gas natural [gCO2eq/kWh]	180	Engineering toolbox
CO2 content petrol [gCO2/kWh]	260	Engineering toolbox
CO2 content Diesel [gCO2/kWh]	250	Engineering toolbox

D.1.3 Calculation of the CO2 balance

The CO2 emissions for each energy vector are aggregated, and the CO2 yearly CO2 capture capacity is subtracted for every scenario to obtain the CO2 balance that is used in the environmental analysis.

D.2 Economical analysis

Table D.3: Data used for the economical analysis

Investment area	**Value**	**Source**
Energy efficiency		
Price per m² renovated [€/m²]	185	
Grant per electric vehicle [€/vehicle]	3000	
Grant per heater replaced [€/household]	1000	
Energy generation		
Investment PV pannels [€/kW]	1120	https://www.miteco.gob.es/es/cambio-climatico/legislacion/documentacion/PER_2011-2020_VOL_I_tcm30-178649.pdf
Investment inversers [€/inv]	7000	https://www.miteco.gob.es/es/cambio-climatico/legislacion/documentacion/PER_2011-2020_VOL_I_tcm30-178649.pdf
Investment district heating and cooling [€/kW]	1150	Average value of DC/DH projects (Denmark, Tallin, Italy, Spain)
Storage system		
Investment storage system [€/kWh]	803.4	https://www.energy.gov/sites/prod/files/2019/07/f65
CO2 removal		
Investment trees [€/tree]	106	https://howmuch.net/costs/tree-install

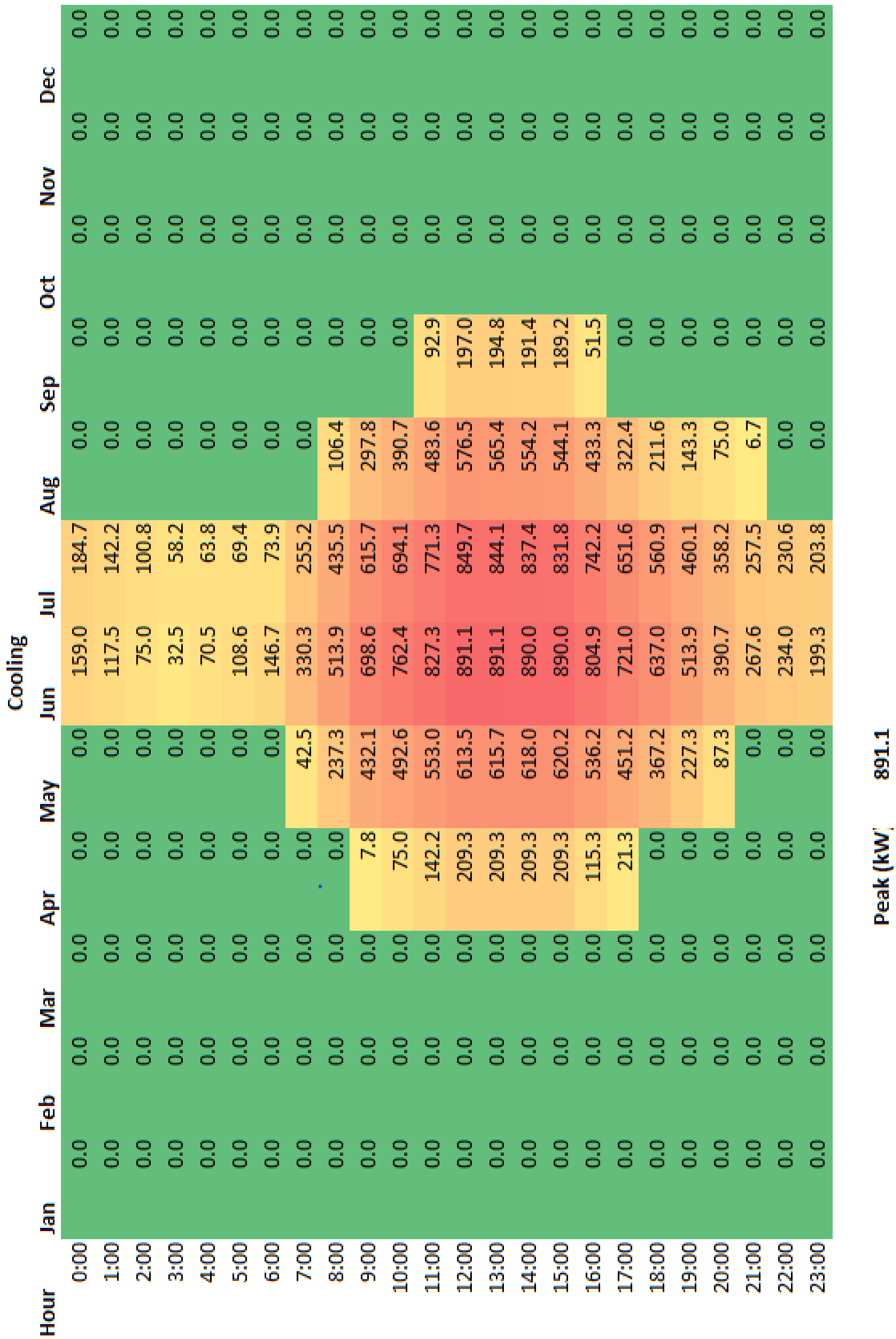
The sizing of the district heating and cooling system is necessary to calculate the investment. This has been estimated by calculating the heating and cooling profiles. The hourly evolution of the outdoor temperatures for a typical day of each month can be extracted from PVGIS. The temperature of comfort has been supposed equal to 22°C in this calculation. Calculating the difference between the temperature of comfort and the outdoor temperature, the heating degree days can be calculated for each typical day, and for each month, and by summing them, for a year.
To simplify the calculation, the yearly heating demand as been assumed equal to 80% of the yearly natural gas demand and the yearly cooling demand as been assumed equal to 20% of the yearly natural gas demand.
Knowing the number of HDD and CDD for a year and the heating and cooling demand in kWh for a year, the number of kWh per HDD or CDD can be calculated.
The hourly distribution of the heating or cooling degree day for a month is then multiplicated by this value to obtain the power necessary per hour. The maximum peak power demand (for cooling and heating demand) is used to size the district heating and cooling system.
Figures D.6 and D.7 present the results of the hourly power required to cover the heating and cooling demand for a typical day of each month.

Heating

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0:00	1406	1358	1211	952	622	197	0	0	88	433	972	1329
1:00	1440	1395	1252	997	663	241	0	0	133	469	1006	1365
2:00	1472	1432	1293	1043	704	285	0	0	179	505	1041	1401
3:00	1506	1469	1333	1089	746	329	0	0	224	541	1076	1435
4:00	1523	1492	1361	1092	702	271	0	0	242	566	1098	1449
5:00	1539	1517	1389	1094	659	212	0	0	259	592	1120	1461
6:00	1557	1540	1417	1096	617	152	0	0	277	617	1142	1473
7:00	1470	1408	1214	873	409	0	0	0	85	450	1018	1386
8:00	1384	1276	1010	650	200	0	0	0	0	283	893	1299
9:00	1296	1144	806	428	0	0	0	0	0	116	769	1211
10:00	1122	987	682	348	0	0	0	0	0	12	631	1058
11:00	947	832	558	269	0	0	0	0	0	0	494	905
12:00	774	675	433	190	0	0	0	0	0	0	356	751
13:00	740	653	415	193	0	0	0	0	0	0	344	732
14:00	708	631	397	196	0	0	0	0	0	0	331	713
15:00	675	609	380	199	0	0	0	0	0	0	318	694
16:00	833	764	515	294	0	0	0	0	0	0	456	832
17:00	991	917	650	391	0	0	0	0	0	87	593	969
18:00	1149	1071	785	486	73	0	0	0	0	225	732	1107
19:00	1215	1146	877	594	206	0	0	0	0	281	795	1169
20:00	1281	1223	969	703	339	0	0	0	0	337	859	1230
21:00	1347	1299	1061	812	472	53	0	0	0	393	922	1291
22:00	1370	1317	1107	858	517	95	0	0	29	410	946	1303
23:00	1393	1333	1153	902	563	138	0	0	65	427	969	1315

Peak (kW) **1557.2**

Figure D.6: DH sizing : Power necessary to cover heating demand [kW]



Cooling

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0:00	0.0	0.0	0.0	0.0	0.0	159.0	184.7	0.0	0.0	0.0	0.0	0.0
1:00	0.0	0.0	0.0	0.0	0.0	117.5	142.2	0.0	0.0	0.0	0.0	0.0
2:00	0.0	0.0	0.0	0.0	0.0	75.0	100.8	0.0	0.0	0.0	0.0	0.0
3:00	0.0	0.0	0.0	0.0	0.0	32.5	58.2	0.0	0.0	0.0	0.0	0.0
4:00	0.0	0.0	0.0	0.0	0.0	70.5	63.8	0.0	0.0	0.0	0.0	0.0
5:00	0.0	0.0	0.0	0.0	0.0	108.6	69.4	0.0	0.0	0.0	0.0	0.0
6:00	0.0	0.0	0.0	0.0	0.0	146.7	73.9	0.0	0.0	0.0	0.0	0.0
7:00	0.0	0.0	0.0	0.0	42.5	330.3	255.2	0.0	0.0	0.0	0.0	0.0
8:00	0.0	0.0	0.0	0.0	237.3	513.9	435.5	106.4	0.0	0.0	0.0	0.0
9:00	0.0	0.0	0.0	7.8	432.1	698.6	615.7	297.8	0.0	0.0	0.0	0.0
10:00	0.0	0.0	0.0	75.0	492.6	762.4	694.1	390.7	0.0	0.0	0.0	0.0
11:00	0.0	0.0	0.0	142.2	553.0	827.3	771.3	483.6	92.9	0.0	0.0	0.0
12:00	0.0	0.0	0.0	209.3	613.5	891.1	849.7	576.5	197.0	0.0	0.0	0.0
13:00	0.0	0.0	0.0	209.3	615.7	891.1	844.1	565.4	194.8	0.0	0.0	0.0
14:00	0.0	0.0	0.0	209.3	618.0	890.0	837.4	554.2	191.4	0.0	0.0	0.0
15:00	0.0	0.0	0.0	209.3	620.2	890.0	831.8	544.1	189.2	0.0	0.0	0.0
16:00	0.0	0.0	0.0	115.3	536.2	804.9	742.2	433.3	51.5	0.0	0.0	0.0
17:00	0.0	0.0	0.0	21.3	451.2	721.0	651.6	322.4	0.0	0.0	0.0	0.0
18:00	0.0	0.0	0.0	0.0	367.2	637.0	560.9	211.6	0.0	0.0	0.0	0.0
19:00	0.0	0.0	0.0	0.0	227.3	513.9	460.1	143.3	0.0	0.0	0.0	0.0
20:00	0.0	0.0	0.0	0.0	87.3	390.7	358.2	75.0	0.0	0.0	0.0	0.0
21:00	0.0	0.0	0.0	0.0	0.0	267.6	257.5	6.7	0.0	0.0	0.0	0.0
22:00	0.0	0.0	0.0	0.0	0.0	234.0	230.6	0.0	0.0	0.0	0.0	0.0
23:00	0.0	0.0	0.0	0.0	0.0	199.3	203.8	0.0	0.0	0.0	0.0	0.0

Peak (kW) 891.1

Figure D.7: DC sizing : Power necessary to cover cooling demand [kW]

E Indicator lists for the case study

E.1 Background indicators

Objective	Specific objective	Background indicator with the best AHP grade	Unit	Description
Decrease other pollution	*Reduce other pollution*	Only specific indicators	-	-
Decrease GHG emissions	*Decarbonize energy generation*	Only specific indicators	-	-
	Decarbonize residential sector	Only specific indicators	-	-
	Decarbonize transportation	Only specific indicators	-	-
Increase citizens satisfaction	*Increase thermal confort*	Only specific indicators	-	-
	Develop advantages for citizens	Number of customers that are positive about how energy systems are controlled (Nc)	number	Evaluate the satisfaction of customers towards the ICT systems during the project
		Number of people using ICT related platform (Nict)	number	Evaluate the number of people controlling their energy consumption through online platforms
		Advantages for stakeholders (A)	Likert scale	The extent to which the project offers clear advantages for the stakeholders. A questionnaire should be developed assessing for example : comfort improvements, sense of belonging, increase of safety feeling.
Increase inclusiveness	*Develop inclusive projets*	Only specific indicators	-	-
	Favorize neighbourhood diversity	Only specific indicators	-	-
	Increase involvment of minorities	Only specific indicators	-	-
Increase citizens engagement	*Increase citizens involvement*	Only specific indicators	-	-
Increase citizens information	*Inform citizens*	Only specific indicators	-	-

Objective	Specific objective	Background indicator with the best AHP grade	Unit	Description
Increase ressources efficiency	*Increase efficiency in the residential sector*	Distribution of energy source for buildings heating and cooling	GWh/y	Measure of the residential use of natural gas, oil and biomass.
		Distribution of residential energy use (SHW, conditioning, heating...)	%	Measure of the repartition of the total energy consumption for heating and cooling, SWH and lightning.
		Energy consumption of public buildings	kWh/m²	Measure the energy consumption of public buildings
		Energy use from district heating	kWh/year	Total energy supplied for district heating in the neighbourhood
		Final energy consumption	kWh/m²	The indicator corresponds with the final uses of the energy for different areas of application within the building
		Primary energy demand and consumption	kWh/m²	This indicator encompasses in addition to the final energy demand the energy that is used within the supply chain of the used energy carriers
	Increase effiency in commercial and indutrial sector	Distribution of commercial and industrial energy use (SHW, conditioning, heating, industrial processes...)	%	Measure of the repartition of the total energy consumption for heating and cooling, SWH, lighting and industrial processes.
	Increase efficiency in transportation	Carpooling location	number	The number of carpooling or car sharing locations.
		Clean mobillity utilisation	number/km	Amount of km and trip in clean vehicles (without fossil fuels).
		Passenger-km public transport and private vehicle	km	Repartition of the number of km in public transport and in private transport (inside the neighbourhood borders).
		Number of efficient vehicles deployed in the area	number	Amount of PHEV, pure electric, biofuel and hydrogen cars.
		Yearly km made through e-car sharing systems	km	Number of kilometers done using the car-sharing system.
		Kilometres of high capacity public transport system per 10000 population	km/ 100 000 inh	Lenght of high capacity public transport (metro, subway, rail systems).
		km of bycicle paths and lines per 100 000 population	km/100 000inh	Lenght of bycicle paths in the neighbourhood.

Objective	Specific objective	Background indicator with the best AHP grade	Unit	Description
		Cost of monthly ticket for public transport in relation with averge wage	€	Measure of the weight of public transport in the household economy
		Number of personal auto per capita	number/capita	Number of auto per capita.
		Daily average lenght by each transport type	km/vehicle/day	Average lenght of trips in the neighbourhood.
		Percentage of electric vehicles	%	Percentage of electric cars, taxis, motorcycles, public buses, trucks, industrial vehicles.
		Daily average time by trip	years	Measure of the time devoted daily to transport by consumers.
		Distribution of vehicles in the city	number	Number of cars, taxis, motorbikes, trucks...
	Net zero water	% of water re-used on site	%	Quantity of water that is reused inside the neighbourhood.
		Water surface per capita	m²	Surface of water in the area considered.
	Net zero waste	% of waste recycled on-site and nearby	%	Quantity of waste recycled in the district and the direct surroundings.
		% of low-GHG emission contruction material	%	Quantity of low GHG emissions construction material in the district.
		% of recycled construction material	%	Quantity of recycled construction material in the district.
		% of reused construction material	%	Quantity of reused construction material in the district.
Green-energy generation	*Develop renewable energy*	energy use (PV, biomass, solar thermal, hydraulic, minieolic, geothermal)	kWh/year	Total energy supplied by biomass, PV, Solar thermal, hydraulic, windfarm,geothermal...)
		Increase in local renewable energy generation	%	The energy produced with a renewable source
		Degree of energetic self-supply by RES	%	Ratio of locally produced energy from renewable source and the energy consumption over a period of time.
	Increase enegy storage	Storage energy losses	%	Energy losses because of battery storage.
		Battery degradation	%	Capacity losses of the batteries used in the district.

Objective	Specific objective	Background indicator with the best AHP grade	Unit	Description
	Increase quality of supply	Energy curtailment of RES (EC)	kWh	Reduction of the energy curtailment due to technical problems.
		Peak load (P)	kW	Compare the peak before and after the agregator implementation
		Average default correction time (CT)	h/month	Monthly average time needed for awareness, localization and isolation of grid default
		Number of unexpected stops (reliability) (Ns)	number/d	Daily number of interruption of energy supply.
Capture GHG emission	*Increase public green-area*	Increased % of green facades	%	surface of facade with a green cover compared to the total surface of facade in the area.
		Increased % of green roofs	%	surface of roof with a green cover compared to the total surface of roofs in the area.
		Vegetable garden per dwelling	m²	Surface of garden per habitation.
Optimize internal processes	*Promote energy transition projects*	Payback period	years	Time it takes to cover investment costs.
		Total annual costs	€/year	Sum of capital-related costs, operation-relative costs and other costs.
		Return on investment	%	Evaluation of the feasability of an investment in comparison with other possible investments.
		Financial benefit for the end-user	€/household/year	Costs savings for end users.
		Total investments	€	Total investment related to energy aspect (eg. High efficient envelope in building)
		Grants	%	Part of the project financed with grants (non repayable funds from government).
		% of the project contribution to the municipal budget	%	Part of the municipal budget allocated to the project.

Objective	Specific objective	Background indicator with the best AHP grade	Unit	Description
	Increase quality of data and monitoring systems	Datasafety (Ds)	number/d	Daily number of blocked malicious hacking attempt.
		Quality of open data (Q)	%	Percentage of data using a standardized methodology.
		Expiration date of open data (Ed)	%	Percentage of outdated datasets on a city platform per timeframe.
		Number of sensors deployed in the city (Nse)	number	Number of sensors (air quality, temperature, wind...) in the area.
	Develop a legal framework for energy transition projects	Signature of covenent of mayor (Sc)	binary	Is the city member of covenant of mayor ?
		Existence of regulations for development of energy efficient districts (Re)	number	Is there any specific regulation for developing energy efficient districts in the city ?
		Existence of local/ national energy performance certificate (Rp)	number	Is there any energy performance certificate for buildings in the city ?
		Existence of regulations for development of sustainable mobitily (Rs)	number	Is there any specific regulation for developing sustainable mobility in the city ?
Develop local economy	*Decrease energy costs*	CO2 reduction cost efficiency	€/tonCO2	Cost in €/ton of CO2 saved per year.
		Reduction of energy price by ICT related technology	%	Assessing the economic benefits of a scheduling strategy for consumers coordinated by an aggregator.
		Fuel poverty	%	A household is considered as energy poor if their energy bill consumes 10% or more of the household income.
	Develop new jobs	Number of sustainable jobs created locally	number	Number of jobs linked to ecological transition created in the area
		Stimulating an innovative environment	no unit	The extent to which a project is part f or stimulates an innovative environment

Figure E.1: List of background indicators for the case study

E.2 Specific indicators

	Objective	Specific objective	Specific indicator with the best AHP grade	Unit	Description
GHG emissions	**Decrease other pollution**	*Reduce other pollution*	Air quality index	ppm or g/m3	Measures the air quality of the location,taking into account all kind of air pollution (PM,O3,NO2,SO2,CO) and their effect relying on European air quality standards EEA.
			Decreased emissions of oxides (NOx)	%	NOx emissions measured in the district, can be directly linked to energy consumption if info not available.Compared to the previous year.
			Decreased emissions of particulate matter	%	PM10 and PM2.5 emissions measured in the district. Compared to the previous year.
	Decrease GHG emissions	*Decarbonize energy generation*	Greenhouse gas emissions in energy generation	gCO2eq/kWh	This indicator measures the greenhouse gases emissions in the energy generation area.
		Decarbonize residential sector	Greenhouse gas emissions in residential buildings	gCO2eq/kWh	This indicator measures the greenhouse gases emissions in the residential area.
		Decarbonize commercial and industrial sector	Greenhouse gas emissions in commerce and industry	gCO2eq/kWh	This indicator measures the greenhouse gases emissions in the commercial and industrial areas
		Decarbonize transportation	Greenhouse gas emissions in transportation	gCO2eq/kWh	This indicator measures the greenhouse gases emissions in the transportation area.
Citizens	**Increase citizens satisfaction**	*Increase thermal confort*	Number of hours per year where the inside temperature is higher (summer) or lower (winter) than the set point temperature	h	Evaluation of the thermal conditions to know how they affect health/wellness of inhabitants.
		Develop advantages for citizens	Index based on colour scale	colour (green,yellow or red)	The index is detailed in table IV.3.
	Increase inclusiveness	*Develop inclusive projets*	% of social housing	%	Part of residential buildings that are considered as social housings.
		Encourage neighbourhood diversity	Repartition of incomes categories	%	% of the population in each category of incomes, the categories must be defined by local stakeholders.
		Increase involvment of	Participation of vulnerable	Likert scale	The likert scale to evaluate the
			People reached in each target groups indentified	%	Percentage of people in the target group identified that have been reached by the project.

	Objective	Specific objective	Specific indicator with the best AHP grade	Unit	Description
Citizens	**Increase citizens engagement**	*Increase citizens involvement*	% of citizens environmental-friendly	%	Level of awareness of environmental problems to create support for environmental projects and programs.
			% of inhabitants involved in the project of the neighborhood	%	The extent to which inhabitants are involved in the meetings of the project.
			Consumers engagement	number	This indicator describes the number of citizens that are involved in the management of their energy consumption.
			Professional stakeholders involvement	Likert scale	The extent to which professional stakeholders outside the project team have been involved in planning and execution. The likert scale must be defined with local stakeholders.
	Increase citizens information	*Inform citizens*	Training of citizens on environmental behaviour	Likert scale	The extent to which citizens have been trained to adopt the basics of an environmentally-friendly behaviour.
			Environmental education	number	This indicator describes the number of educational programs related to environment in the city.
			Number of awareness campaigns	number	This indicator measures the number of campaigns started to improve environmental awareness of citizens and stakeholders.

	Objective	Specific objective	Specific indicator with the best AHP grade	Unit	Description
Resources and processes	**Increase ressources efficiency**	*Increase efficiency in the residential sector*	Total energy demand in residential area in the neighborhood.	kWh/d	The energy necessary to cover comfort of inhabitants in the residential sector. The level of comfort must be defined with local stakeholders (electricity + heating and cooling + SHW).
			Total energy consumption in the residential area in the neighbourhood.	kWh/d	The energy used to cover the energy demand (electricity + heating and cooling + SHW).
			Thermal energy savings	kWh/year	The thermal energy saved compared to the previous year (heating and cooling + SHW).
		Increase efficiency of the commercial and industrial sectors	Total energy demand in the neighborhood.	kWh/d	The energy necessary to cover the industrial activities and reach comfort temperature in commerces and offices (electricity + heating and cooling + SHW)
		Increase efficiency in transportation	Total energy consumption in the transportation area in the neighbourhood.	kWh/d	Can be calculated through by aggregated fuel consumption from the inhabitants of the neighborhood,
		Net zero waste	Quantity of waste produced per activity and per inhabitants.	kg/hab/d	Can be calculated by aggregated the quantity of wastes produced inside the neighbourhood.
		Net zero water	Water consumption per activity and per inhabitants	L/hab/d or m3/hab/d	Can be calculated by aggregated the quantity of water consumed inside the neighbourhood. Although not directly linked to energy transition, water savings is necessary in area highly exposed to droughts, to mitigate effect of climate change.

Objective	Specific objective	Specific indicator with the best AHP grade	Unit	Description
Green-energy generation	*Develop renewable energy*	Daily total renewable energy generation.	MWh/d	This indicator can be calculated by the quantity of energy produced by renewable sources (electricity + heating and cooling) inside the neighbourhood.
	Increase enegy storage	Capacity of energy storage	% of energy produced / y	This indicator can be calculated by dividing the amount of energy stored by the total energy produced in the border of the neighbourhood.
	Increase quality of supply	Index based on factor analysis (IQ)	Number between 0 and 1	The formula to calculate the index is detailed in equation 3.
Capture GHG emission	*Increase public green-area*	Greenspace per inhabitant (parks, urban trees, places...)	m^2/inh	This indicators meaures the quantity of green area in the neghbourhood.
Optimize internal processes	*Promote energy transition projects*	% of the project financed by the municipal budget	%	This indicator present the part of the carbon-neutrality project financed by the municipality. This indicator must
	Increase quality of data and monitoring systems	Index based on factor analysis (IQd)	Number between 0 and 1	The formula to calculate the index is detailed in equation 4.
	Develop a legal framework for energy transition projects	Index based on factor analysis (IL)	Number between 0 and 1	The formula to calculate the index is detailed in equation 5.
Develop local economy	*Decrease energy costs*	Energy cost	€/kWh	Decrease in the energy cost thanks to the measures taken
	Develop new jobs	Local job creation	number	This indicator assesses the creation of direct jobs from the implementation of the project.

Figure E.2: List of specific indicators for the case study

E.3 Key performance indicators

	Objective	Key indicator performance	Unit	Description
GHG emissions	**Decrease other pollution**	*Air pollution index taking into account the Nox and the particulate matter emitted instantaneously*	ppp or g/m3	Both Nox and the particulate matter have a weight based on their impact on environment.
	Decrease GHG emissions	*Daily average greenhouse gas emissions per capita*	tCO2eq/d	This indicator sum up the greenhouse gas emissions for each sector per capita.
Citizens	**Increase citizens satisfaction**	Index based on colour scale	colour (green,yellow or red)	The index is detailed in table IV.3.
	Increase inclusiveness	*Index based on colour scale*	colour (green,yellow or red)	The index is detailed in table IV.3.
	Increase citizens engagement	*Index based on colour scale*	colour (green,yellow or red)	The index is detailed in table IV.3.
	Increase citizens information	*Index based on colour scale*	colour (green,yellow or red)	The index is detailed in table IV.3.
Resources and processes	**Increase ressources efficiency**	*Index based on factor analysis*	Number between 0 and 1	The formula to calculate the index is detailed in equation 6.
	Green-energy generation	*Index based on factor analysis*	Number between 0 and 1	The formula to calculate the index is detailed in equation 7.
	Capture GHG emission	Daily quantity of CO2 captured divided by the district's CO2 emissions compared to average value of the last month.	%	The formula to calculate the index is detailed in equation 8.
	Optimize internal processes	*Index based on factor analysis*	Number between 0 and 1	The formula to calculate the index is detailed in equation 9.
	Develop local economy	*Index based on colour scale*	colour (green,yellow or red)	The index is detailed in table IV.3.

Figure E.3: List of key performance indicators for the case study

F | Targets calculation

Most of the targets calculation rely on the scenarios calculation presented in Appendix C and D (division of yearly results to obtain daily targets, or by the number of inhabitants). However some targets required further calculation. This appendix details the target calculations for the indicators "Greenhouse gas emissions in energy supply, residential area, commercial industrial area, transport area" and "Total investments"

F.1 Greenhouse gas emissions

The calculation of the yearly targets for these indicators for each sector relies on the calculation of the CO2 content of each source of energy and the quantity of energy consumed for each source of energy divided by the total energy consumption

$$\frac{Elec. * CO_2contentelec. + Gas. * CO_2contentgas + Gasoline. * CO_2contentgasol. + diesel. * CO_2contentdiesel}{Totalenergyconsumption} \quad (F.1)$$

The CO2 contents of electricity, natural gas, diesel and gasoline are presented in Appendix D.

F.2 Total investments

The yearly improvement of energy efficiency, energy generation, energy storage and CO2 capture are detailed in the scenarios presentation part. The yearly investment necessary has been calculated between 2023 and 2030 and is presented in the following figure:

Investment breakdown scenario 8	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**
Investment energy efficiency	**0.9**	**0.9**	**0.9**	**0.9**	**0.9**	**0.9**	**0.9**
Investment energy efficiency - Refurbishment	13.2	13.2	13.2	13.2	13.2	13.2	13.2
Investment energy efficiency - Electric vehicles	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Investment energy efficiency - Heaters	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Investment energy generation	**8.2**	**7.8**	**7.5**	**7.1**	**6.7**	**6.4**	**6.0**
Investment energy generation - PV pannels	7.9	7.6	7.2	6.8	6.5	6.1	5.8
Investment energy generation - DH/DC	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Investment storage system	**9.9**	**10.2**	**10.6**	**11.0**	**11.4**	**11.8**	**12.2**
Investment CO2 removal	**1.9**	**1.4**	**1.4**	**1.4**	**1.4**	**1.4**	**1.4**
Total investment [m€]	**42.2**	**41.3**	**41.0**	**40.7**	**40.3**	**40.0**	**39.7**

Figure F.1: Yearly investment breakdown

G | Indicator database

Characterization						Sorting				Rating				
Indicator name	Scope	Target stakeholder	Type	Precision	Source	BSC category	Use of indicator	Main objective	Specific objective	S	T	M	UF	AHP
Consumers engagement	CityProject	TSP/Endusers/Governance	IMPACT	QUANTITATIVE	SCIS;IRIS	Citizens	specific	Increase citizens engagement	Increase involvment towards energy transition	5	5	5	5	5.00
% of inhabitants involved in the project of the neighborhood	CityProject	Endusers/Governance	OUTCOME	QUANTITATIVE	SMARTENCITY;JR	Citizens	specific	Increase citizens engagement	Increase involvment towards energy transition	3	3	5	5	4.20
Professional stakeholders involvment	CityProject	TSP/Governance	OUTCOME	QUALITATIVE	IRIS;SMARTENCI	Citizens	specific	Increase citizens engagement	Increase involvment towards energy transition	5	5	5	5	5.00
Advantages for stakeholders	CityProject	DSO/TSP/endusers	OUTCOME	QUALITATIVE	IRIS	Citizens	background	Increase citizens satisfaction	Develop advantages for citizens	5	5	5	5	5.00
% of citizens environmental-friendly	CityProject	TSP/Endusers/Governance	IMPACT	QUALITATIVE	IRIS;JRCMISSION	Citizens	specific	Increase citizens engagement	Increase involvment towards energy transition	5	5	5	5	5.00
no. Community participation in the organized events	CityProject	TSP/Endusers/Governance	OUTPUT	QUANTITATIVE	CITYxCHANGE	Citizens	specific	Increase citizens engagement	Increase involvment towards energy transition	5	5	5	5	5.00
No of study visits by regulatory autorities	CityProject	Endusers/Governance	OUTPUT	QUANTITATIVE	CITYxCHANGE	Citizens	specific	Increase citizens engagement	Increase involvment towards energy transition	5	5	5	5	5.00
No citizen observatories established	CityProject	Endusers/Governance	OUTPUT	QUANTITATIVE	CITYxCHANGE	Citizens	specific	Increase citizens engagement	Increase involvment towards energy transition	5	5	5	5	5.00
No. Of community participation events/actions	CityProject	Endusers/Governance	OUTPUT	QUANTITATIVE	CITYxCHANGE	Citizens	specific	Increase citizens engagement	Increase involvment towards energy transition	5	5	5	5	5.00
No. Of innovatio labs contributing to projects	CityProject	Endusers/Governance	OUTPUT	QUANTITATIVE	CITYxCHANGE	Citizens	specific	Increase citizens engagement	Increase involvment towards energy transition	5	5	5	5	5.00
Increased consciousness of citizenship	CityProject	TSP/Endusers	IMPACT	QUALITATIVE	IRIS	Citizens	specific	Increase citizens engagement	Increase involvment of minorities	3	5	5	3	4.44
No. Of municipal staff trained to use decision support tool	CityProject	Endusers/Governance	OUTPUT	QUANTITATIVE	CITYxCHANGE	Citizens	specific	Increase citizens information	Inform the citizens	5	5	5	5	5.00
Ease of use for final user	CityProject	Endusers/Governance	OUTCOME	QUALITATIVE	IRIS	Citizens	specific	Increase citizens information	Inform the citizens	5	5	5	5	5.00
Environmental education	City	Endusers/Governance	INPUT	QUANTITATIVE	SMARTENCITY	Citizens	specific	Increase citizens information	Inform the citizens	5	5	5	5	5.00
% of citizens trained on environmental behaviour	CityProject	governance	IMPACT	QUANTITATIVE	JRCMISSION	Citizens	specific	Increase citizens information	Inform the citizens	5	5	5	5	5.00
Number of awareness campaign	CityProject	Endusers/Governance	OUTPUT	QUANTITATIVE	SMARTENCITY	Citizens	specific	Increase citizens information	Inform the citizens	5	5	5	5	5.00
Number of hours per year where the inside temperature is higher (summer) or lower (winter) than the set point temperature	CityProject	DSO/TSP/governance	OUTCOME	QUANTITATIVE	SMARTENCITY;IR	Citizens	specific	Increase citizens satisfaction	Increase citizens satisfaction	5	5	5	5	5.00
Number of customers that are positive about how energy systems are controlled	CityProject	TSP/Endusers/Governance	OUTPUT	QUALITATIVE	IRIS	Citizens	background	Increase citizens satisfaction	Develop advantages for citizens	5	3	5	5	4.60
Social compatibility	CityProject	Endusers/Governance	IMPACT	QUALITATIVE	IRIS	Citizens	specific	Increase inclusiveness	Develop inclusive projets	5	1	5	5	4.20
People reached	CityProject	DSO/TSP/Governance	OUTCOME	QUANTITATIVE	IRIS	Citizens	specific	Increase inclusiveness	Increase involvment of minorities	3	5	5	3	4.44
Increased participation of vulnerable groups	CityProject	TSP/Endusers/Governance	OUTCOME	QUALITATIVE	IRIS	Citizens	specific	Increase inclusiveness	Increase involvment of minoritie	5	5	3	5	3.96
% of social housing	CityProject	governance	INPUT	QUANTITATIVE	JRCMISSION	Citizens	specific	Increase inclusiveness	Develop inclusive projets	5	5	3	5	3.96
% of middle-class housing	CityProject	governance	INPUT	QUANTITATIVE	JRCMISSION	Citizens	specific	Increase inclusiveness	Develop inclusive projets	3	1	5	3	3.64
% of privatly owned houses	CityProject	governance	INPUT	QUANTITATIVE	JRCMISSION	Citizens	specific	Increase inclusiveness	Develop inclusive projets	5	5	5	5	5.00
Repartition of buildings type	CityProject	governance	INPUT	QUANTITATIVE	JRCMISSION	Citizens	specific	Increase inclusiveness	Favorize neighbourhood diversity	5	5	5	5	5.00
Repartition of housings type	CityProject	governance	INPUT	QUANTITATIVE	JRCMISSION	Citizens	specific	Increase inclusiveness	Favorize neighbourhood diversity	5	5	5	5	5.00
Greenhouse gas emissions in energy generation	CityProject	DSO/TSP/Endusers/Governance	INPUT	QUANTITATIVE	SCIS	GHG emissions	specific	Decrease GHG emissions	Decarbonize energy generation	5	5	5	5	5.00
Carbon dioxide emission reduction in energy generation per capita	CityProject	DSO/TSP/Endusers/Governance	INPUT	QUANTITATIVE	SCIS;IRIS;CITYxC	GHG emissions	specific	Decrease GHG emissions	Decarbonize energy generation	5	5	5	3	4.84
Greenhouse gas emissions in residential buildings	CityProject	DSO/TSP/Endusers/Governance	INPUT	QUANTITATIVE	SCIS;SMARTENCI	GHG emissions	specific	Decrease GHG emissions	Decarbonize residential sector	5	3	5	5	4.60
Carbon dioxide emission reduction in residential buildings per capita	CityProject	DSO/TSP/Endusers/Governance	OUTCOME	QUANTITATIVE	SCIS;IRIS;CITYxC	GHG emissions	specific	Decrease GHG emissions	Decarbonize residential sector	5	5	5	3	4.84
Greenhouse gas emissions in residential buildings	CityProject	DSO/TSP/Endusers/Governance	OUTCOME	QUANTITATIVE	SMARTENCITY	GHG emissions	specific	Decrease GHG emissions	Decarbonize residential sector	5	5	3	5	3.96
Greenhouse gas emissions in transportation	CityProject	DSO/TSP/Endusers/Governance	OUTCOME	QUANTITATIVE	SCIS	GHG emissions	specific	Decrease GHG emissions	Decarbonize transportation	5	5	3	5	3.96
Carbon dioxide emission reduction in transportation per capita	CityProject	DSO/TSP/Endusers/Governance	IMPACT	QUANTITATIVE	SCIS;IRIS;CITYxC	GHG emissions	specific	Decrease GHG emissions	Decarbonize transportation	5	5	5	3	4.84

Characterization						Sorting				Rating				
Indicator name	Scope	Target stakeholder	Type	Precision	Source	BSC category	Use of indicator	Main objective	Specific objective	S	T	M	UF	AHP
Daily total greenhouse gas emissions	CityProject	DSO/TSP/Endusers/Governance	OUTPUT	QUANTITATIVE	SCIS	GHG emissions	core	Decrease GHG emissions	Reduce GHG emissions	5	5	5	3	4.84
Decreased emissions of particulate matter	CityProject	DSO/TSP/Endusers/Governance	OUTCOME	QUANTITATIVE	IRIS	GHG emissions	specific	Decrease other pollution	Reduce other pollution	5	5	5	1	4.69
Decreased emission of oxides (Nox)	CityProject	DSO/TSP/Endusers/Governance	OUTCOME	QUANTITATIVE	IRIS;CITYxCHANG	GHG emissions	specific	Decrease other pollution	Reduce other pollution	5	3	3	5	3.56
Air quality index Nox	CityProject	DSO/TSP/Endusers/Governance	OUTPUT	QUANTITATIVE	SMARTENCITY	GHG emissions	specific	Decrease other pollution	Reduce other pollution	5	3	3	5	3.56
Global warming potential per capita	CityProject	DSO/TSP/Endusers/Governance	OUTPUT	QUANTITATIVE	SMARTENCITY	GHG emissions	background	Decrease GHG emissions	Reduce GHG emissions	5	5	3	5	3.96
Greenspace per 100 000 population (parks, urban trees, places...)	CityProject	DSO/TSP/Endusers/Governance	OUTPUT	QUANTITATIVE	SMARTENCITY;JR	Resources and processes	specific	Capture GHG emissions	Increase green-area	5	5	3	3	3.80
Vegetable garden per dwelling	CityProject	governance	INPUT	QUANTITATIVE	JRCMISSION	Resources and processes	background	Capture GHG emissions	Increase green-area	3	5	5	3	4.44
Increased % of green roofs	CityProject	governance	OUTPUT	QUANTITATIVE	NATURALeza	Resources and processes	background	Capture GHG emissions	Increase green-area	5	5	3	5	3.96
Increased % of green facades	CityProject	governance	OUTPUT	QUANTITATIVE	NATURALeza	Resources and processes	background	Capture GHG emissions	Increase green-area	5	5	3	5	3.96
Reduction of energy cost	CityProject	DSO/TSP/Endusers	OUTCOME	QUANTITATIVE	IRIS	Resources and processes	specific	Develop local economy	Decrease energy costs	5	5	3	5	3.96
CO2 reduction cost efficiency	CityProject	DSO/TSP/citizens	OUTCOME	QUANTITATIVE	IRIS	Resources and processes	background	Develop local economy	Decrease energy costs	5	5	3	3	3.80
Reduction of energy price by ICT related technology	CityProject	DSO/TSP/endusers/Governance	OUTCOME	QUANTITATIVE	SCIS	Resources and processes	background	Develop local economy	Decrease energy costs	5	1	5	3	4.04
Local job creation	CityProject	TSP/Endusers/Governance	OUTCOME	QUALITATIVE	IRIS	Resources and processes	specific	Develop local economy	Develop new jobs	3	5	5	5	4.60
Fuel poverty	CityProject	DSO/TSP/Endusers/Governance	IMPACT	QUANTITATIVE	IRIS	Resources and processes	background	Develop local economy	Decrease energy costs	5	3	5	5	4.60
Awareness of economic benefits of reduced energy consumption	CityProject	Endusers/RCG/Citizen ambassador	OUTCOME	QUANTITATIVE	IRIS	Resources and processes	background	Develop local economy	Decrease energy costs	5	1	5	5	4.20
Number of sustainable jobs created locally	CityProject	governance	IMPACT	QUANTITATIVE	JRCMISSION	Resources and processes	background	Develop local economy	Develop new jobs	5	1	5	5	4.20
Stimulating an innovative environment	City	TSP/Governance	INPUT	QUALITATIVE	IRIS	Resources and processes	background	Develop local economy	Develop new jobs	5	1	5	5	4.20
Local renewable energy generation	CityProject	DSO/TSP/governance	OUTCOME	QUANTITATIVE	SCIS	Resources and processes	specific	Green energy generation	Develop renewable energy	5	5	3	5	3.96
percentage of total energy derived from renewable sources	CityProject	DSO/TSP/governance	OUTCOME	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Green energy generation	Develop renewable energy	5	5	3	5	3.96
Reduced energy curtailment of RES	CityProject	DSO/TSP	OUTCOME	QUANTITATIVE	SCIS;CITYxCHAN(	Resources and processes	background	Green energy generation	Increase quality of supply	5	3	3	5	3.56
Energy use (PV, biomass, solar thermal, hydraulic, minieolic, geothermal)	CityProject	DSO/TSP/governance	OUTPUT	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Green energy generation	Develop renewable energy	5	3	3	5	3.56
Degree of energetic self-supply by RES	CityProject	DSO/TSP/End users	OUTCOME	QUANTITATIVE	SCIS;IRIS;CITYxC	Resources and processes	background	Green energy generation	Develop renewable energy	5	3	3	3	3.40
Energy return on energy investment	CityProject	DSO/TSP	OUTCOME	QUANTITATIVE	IRIS	Resources and processes	background	Green energy generation	Develop renewable energy	1	1	5	3	3.25
Increased reliability	CityProject	DSO/TSP/endusers	IMPACT	QUANTITATIVE	SCIS	Resources and processes	background	Green energy generation	Increase quality of supply	3	3	3	5	3.16
Increase in new RES integration	CityProject	DSO/TSP/governance	OUTCOME	QUANTITATIVE	CITYxCHANGE	Resources and processes	background	Green energy generation	Develop renewable energy	5	1	5	5	4.20
Percentage city level production versus total energy consumption	CityProject	DSO/TSP/governance	OUTCOME	QUANTITATIVE	CITYxCHANGE	Resources and processes	background	Green energy generation	Develop renewable energy	5	3	5	5	4.60
Increased power quality and quality of supply	CityProject	DSO/TSP/endusers/Governance	OUTCOME	QUANTITATIVE	SCIS	Resources and processes	background	Green energy generation	Increase quality of supply	5	3	5	5	4.60
Peak load reduction	CityProject	DSO/TSP	OUTCOME	QUANTITATIVE	SCIS; IRIS	Resources and processes	background	Green energy generation	Increase quality of supply	5	5	5	5	5.00
Increase hosting capacity of RES, electric vehicles and new loads	CityProject	DSO/TSP/Governance	OUTCOME	QUANTITATIVE	SCIS	Resources and processes	background	Green energy generation	Increase quality of supply	3	5	5	5	4.60
Smart storage capacity	CityProject	DSO/TSP	INPUT	QUANTITATIVE	IRIS;CITYxCHANG	Resources and processes	specific	Green energy generation	Increase energy storage	3	2	5	5	4.00
Battery degradation	CityProject	DSO/TSP/End users	OUTPUT	QUANTITATIVE	IRIS	Resources and processes	background	Green energy generation	Increase energy storage	5	1	5	5	4.20
Storage energy losses	CityProject	DSO/TSP/End users	OUTPUT	QUANTITATIVE	IRIS	Resources and processes	background	Green energy generation	Increase energy storage	3	3	5	5	4.20
Percentage of total distributed energy resource capacity utilized	CityProject	DSO/TSP/governance	OUTCOME	QUANTITATIVE	CITYxCHANGE	Resources and processes	background	Green energy generation	Develop renewable energy	5	1	5	5	4.20
Increased system flexibility for energy players	CityProject	DSO/TSP	OUTCOME	QUANTITATIVE	SCIS	Resources and processes	background	Green energy generation	Increase quality of supply	3	5	5	5	4.60
Average number of electrical interruptions per customers per year	CityProject	DSO/Endusers	OUTPUT	QUANTITATIVE	IRIS	Resources and processes	background	Green energy generation	Increase quality of supply	3	5	3	5	3.56
Average length of electrical interruptions (in hours)	CityProject	DSO/Endusers	OUTPUT	QUANTITATIVE	IRIS	Resources and processes	background	Green energy generation	Increase quality of supply	3	5	3	5	3.56

Characterization						Sorting				Rating				
Indicator name	Scope	Target stakeholder	Type	Precision	Source	BSC category	Use of indicator	Main objective	Specific objective	S	T	M	UF	AHP
Maximum hourly deficit	CityProject	DSO/TSP/End users	OUTPUT	QUANTITATIVE	IRIS	Resources and processes	background	Green energy generation	Increase quality of supply	3	5	3	5	3.56
Percentage of peakload reduction	CityProject	DSO/TSP/governance	OUTCOME	QUANTITATIVE	CITYxCHANGE	Resources and processes	background	Green energy generation	Increase quality of supply	3	5	5	5	4.60
Number of citizens using ICT oriented platform	CityProject	TSP/Governance	OUTPUT	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Increase citizens satisfaction	Develop inclusive projets	5	5	5	5	5.00
Energy demand and consumption	CityProject	DSO/governance	OUTPUT	QUANTITATIVE	SCIS;IRIS	Resources and processes	specific	Increase resources efficiency	Increase efficiency in the residential sector	5	5	5	5	5.00
Energy savings	CityProject	DSO/governance	IMPACT	QUANTITATIVE	SCIS;IRIS	Resources and processes	specific	Increase resources efficiency	Increase efficiency in the residential sector	5	5	5	5	5.00
Total building energy consumption in the city per capits	CityProject	DSO/TSP/governance	OUTPUT	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Increase resources efficiency	Increase efficiency in the residential sector	5	5	5	5	5.00
Residential buildings energy consumption per capita	CityProject	DSO/TSP/governance	OUTPUT	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Increase resources efficiency	Increase efficiency in the residential sector	5	5	5	5	5.00
Distribution energy source buildings use	CityProject	DSO/TSP/governance	OUTPUT	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Increase resources efficiency	Increase efficiency in the residential sector	5	5	5	5	5.00
Distribution of residential energy use (SHW, conditioning, heating...)	CityProject	DSO/TSP/governance	OUTPUT	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Increase resources efficiency	Increase efficiency in the residential sector	5	5	5	5	5.00
Energy consumption of public buildings	CityProject	DSO/TSP/governance	OUTPUT	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Increase resources efficiency	Increase efficiency in the residential sector	5	5	5	5	5.00
Energy use from district heating	CityProject	DSO/TSP/governance	OUTPUT	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Increase resources efficiency	Increase efficiency in the residential sector	5	5	5	5	5.00
Primary energy demand and consumption	CityProject	DSO/TSP/governance	OUTPUT	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Increase resources efficiency	Increase efficiency in the residential sector	5	5	5	5	5.00
Final energy consumption	CityProject	DSO/TSP/governance	OUTPUT	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Increase resources efficiency	Increase efficiency in the residential sector	5	5	5	5	5.00
Carpooling location	CityProject	DSO/TSP/End users	PROCESS	QUANTITATIVE	SCIS	Resources and processes	background	Increase resources efficiency	Increase efficiency in transportation	5	5	5	5	5.00
Clean mobillity utilisation	CityProject	DSO/TSP/End users	PROCESS	QUANTITATIVE	SCIS	Resources and processes	background	Increase resources efficiency	Increase efficiency in transportation	5	5	5	5	5.00
% of waste recycled on-site and nearby	CityProject	governance	OUTCOME	QUANTITATIVE	JRCMISSION	Resources and processes	background	Increase resources efficiency	Net zero waste	5	5	5	5	5.00
% of water re-used on site	CityProject	governance	OUTCOME	QUANTITATIVE	JRCMISSION	Resources and processes	background	Increase resources efficiency	Net zero water	5	5	5	5	5.00
Water consumption per activity and per inhabitants	CityProject	governance	OUTPUT	QUANTITATIVE	JRCMISSION	Resources and processes	specific	Increase resources efficiency	Net zero water	5	5	5	3	4.84
Energy consumption data aggregated by sector fuel	CityProject	DSO/TSP/governance	OUTPUT	QUANTITATIVE	IRIS;SCIS	Resources and processes	specific	Increase resources efficiency	Increase efficiency in the residential sector	5	5	5	3	4.84
Density of final energy demand	CityProject	DSO/TSP/governance	OUTPUT	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Increase resources efficiency	Increase efficiency in the residential sector	5	5	5	3	4.84
Peak load and profile of electricity demand	CityProject	DSO/TSP/governance	OUTPUT	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Increase resources efficiency	Increase efficiency in the residential sector	5	5	5	3	4.84
% of reused construction material	CityProject	governance	OUTPUT	QUANTITATIVE	JRCMISSION	Resources and processes	background	Increase resources efficiency	Net zero waste	5	5	5	3	4.84
% of recycled construction material	CityProject	governance	OUTPUT	QUANTITATIVE	JRCMISSION	Resources and processes	background	Increase resources efficiency	Net zero waste	5	5	5	3	4.84
% of low-GHG emission contruction material	CityProject	governance	OUTPUT	QUANTITATIVE	JRCMISSION	Resources and processes	background	Increase resources efficiency	Net zero waste	5	3	5	5	4.60
Yearly km made through e-car sharing systems	CityProject	Endusers	OUTPUT	QUANTITATIVE	IRIS	Resources and processes	background	Increase resources efficiency	Increase efficiency in transportation	5	3	5	5	4.60
Kilometres of high capacity public transport system per 10000 pop	CityProject	DSO/TSP/End users	OUTPUT	QUANTITATIVE	SCIS;SMARTENCI	Resources and processes	background	Increase resources efficiency	Increase efficiency in transportation	5	3	5	5	4.60
Passenger-km public transport and private vehicle	CityProject	DSO/TSP/End users/Governance	OUTPUT	QUANTITATIVE	SCIS	Resources and processes	background	Increase resources efficiency	Increase efficiency in transportation	5	3	5	5	4.60
km of bycicle paths and lines per 100 000 population	CityProject	TSP/Endusers/Governance	INPUT	QUANTITATIVE	SCIS	Resources and processes	background	Increase resources efficiency	Increase efficiency in transportation	5	3	5	5	4.60
Number of personal auto per capita	CityProject	TSP/Endusers/Governance	INPUT	QUANTITATIVE	SCIS	Resources and processes	background	Increase resources efficiency	Increase efficiency in transportation	3	5	5	5	4.60
Free floating subscribers	City	TSP/Governance	OUTPUT	QUANTITATIVE	IRIS	Resources and processes	background	Increase resources efficiency	Increase efficiency in transportation	5	3	5	5	4.60
Number of efficient vehicles deployed in the area	CityProject	TSP/Endusers/Governance	INPUT	QUANTITATIVE	IRIS;SCIS	Resources and processes	background	Increase resources efficiency	Increase efficiency in transportation	5	3	5	5	4.60
Distribution of vehicles in the city	City	DSO/TSP/governance	INPUT	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Increase resources efficiency	Increase efficiency in transportation	5	3	5	5	4.60
Daily average time by trip	CityProject	DSO/TSP/governance	PROCESS	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Increase resources efficiency	Increase efficiency in transportation	5	3	5	5	4.60
Daily average lenght by each transport type	CityProject	DSO/TSP/governance	PROCESS	QUANTITATIVE	SMARTENCITY;JR	Resources and processes	background	Increase resources efficiency	Increase efficiency in transportation	5	3	5	5	4.60
Percentage of electric vehicles	CityProject	DSO/TSP/governance	INPUT	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Increase resources efficiency	Increase efficiency in transportation	5	3	5	5	4.60

Characterization						Sorting				Rating				
Indicator name	Scope	Target stakeholder	Type	Precision	Source	BSC category	Use of indicator	Main objective	Specific objective	S	T	M	UF	AHP
Cost of monthly ticket for public transport in relation with averge wage	CityProject	DSO/TSP/governance	INPUT	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Increase resources efficiency	Increase efficiency in transportation	5	3	5	5	4.60
Water surface per capita	CityProject	governance	INPUT	QUANTITATIVE	JRCMISSION	Resources and processes	background	Increase resources efficiency	Net zero water	5	3	5	3	4.44
Number of Evs charging stations and solar powered V2G charging stations deployed in the area	CityProject	DSO/TSP/Endusers/Governance	INPUT	QUANTITATIVE	IRIS;SCIS;Smarte	Resources and processes	background	Increase resources efficiency	Increase efficiency in transportation	3	3	5	5	4.20
Average distance from each building to the closest public transport stop	CityProject	governance	INPUT	QUANTITATIVE	JRCMISSION	Resources and processes	background	Increase resources efficiency	Increase efficiency in transportation	5	1	5	5	4.20
Average age of motor vehicles for public transport	CityProject	DSO/TSP/governance	INPUT	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Increase resources efficiency	Increase efficiency in transportation	5	5	3	5	3.96
kwh/m² per year improved energy efficiency	CityProject	DSO/TSP/governance	OUTCOME	QUANTITATIVE	CITYxCHANGE	Resources and processes	background	Increase resources efficiency	Increase efficiency in the residential sector	5	5	3	5	3.96
Quantity of waste produced per activity and per inhabitants	CityProject	governance	OUTPUT	QUANTITATIVE	JRCMISSION	Resources and processes	specific	Increase resources efficiency	Net zero water	3	5	3	5	3.56
Percentage modal shift from fossil fuel vehicle to electric mobility	CityProject	DSO/TSP/governance	OUTCOME	QUANTITATIVE	CITYxCHANGE	Resources and processes	background	Increase resources efficiency	Increase efficiency in transportation	5	5	5	5	5.00
Total investments	Project	DSO/TSP	INPUT	QUANTITATIVE	SCIS;IRIS	Resources and processes	background	Optimize internal processes	Promote energy transition projects	5	5	5	5	5.00
Total annual costs	Project	DSO/TSP	INPUT	QUANTITATIVE	SCIS;IRIS	Resources and processes	background	Optimize internal processes	Promote energy transition projects	5	5	5	5	5.00
Payback period	Project	DSO/TSP	OUTCOME	QUANTITATIVE	SCIS	Resources and processes	background	Optimize internal processes	Promote energy transition projects	5	5	5	5	5.00
Return on investment	Project	DSO/TSP	OUTCOME	QUANTITATIVE	SCIS;IRIS	Resources and processes	background	Optimize internal processes	Promote energy transition projects	5	5	5	5	5.00
Financial benefit for the end-user	CityProject	Endusers/governance	OUTCOME	QUANTITATIVE	IRIS	Resources and processes	background	Optimize internal processes	Promote energy transition projects	5	5	5	5	5.00
Grants	City	TSP/Endusers/Governance	INPUT	QUANTITATIVE	IRIS;SCIS	Resources and processes	background	Optimize internal processes	Promote energy transition projects	5	5	5	5	5.00
% of the project financed by the municipal budget	Project	governance	INPUT	QUANTITATIVE	JRCMISSION	Resources and processes	specific	Optimize internal processes	Promote energy transition projects	5	5	5	5	5.00
% of the project contribution to the municipal budget	Project	governance	OUTCOME	QUANTITATIVE	JRCMISSION	Resources and processes	background	Optimize internal processes	Promote energy transition projects	5	5	5	5	5.00
Signature of covenent of mayor	City	governance	INPUT	QUALITATIVE	SMARTENCITY	Resources and processes	background	Optimize internal processes	Develop a legal framework for energy transition	5	5	5	1	4.69
Expiration date of open data	CityProject	TSP/Governance	PROCESS	QUANTITATIVE	IRIS	Resources and processes	background	Optimize internal processes	Increase quality of data and monitoring system	5	5	5	1	4.69
quality of open data	CityProject	TSP/Governance	IMPACT	QUALITATIVE	IRIS	Resources and processes	background	Optimize internal processes	Increase quality of data and monitoring system	5	5	5	1	4.69
datasafety	CityProject	TSP/Governance	OUTPUT	QUANTITATIVE	IRIS	Resources and processes	background	Optimize internal processes	Increase quality of data and monitoring system	5	3	5	5	4.60
Existence of public incentives to promote energy efficient districts	City	Endusers/Governance	INPUT	QUALITATIVE	SMARTENCITY	Resources and processes	background	Optimize internal processes	Promote energy transition projects	5	3	5	5	4.60
Existence of public incentives to promote sustainable mobility	City	Endusers/Governance	INPUT	QUALITATIVE	SMARTENCITY	Resources and processes	background	Optimize internal processes	Promote energy transition projects	5	3	5	5	4.60
Existence of ergulations for development of energy efficient districts	City	governance	INPUT	QUALITATIVE	SMARTENCITY	Resources and processes	background	Optimize internal processes	Develop a legal framework for energy transition projects	5	3	5	5	4.60
Existence of regulations for development of sustainable mobitily	City	governance	INPUT	QUALITATIVE	SMARTENCITY	Resources and processes	background	Optimize internal processes	Develop a legal framework for energy transition projects	5	3	5	5	4.60
Existence of local/ national energy performance certificate	City	governance	INPUT	QUALITATIVE	SMARTENCITY	Resources and processes	background	Optimize internal processes	Develop a legal framework for energy transition projects	5	3	5	5	4.60
Expenditures by the municipality to energy transition	City	governance	INPUT	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Optimize internal processes	Promote energy transition projects	5	1	5	5	4.20
Number of air quality station	CityProject	TSP/Governance	OUTPUT	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Optimize internal processes	Increase quality of data and monitoring system	5	1	5	5	4.20
Number of sensors deployed in the city	CityProject	TSP/Governance	OUTPUT	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Optimize internal processes	Increase quality of data and monitoring system	5	1	5	5	4.20
Number of smartmeters instlles	CityProject	TSP/Governance	OUTPUT	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Optimize internal processes	Increase quality of data and monitoring system	5	1	5	3	4.04
greenbuilding self-consumption / smartEV/ symbiotic waste, energy flexibility legal framework compatibility	CityProject	governance	IMPACT	QUALITATIVE	IRIS	Resources and processes	background	Optimize internal processes	Develop a legal framework for energy transition projects	5	1	5	3	4.04

Characterization						Sorting				Rating				
Indicator name	Scope	Target stakeholder	Type	Precision	Source	BSC category	Use of indicator	Main objective	Specific objective	S	T	M	UF	AHP
Change in rules and regulation	City	governance	IMPACT	QUALITATIVE	IRIS	Resources and processes	background	Optimize internal processes	Promote energy transition projects	5	5	3	5	3.96
reduction of investment in energy grid	CityProject	DSO/TSP	OUTCOME	QUANTITATIVE	CITYxCHANGE	Resources and processes	background	Optimize internal processes	Promote energy transition projects	5	5	3	5	3.96
Total new investment generated	CityProject	DSO/TSP/governance	INPUT	QUANTITATIVE	CITYxCHANGE	Resources and processes	background	Optimize internal processes	Promote energy transition projects	5	5	3	5	3.96
Percentage reduction in simple PB period	CityProject	DSO/TSP/governance	OUTCOME	QUANTITATIVE	CITYxCHANGE	Resources and processes	background	Optimize internal processes	Promote energy transition projects	3	1	5	5	3.80
Automated management system (waste, traffic, light, noise...)	CityProject	TSP/Governance	OUTPUT	QUANTITATIVE	SMARTENCITY	Resources and processes	background	Optimize internal processes	Increase quality of data and monitoring system	5	3	3	5	3.56
No. Of politically approved projects with guidelines, roadmaps and action plans	CityProject	governance	IMPACT	QUANTITATIVE	CITYxCHANGE	Resources and processes	background	Optimize internal processes	Promote energy transition projects	5	3	3	5	3.56
No. Of changes in regulations	City	governance	OUTPUT	QUALITATIVE	CITYxCHANGE	Resources and processes	background	Optimize internal processes	Promote energy transition projects	3	5	3	5	3.56