RES4CITY

renewable energies system for cities

Deliverable D2.2

RES4CITY multidisciplinary and multi sector lighthouses

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List of Acronyms

Acronym	Meaning
BAF	Beyond Armchair Feminism
BS	Baseline Scenario
CAPEX	Capital Expenditure
CCGT	Combined Cycle Gas Turbine
DVLA	Driver and Vehicle Licensing Agency
EU	European Union
EV	Electric Vehicle
GEP	Gender Equality Plan
GHG	Greenhouse gases
HOMER	Hybrid Optimization Model for Multiple Energy Resources
ICE	Internal Combustion Engines
ICEN	Inventory of Carbon and Energy
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
LCA	Life Cycle Assessment
LCOE	Levelized Cost of Energy
LTM	Municipality of Lyngby-Taarbæk
MGO	Marine Gasoil
NBS	Natural Based Solutions
NPV	Net Present Value
PPA	Power Purchase Agreement
PV	Photovoltaic
PVGIS	Photovoltaic Geographical Information System
RES4CITY	Renewable Energies Systems for Cities
SLB	Second-hand Electric Vehicle Batteries
SoH	State of Health
WACC	Weighted average cost of capital
ZVI	Zones of visual influence
SAFS	Succession Agroforestry System

Executive Summary

RES4CITY is a 36-month project funded by the European Commission, initiated in October 2022. Its primary objective is to advance the development of sustainable renewables and fuel technologies within cities. This is achieved by collaborative efforts in designing innovative educational micro-programmes involving various stakeholders. The project also emphasizes the promotion of sustainability and circularity, bridging the knowledge and skills gaps essential for a successful energy transition.

This deliverable, designated as D.2.2 *RES4CITY multidisciplinary and multi sector lighthouses*, is developed under task T2.2 *Lighthouse case studies development* of the RES4CITY project during M12 (September 2023). Task T2.2 builds upon the energy-related urban challenges identified in T2.1 *Innovative sustainable strategies for carbon neutral smart cities*. In essence, task T2.2 focuses on creating lighthouse case studies that address these identified challenges. To ensure a comprehensive and effective approach, task T2.2 collaborates closely with task T3.2, actively engaging the community of stakeholders. The culmination of these collaborative efforts results in the production of pre-feasibility analyses tailored to the specific urban context under consideration.

The document comprises three chapters. The first chapter introduces task T2.2, which involved the development of ten lighthouse case studies by project partners, along with their corresponding HUBs. This chapter describes the approach to ensuring clarity and enhancing reader comprehension, thereby amplifying the impact and dissemination of these case studies. To achieve this, the case studies followed a predefined template designed with a structure like that of a scientific article. This structure encompasses not only an introductory section addressing the challenge under scrutiny and introducing the case study but also includes sections dedicated to presenting results, recommendations, and conclusions.

In the second chapter, the ten lighthouse case studies are compiled and presented individually. This set of lighthouse case studies contributes to fulfilling the RES4CITY's Milestone 11 *Lighthouse available for case study education*. Each case study is accompanied by an executive summary, which complements the existing Abstract and Graphical Abstract elements that are part of the case study structure. The objective of creating this executive summary is to provide an additional resource that can be examined independently of the complete case study. Its purpose is to facilitate an understanding of the subject matter and the case study itself while highlighting key results and conclusions. This approach enables the case studies to be used independently. Within the framework of this Deliverable, the executive summary serves as tool for readers to grasp the key points of each case study swiftly and concisely. This empowers readers to determine, based on their interests and requirements, whether they want to delve deeper into the individual case studies for more detailed analysis.

In the third and concluding chapter, each lighthouse case study developed by the project partners is presented in a straightforward and concise manner. Furthermore, this chapter highlights key concluding remarques derived from each of the case studies. Lastly, it emphasizes the dual purposes for which these case studies were developed: as learning tools in the RES4CITY learning and upskilling programs and as multipliers for replication in other contexts.

The Deliverable 2.2 was concluded and submitted in September 2023 by (UCOI) with the support of the partners listed in Table *1*.

1. Introduction

Under task T2.2 of the RES4CITY project, a total of ten lighthouse case studies were developed (Table 1). These case studies cover different aspects of the urban context, including industrial areas, transportation, public services, buildings, etc., and different dimensions, namely environmental sustainability, technical feasibility, business model, financial sustainability, social equality and acceptance, and diffusion. These case studies address specific energy related urban challenges previously identified in task T2.1 *Innovative sustainable strategies for carbon neutral smart cities*.

By analysing specific urban challenges, each lighthouse case study, conducted by different project partners in collaboration with their respective HUB partners, contributes to promoting and accelerating the deployment of renewable energy systems in urban contexts. To this end, these case studies will fulfil two pivotal roles. First, they will be used as learning tools in the RES4CITY learning and upskilling programs, allowing contact with more detailed and practical examples of concrete topics to be taught. Secondly, these case studies will serve as multipliers for replication in other contexts, aligning with the aspirations of WP6 *Dissemination, Communication, Exploitation and Replication*. This approach widens the project's reach by establishing them as examples and guidelines for implementing these types of projects in different contexts, subject to necessary adaptations.

Deliverable D2.2 *RES4CITY multidisciplinary and multi sector lighthouses* fulfils the purpose of aggregating and presenting the lighthouse case studies developed within RES4CITY project, contributing to Milestone 11 *RES4CITY's lighthouse available for case studies education*. Throughout the document, each of the ten lighthouse case studies can be consulted in detail.

To ensure consistency and enhance reader comprehension, the case studies followed a predefined template consisting of a structure akin to that of a scientific paper. The document initiates with an abstract and a graphical abstract, facilitating straightforward, concise, and instinctive dissemination of the case study's information. This approach not only contextualizes the addressed challenge but also outlines the case study, its methodology, and the resulting conclusions and recommendations.

The Introduction section establishes the subject's framework, detailing the challenge under scrutiny, introducing the case study, and contextualizing their interrelation. This leads to the Case Study Description and Case Study Solution sections. The former provides a comprehensive depiction of the case study and elucidates the approach to addressing and tackling the challenge. The latter delineates the applied methodology, methods, and technologies leveraged to conduct the analysis.

Moving forward, the Results and Discussion section scrutinizes and deliberates upon the findings. Finally, the Conclusion and Recommendations section synthesizes the entire case study's framework, presenting the major conclusions and recommendations. Additionally, citations referencing external sources or scientific materials consulted during the case study are appropriately cited within the document, with a comprehensive reference list provided at the end of the document.

Developer	Lighthouse Case Studies
Tipperary Energy Agency (TIPP)	Templederry Community Windfarm
University of Genoa (UNIGE) & University of Naples Parthenope (UNIPARTH)	Pre-feasibility study of the cold ironing for cruise ship. A 3E Analysis
Polytechnic University of Valencia (UPV)	Methodology to estimate the decarbonization potential at the neighborhood level. Case study: Benicalap
University of Grenoble Alpes (UGA)	Advance controls of storage and use of waste heat from a nearby industry
National University of Ireland Maynooth (NUIM)	Electric Vehicle Battery Analysis: Insights for Recycling and Second-Life Use
University of Sassari (UNISS)	Promoting Sustainability in Urban Areas through the Use of Green Materials and Recycling in Building Construction – A case study in Sardinia (Italy)
Technical University of Denmark (DTU)	Decarbonisation of the heating sector: A multidimensional approach mixing centralised and decentralised heating systems in Lyngby Municipality, Denmark
University of Coimbra (UCOI)	Smart manufacturing in urban areas with carbon sequestration systems
Halmstad University (HU)	Sustainable Bioenergy and Side bio-products Production on coastal urban areas
WiTEC (WTC)	Gender inclusion in work processes with renewable energy projects in cities

Table 1. RES4CITY – Lighthouse Case Studies

2. Lighthouse Case Studies

2.1 Tipperary Energy Agency – Templederry Community Windfarm

2.1.1 Executive Summary

The case study describes the establishment and success of Ireland's first community-owned wind farm. Initiated by community members with a Certificate in Renewable Energy, the project aimed to revitalize a declining area through renewable energy. Despite challenges such as securing funding and obtaining planning permissions, the community set up a wind development company and installed two turbines. The wind farm's success led to the creation of Community Power (Figure 1), the first community-owned electricity supplier in Ireland, underlining the shared benefits of renewable energy, especially at a local level. The case study highlights the importance of local ownership and involvement in renewable energy projects, such as wind farms, for community revitalization and sustainable energy future.

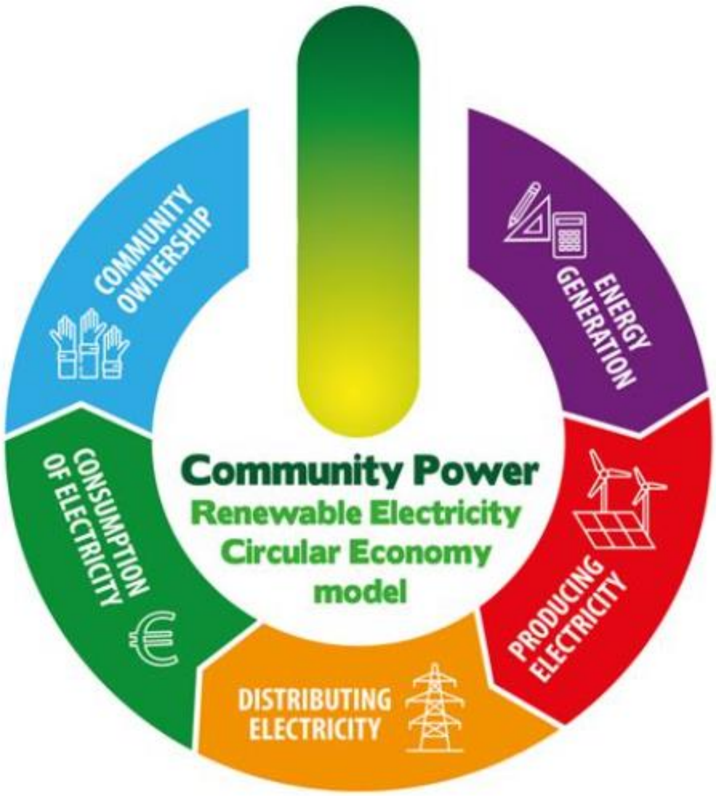

Figure 1. Templederry Community Windfarm – Graphical Abstract

2.1.2 Case Study

2.1.2.1 Abstract

Templederry Community Windfarm, the first and only community owned wind farm in Ireland, became operational in November 2012. The development consists of two 2.3 MW Enercon turbines.

Templederry community is located in County Tipperary on the northern edge of the Slieve Felim mountains. The area suffered from population decline and there were limited local employment opportunities.

The community wind farm project began when four individuals from the community completed a Certificate in Renewable Energy at the then Tipperary Institute and, following from this, sought to explore opportunities for a renewable energy project in the region, as part of the Environmental Protection goal within their Community Development Plan.

2.1.2.2 Introduction

Templederry community group was established as a result of a number of local individuals commissioning a Development Plan study to ascertain the economic development potential of the parish. The community applied for LEADER funding to develop this Community Development Plan. Once funding was obtained, public meetings were held in four parish centres to engage the wider community in the process and information was circulated to all community groups in the area.

The study report identified renewable energy, including wind, biomass and anaerobic digestion, as a means to achieve social, economic and environmental development for the community. Feasibility studies, funded by the County Enterprise Board and carried out by the Tipperary Energy Agency, were carried out into these three forms of renewable energy (Tipperary Energy Agency, 2023). After the feasibility assessed the pros and cons of each, the group decided on wind energy, as they believed it would be the quickest to develop.

Some of the original objectives for this community renewable energy development project were to generate a substantial amount of energy from renewables, to support the declining rural economy and to demonstrate what can be achieved for communities through the development of such projects. One of the key questions that the group considered before deciding on a project was what return they would like to obtain for each investor in the project and this decision influenced their thinking on the type and scale of project.

The group set up a dedicated wind development company, where anyone interested could take shares. The group aimed to raise €30,000 for the original planning application. The original project grouping was established through local community meetings in parish and school halls. This group then sought investors from the local community via an invitation in the parish newsletters and the local paper as well as announcements during local religious services. While initial interest was limited, the group managed to secure investment from 30 members of the local community.

2.1.2.3 Description of Case Study

The aim of this project for Tipperary Energy Agency was to assist Templederry Community Group in the development of wind energy in their Community by providing them with the resources to analyse and determine the most appropriate mechanism for the development of wind energy by the community (Tipperary Energy Agency, 2023). Key Objectives of the project were:

- Identify suitable sites in the community for the development of wind energy;
- Assist the community in the purchase of an anemometer;
- Erect anemometer on site, selected by the community;
- Record and analyse the wind speed data in the area;
- Assist the community in negotiations with wind developers to ensure maximisation of their involvement in wind development;
- Educate the local community with regard to development of renewable energy in the area.

2.1.2.4 Case Study Solution

Once the dedicated wind energy company was set up, the group began to consider potential turbine locations. The assessment of the potential wind energy resource at any site is a complex task and particularly so for a small community which has no expertise or general knowledge in this area. It was in this regard that the community sought to link with the Tipperary Energy Agency to ensure that this work could be done at a local level and a mechanism could be developed to increase the knowledge and skills in the local community about renewable energy (Tipperary Energy Agency, 2023). The wind resource was assessed as follows: Tipperary Energy Agency had produced a wind resource map for Co. Tipperary (as part of an EU Funded project). This was assessed to isolate the Templederry community, and the data was overlayed on a local topographical map. This resulted in a total of 20 potential sites being identified. Each site was visited individually and assessed in terms of elevation, ownership, archaeology, proximity of dwellings, grid connection, aspects and openness to prevailing winds and transport access (Tipperary Energy Agency, 2023).

A member of the local authority planning team also helped the group by suggesting a particular hill that was free from designation constraints and which took zones of visual influence (ZVI) into consideration and therefore would be considered more suitable from a planning viewpoint. The community group accepted this suggestion and, with the help of funding from the European Union (EU) Rural Development programme LEADER1, set up a wind monitoring mast on site.

Once they had determined that the site was feasible for wind energy development, planning permission for three 1.3 MW turbines was sought. The wind farm was granted planning permission and the group then applied for grid connection.

Due to grid capacity issues at the time, the ability to get connection was delayed and it was around 3.5 years before grid connection became possible.

Significant funds were required in order to secure the grid connection (the group needed to pay for 50% of grid connection costs, which were €940,000), which could not be funded by the local community group. For this project an Enercon loan and LEADER grant each funded €200,000 to help secure the grid connection. Without this funding, the project could not have gone ahead.

When the grid connection was secured, it was found that the delivery time for turbines would be just over 2 years. Due to these delays the original planning permission expired and the group needed to reapply for planning permission. This time they applied for two 2.3 MW turbines. While this was eventually granted, a number of objections were lodged to the second application, and it was rejected by the local planning authority. The decision was appealed to an Bord Pleanala and it took over two years before a decision was reached and planning permission was granted.

Once planning permission was received, the community group sought a Power Purchase Agreement (PPA) to sell the output from the wind turbines. They negotiated with a number of energy companies and reached an appropriate agreement.

In addition to the LEADER grant aid and Enercon loan, the project was financed by a range of other sources including shareholder equity, a business expansion scheme and project finance from De-Lage Landen (a subsidiary of Rabo-Bank).

The community group signed a turbine delivery contract with Enercon. The turbines were delivered on 17th September 2012, were up and running by the middle of November 2012 and were fully tested and commissioned by 1st January 2013. To date they have been performing better than expected.

This project has had a number of benefits within the local community, many of which will continue to benefit the community into the future. Some key benefits include:

Complete local ownership of the project, which means that, other than capital and finance costs, the full income will revert to the community group investors.

Specific community-level projects have not yet been funded. However, such projects are envisioned for the future once the project loans have been paid off. The choice of any projects funded and any community benefit they generate will be in full control of the Templederry community group. The community group have indicated that potential future projects that may be considered include low carbon housing for the elderly, schools projects and social housing projects.

From the viewpoint of the community group, having 100% of the profits going to the community is much better than a single developer building a wind farm with only a small percentage going to the community.

Demonstration of what can be achieved when individuals in the community work together, enhancing public acceptance and awareness of renewable energy projects within the community. The community group is considering the development of additional renewable energy projects. Any such projects will benefit from the expertise gathered in the local community. The company that set up the wind farm is now examining other options for renewable energy generation.

While the second planning application in this project had some level of objection (indicating that there was not full community acceptance of the project), now that the project is completed there is a much greater level of interest in renewable energy initiatives throughout the community.

The community group also now has the experience and expertise to help other groups with planning, selecting turbines, PPA, developing finance packages, etc.

2.1.2.5 Results and Discussion

It should be noted that given the conditions in relation to wind development in Ireland at the time in terms of price paid per kWh of electricity produced the Templederry region could not be considered to be ideal. There were few areas with average wind speeds above 8.5 m/s and indeed it was projected that the wind speeds in the site selected would be in the region of 6.5-7.5 m/s. However, the community sought to link with relevant lobby groups such as Meitheal na Gaoithe (Irish Wind Farm Co-operative) to seek specific support for community-based projects such as theirs to improve their economic viability.

Templederry Community Windfarm has been generating electricity since 2012 and has led to the development of Community Power (Community Power, 2023). Community Power is Ireland's first community owned electricity supplier (Community Power, 2023). They are a partnership of community energy groups working for a sustainable energy future for Ireland who grew out of Ireland's first community owned wind farm, Templederry Wind Farm in Co Tipperary, and now are working with Irish communities to develop more renewable energy projects owned by people (Community Power, 2023).

As well as the electricity generated from Templederry Community Windfarm, Community Power are also buying renewably generated electricity from a handful of small and micro hydro and wind generators across Ireland and selling it to their customers to use in their homes, businesses, farms and community buildings (Community Power, 2023).

The mission of Community Power is to support Ireland to run on clean, renewable power, but they also feel people should have a real stake in it, and own it for themselves. They recognise that Ireland's energy system is in crisis, with over 90% reliance on climate polluting fossil fuels, but many people are struggling to pay high energy bills in cold homes (Community Power, 2023). That's why Community Power are working to make sure the many benefits of generating renewable power is shared by the people and communities of Ireland (Community Power, 2023).

2.1.2.6 Conclusion and Recommendations

Templederry Community Windfarm is Ireland's first community owned windfarm which has been in operation since 2012 and has since led to the development of Community Power (Community Power, 2023). The project is seen as a success story and is a flagship case study for any local community energy groups interested in developing their own project. However, there has been very few projects of it's kind in Ireland since. One of the key issues affecting wind farm development is the acceptability by the local community. It is widely thought that this can be overcome by the community getting involved in the wind farm, and benefiting directly from the green electricity being generated. Therefore, community ownership is critical to the future of wind farms in Ireland. One of the key benefits of renewable energy that is often quoted is the ability for these energy sources to be developed at a local level bringing local benefits. However, it is often the case that this particular benefit can often be the most difficult to maximise.

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2.2 University of Genoa & University of Naples Parthenope – Pre-feasibility study of the cold ironing for cruise ship. A 3E Analysis

2.2.1 Executive Summary

This case study evaluates the application of cold ironing technology as an alternative to using auxiliary or main engines powered by marine fuel oil to supply cruise ships with energy during the hotelling phase. By calculating energy consumption, pollutant emissions and externality costs for both on-board production and cold ironing for a cruise ship in an Italian port (Figure 2), the results show that cold ironing technology reduces fossil fuel consumption and greenhouse gas and air pollutant emissions, while ensuring economic viability. Assuming a connection fee of 46 €/MWh, the estimated savings per cruise ship are 9 M€ in fuel savings over 30 years and 31 M€ per year in externality costs.

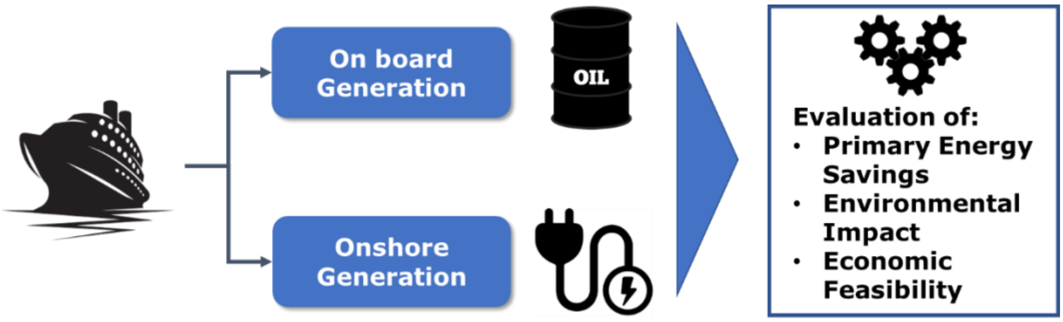

Figure 2. Pre-feasibility study of the cold ironing for cruise ship. A 3E Analysis – Graphical Abstract

2.2.2 Case Study

2.2.2.1 Abstract

Freight and passenger transport is continuously growing, including the cruise sector which is an increasing business field for ports and cities that generates an additional income for the city and related economic sectors. On the other hand, anchoring ships have relevant energy consumption, noise generation, and pollutant emissions which have a substantial environmental impact. This issue is tighter when ports are close or connected with urban areas, as often happens.

It is estimated that 10%-15% of harmful emissions occur in the port. Even though most of the emissions happens during the navigation, port emissions have a relevant impact on the urban areas of many EU cities, thus it is fundamental to highlight solutions for the reduction of the pollutant emissions.

An effective option to decrease energy consumption and the corresponding pollutant emissions of anchoring ships is to switch the energy supply modality, namely from ship-based to land-based modality.

The land-based modality consists in shifting energy generation from the ship to the land. Thus, the ship is supplied with energy generated somewhere else. In particular, the power load is covered with electricity generated in another location (ideally renewable based generation) while decreasing at minimum the load of ship engines. This approach, known as “cold ironing”, drastically reduces the emissions while the ship is anchoring.

The present case study will develop an energy, environmental, and economic (3E) analysis of the impact of “cold ironing” of a cruise ship anchoring in an Italian port.

The analysis demonstrated that the cold ironing is a viable option from energy, environmental, and economic point of view.

In particular, a connection fee of 46 €/MWh is estimated for the cold ironing system. Furthermore, the cold ironing guarantees fuel savings of 9 M€ in a period of 30 years for a cruise ship anchoring. The impact of the reduction in the externality cost is much more substantial and estimated in 31 M€/year per cruise ship. The analysis is developed for one cruise ship and it can be easily extended to evaluate the impact on one port or on the Italian cruise ship sector.

2.2.2.2 Introduction

In port emissions are a relevant issue for vessels anchored in ports especially when the port is located close to the urban areas. The problem is not negligible since maritime traffic constantly increased during the years. In terms of pollutant emissions, NO_x, SO_2 and soot emissions are the typical ones in addition a substantial amount of carbon emissions is also released.

Among the different typologies of vessels, cruise ships can be considered one of the most pollutant one while hotelling in ports since they need to provide services for a large amount of people (i.e., 5k-10k passengers) thus provoking a substantial environmental impact.

The problem is highlighted in the scientific and technical literature and different authors analysed it in various countries. Maragkogianni & Papaefthimiou (2015) studied the level of emissions from cruise ships in the first 5 Greek ports. They found that emissions during the hotelling represent the 85% of the total and largely exceeded those related to manoeuvring which represented 12%. Furthermore, seasonality has a significant effect on the level of emissions which are concentrated in summer season due to the higher cruise traffic.

For reducing the emissions level most ship-owners prefer to pollutant emissions reducing systems such as Scrubbers and Selective Catalytic Reactor Systems which can be connected with internal combustion engines (ICE) burning heavy fuel oil (Armellini et al., 2019). An alternative solution could be the utilization of a gas turbine fuelled with Marine Gas Oil combined with an ICE and tri-generation systems in order to exploit the positive features of all the systems as discussed by (Armellini et al., 2019).

Emissions from cruise ships in ports determine social cost for the neighbouring port areas and (Tichavska & Tovar, 2015) developed an analysis for the quantification of the externality costs from cruise ships in the port of Las Palmas in Tenerife.

Detailed bottom-up calculation of the emissions from cruise ships in Greek ports, i.e., 18 ports investigated, demonstrated that more than 89% of the emissions are due to the hotelling and the enlargement of the tourism season in October and November has extended the period of exposure of the population in nearby area to high emissions level (Papaefthimiou et al., 2016). Other authors implemented machine learning tools to determine the emissions from cruise ship as is the case of Barcelona port (Fabregat et al., 2022).

The analysis of the environmental and social impact of cruise tourism is object of many studies since researchers attempt to understand if the environmental cost is offset by a social gain in terms of improvement of social conditions of people leaving in urban areas close to cruise ports.

MacNeill & Wozniak (2018) proposed a methodology to measure the economic, social, and environmental impact of cruise tourism on a local community. They tested their methodology in the

Trujillo-area cruise ship project in Honduras. They detected an improvement of the safety of the area, since crime decreased due to increase of spending in police services, but they also noted an increase of pollution and corruption. These results cannot be generalized overall but they can be an indication of possible effects especially in developing countries.

Carić & Mackelworth (2014) discussed the overall environmental impact from cruise tourism, including waste and sewage water, in the Mediterranean Sea with a specific focus on Croatia which is an emerging destination. They observe that the level of consumption of cruise passengers is often much higher than those of people in local communities hosting cruise ships thus the resource consumption and consequent emissions of cruise tourists overcome those of residents. Furthermore, they estimate that the environmental cost can be up to seven times higher with respect to the economic benefits to local Croatian communities.

Johnson (2002) proposed a categorization to highlight which are the action that cruise operators and cruise destinations can implement to reduce the environmental impact of cruise tourism. Similarly, Klein (2011) analysed possible path lines for the sustainable development of cruise tourism by focusing on three dimensions, namely environmental impact on coastal and marine environment, local economies, and socio-cultural aspects of local ports communities.

An innovative approach to reduce the environmental impact of cruise ships while hotelling is the utilization of the so-called *cold ironing,* namely the onshore electricity supply to the vessel for ensuring all the necessary activities. This approach consents to switch off the engines or to reduce their power substantially and, consequently, a total or relevant reduction of the pollutant emissions is achieved locally. On the other hand, if the power generation mix of the country is low carbon intensive, there is an overall positive environmental benefit since the global amount of pollutant and carbon emissions is reduced.

This approach attracted the interest of many scholars who investigated the issue and proposed different solutions and analyses. Ballini & Bozzo (2015) studied the socio-economic benefits of implementing cold ironing for cruise ships. They implemented the Economic Evaluation of Air Pollution model, EVA, and estimated that if 60% of the cruise ships in Copenhagen would use cold ironing, a saving in externality of 3 M€/year is achieved.

Innes & Monios (2018) developed the feasibility analysis of cold ironing in a medium size port, namely Aberdeen. They estimated that the external cost benefits would be able to repay the investment in a period of 3.5-7 years.

Caprara et al. (2021) studied the possibility to implement cold ironing in cruise port of Civitavecchia, near Rome. They concluded that the current port facilities do not allow to sustain cold ironing since they are unable to supply the necessary power. On the other hand, they suggest developing an electrical storage system to support the current infrastructure and to exploit possible local for renewable energy sources.

Sciberras et al. (2016) analyse the different electrical configurations available for cold ironing. They modelled the different approaches by using real operational data from European ports. They conclude that carbon emissions can be reduced up to 40%.

Zis et al. (2014) propose a methodology for the analysis of pollutant and carbon emissions reduction in ports using cold ironing. Based on their methodology, they evaluated the impact of different emission reduction policies.

Finally, Zis (2019) developed a review to provide a picture on the state of art of the implementation of this technology and the barriers hampering its wide diffusion. Abu Bakar et al. (2023) also propose a complete review of studies related to cold ironing. In particular, they provide an overview of calculation methodologies for emissions and costs assessment.

Based on previous analyses, the present document proposes the development of a case study to estimate the energy, environmental, and economic impact of implementing cold ironing for cruise ships in Italian ports. The topic is of paramount importance since Italy is one of the world's leading touristic destinations and in 2023 about 5000 cruise ship dockings are foreseen.

2.2.2.3 Description of Case Study

The present case study focuses on the application of the *cold ironing* technology for supplying energy to cruise ships while hoteling (i.e., when they stop in ports). Cruise ships need relevant amount of energy while hoteling since all the services for the boarded tourists (i.e., air conditioning, warm water, electricity supply) are active. This energy is normally supplied by using auxiliary engines or main engines fuelled with marine fuel oil.

This determines a relevant environmental, but also noise impact, of cruise ships in ports, especially when port infrastructures are close to city centres. Based on this, the mitigation of the environmental impact is necessary.

An effective way to reduce both environmental and noise pollution could be the electrification of the consumption by providing onshore electricity as is usually done with yachts. On the other hand, the power necessary to supply a cruise ship is much higher, i.e., in the range of 10-20 MW, thus a robust infrastructure in terms of power transmission and generation is needed.

Furthermore, it must be added that the environmental sustainability of the cold ironing approach depends on the power generation mix of the individual country where it is implemented. The higher is the share of renewables and the more sustainable is to implement the cold ironing.

The present case study will analyse the implementation of the cold ironing for cruise ship in the Italian context. The analysis will consider the electrification of one cruise dock to analyse its energy, environmental, and economic feasibility.

2.2.2.4 Case Study Solution

The proposed methodology consists in the calculation of on-board and onshore energy and pollutant emissions; thus, the savings can be estimated.

On-board total power supply is given by the sum of the operation of the main engine, the auxiliary engine and the boiler according to Equation 1.

$$P_{Tot} = P_{ME} \cdot LF + P_{Aux} + P_B \quad (1)$$

Where LF is the load factor of the main engine set at 20% as suggested in (Bacalja, et al., 2020). Table 2 reports the main features of the different engines.

Table 2. Power of the different engines during the hotelling phase (Smith, et al., 2015)

	Main Engine	Auxiliary	Boiler
Power [MW]	7.2	7.5	0.8
Specific Consumption [g/kWh]	208	225	300

By multiplying P_{Tot} for the hotelling time, H, the total energy consumption is obtained, as given in Equation 2:

$$EC = P_{Tot} \cdot H \quad (2)$$

The consumption of fuel oil is determined by multiplying the energy generated by each engine for its specific consumption, as given in Equation 3:

$$FOC_i = SC_i \cdot EC_i \quad (3)$$

Where i is referred to main engine, auxiliary engine, and boiler.

Once estimated the fuel oil consumption, it is possible to obtain the pollutant, i.e., NO_x, SO_x, and soot, and the carbon emissions by multiplying the oil consumption for the corresponding emission factors as highlighted by Equation 4:

$$EM_j = FOC \cdot EF_j \quad (4)$$

Where EM are the j-th emission typology (i.e., NO_x, SO_x, soot, and CO_2) and EF is the corresponding emission factor. EF values are summarized in Table 3.

Table 3. Emission factors for on-board and onshore generation (City & Port Development, 2015), (Becker, et al., 2008).

	CO_2 [g/kWh]	NO_x [g/kWh]	SO_x [g/kWh]	PM [mg/kWh]
Marine Gasoil	645	13.2	0.2	207
Coal	925	2.5	2.5	80
Fuel Oil	872	2.6	1.2	130
Natural Gas	461	0.5	0.03	10

Energy consumption and emissions from on-board generation are compared to those from onshore generation.

Onshore emissions depend on the power supply mix of the considered country, namely by the share of coal, natural gas, and fuel oil power generation facilities in the power generation fleet. The higher is the share of renewables and the lower are emission levels.

By multiplying the emissions factor for the share of the different fossil power generation sources, the emissions are obtained with a relation similar to Eq. (4), where FOC is substitute with the considered fuel (e.g., coal, fuel oil, natural gas, waste, etc.) available in the energy mix.

Eqs. (1)-(4) allow to determine the energy consumption of cruise ships during the hotelling phase and the corresponding emissions, thus they consent to estimate the energy and environmental performance of the two solutions on daily basis. To estimate the yearly impact, it is necessary to multiply EC, FOC, and EM for the days of the year, i.e., 365, and for a load factor which considers the effective operational day of the cruise ship in one year. The basis assumption in this work is consider a yearly load factor of 50% for a cruise ship.

In addition to the energy and environmental performance, the economic viability should be assessed. Thus, the NPV, Eq. (5) is calculated by using a hurdle rate as discount factor. In such a way it is possible to determine the minimum sale price of the electricity to cruise ships in order to have a profitable investment.

$$NPV = -INV + \sum_{i=1}^{n} \frac{CIS_i \cdot E_i - COS_i}{(1+HR)^i} \quad (5)$$

Where INV is the investment cost for developing the power connection to supply the dock, E is the electrical energy supplied to the ship, CIS is the selling price of the cold ironing service, COS groups all the possible costs (i.e., O&M), n is the operating life of the infrastructure, i is the year index, and HR is the hurdle rate (i.e., the wanted rate of return for the project). HR is set at 12% as base case. By setting NPV equal to zero, thus the wanted rate of return is guaranteed, it is possible to estimate the price of electricity, supposed constant in real terms, to apply.

CIS must be added to the electricity price and this total cost for cold ironing is to be compared with the cost of the traditional energy supply (e.g., fuel oil used onboard). If the total cost for cold ironing is lower than it can said that it represents the most convenient solutions.

To make a more in-depth study, externality costs of onboard and onshore energy generation are also considered. Since the hotelling is a relevant source of air pollutant and greenhouse gas emissions, externalities connected with SO_x, NO_x, PM, and CO_2 emissions are considered.

In consideration of the fact that most of the port infrastructures are located close to densely populated areas, the impact of externality costs is relevant and it could also represent the main decision driver.

2.2.2.5 Results and Discussion

By applying the methodology illustrated in the previous section, it is possible to determine the energy consumption of a cruise ship during the hotelling phase. According to Eq. (1), the average load during the hotelling phase is 15.5 MW and, since the duration of the hotelling is estimated in 10 hours, i.e., usually the central part of the day, while the night is reserved to the navigation, the energy consumption is equal to 155 MWh.

This energy can be supplied in different ways, namely through on-board generation or through cold ironing facilities. If the supply is guaranteed through on-board generation, to estimate the average consumption of marine gasoil, the average fuel specific consumption is multiplied for the energy supply and a total of 34 t/day of fuel is obtained.

If a cold ironing facility is considered to supply the necessary energy, the primary energy consumption depends on the power generation mix of the correspondent power system (e.g., in case the port object of the study is in Italy, primary energy consumption for power generation will depend on the Italian mix). The present study considers the Italian energy mix and it takes into account the average pre-covid generation mix where RES generation has the 32% of the share versus the 68% of fossil fuels as shown by IEA data for Italy. In terms of fossil fuel consumption for power generation, the following share estimated: 32% coal, 12% fuel oil, 53% natural gas, and 3% waste.

Pre-covid values are considered in order to be conservative with respect to peculiar effect connected with the specific period rather than with the evolution of the power system. In such a way possible distortions are avoided.

Once known the fossil fuel energy consumption in both cases, it is possible to determine the pollutant emissions by considering appropriate emission factors as shown in Table 4.

Table 4. Emission factors and externality costs of air pollutants and greenhouse gas emissions.

Emission Factor	SO_x	NO_x	PM	CO_2
Emission Factor on-board Generation [g/kWh]	0.2	13.2	0.207	645
Emission Factor onshore Generation [g/kWh]	1.0	1.4	0.049	672
Externality Cost [€/kg]	12.3	27.4	109	0.1

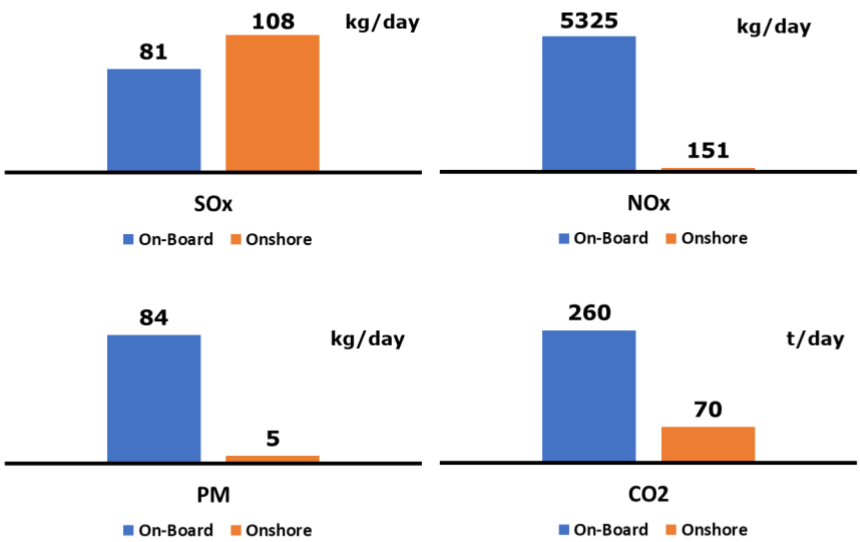

Figure 3. Air pollutant emissions and carbon emissions in case of on-board and onshore energy supply during the hotelling phase for a cruise ship.

Figure 3 highlights that the pollutant emissions are generally lower when onshore generation, i.e., cold ironing, is considered. In particular, NO_x, PM, and CO_2 emissions are noticeably lower. On the contrary SO_2 emissions are lower in case of on-board generation. SO_2 emissions are higher in power generation mainly due to the presence of coal in the power mix, furthermore marine fuel oil has a low sulphur content, thus its emission coefficient is very low. Pollutant emission coefficients for the onshore generation vary according to the power generation mix. For example, in the extreme case of a 100% RES system, the average pollutant emission coefficients will be equal to zero and no pollutant emissions (or very limited amounts if overall life cycle is considered) are emitted.

The overall impact due to the reduction of pollutant and greenhouse gas emissions can be estimated by considering the reduction of the externalities. It is calculated that the total externality cost in case of on-board generation is equal to 33 M€/year, whereas in case of onshore generation it is equal to 2.4 M€/year. Thus, if cold ironing is implemented in Italy a saving of 31 M€/year/cruise ship is achieved. This is a substantial saving also in consideration that a lot of people is involved since cruise port terminals are usually located close to city centres.

Externality saving has a crucial role in the decision process if the cold ironing infrastructure is financed by public institutions with public money.

The CAPEX for developing a cold ironing infrastructure to connect a cruise ship with an average load of maximum 20 MW is about 10 M€ (City & Port Development, 2015). If an operating life of 30 years, a hurdle rate of 12%, O&M cost of 0.1 $M€_{2021}$/year, and a yearly load factor of 50% are considered, a connection fee of 46 €/MWh is necessary to have NPV=0 according to Eq. (5). This connection fee will make the investment profitable (i.e., the hurdle rate includes both the WACC and the target profitability). On top of the connection fee, the electricity cost must be added.

The cost of power supply is estimated by hypothesizing that the combined cycle gas turbine (CCGT) will be the marginal technology, i.e., the one setting the price on the power market, during the whole operating life of the cold ironing system. This is in line with the current and next future structure of the Italian power system (Bianco & Scarpa, 2018).

Thus, natural gas and CO_2 cost evolutions are considered according to the World Energy Outlook "Stated Policy Scenario" (IEA, 2022b) and the "Gas Market Report 2022" (IEA, 2022a). Furthermore, the evolution of the MGO price is estimated by applying the oil price evolution foreseen in the "Stated Policy Scenario" of the World Energy Outlook 2022 (IEA, 2022b) to the real market price of 2021.

With these data it is possible to estimate the variable cost of the marginal CCGT according to the following equation:

$$VC_{CCGT} = \frac{C_{Ngas}}{\eta} + \frac{C_{CO2} \cdot EF_{CO2}}{\eta} + VOM \quad (6)$$

Where η is the efficiency of the CCGT set equal to 56%, EF_{CO2} is the carbon emission factor of natural gas equal to 0.0555 t/GJ and VOM is the Variable Operating and Maintenance cost set equal to 5 $€_{2021}$/MWh.

Figure 4 reports the cost evolutions according to the formulated assumptions.

Thus, the final fee for the cold ironing will be given by the connection fee plus the electricity cost which is set equal to the CCGT cost reported in Figure 4. The final fee is to be compared with the on-board generation cost given by the MGO fuel consumption multiplied for its cost, whose evolution is shown in Figure 4.

The final result is that if cold ironing is considered, a total of 9 M€ is saved in terms of energy cost within a period of 30 years. This is a very conservative estimation since it does not take into account the possibility that renewables could change the system price on the power market. For example, the LCOE of a PV plant, that could be the technology substituting the CCGT in peak hours, is much lower than the CCGT variable cost (i.e., about 30€/MWh vs. 90€/MWh).

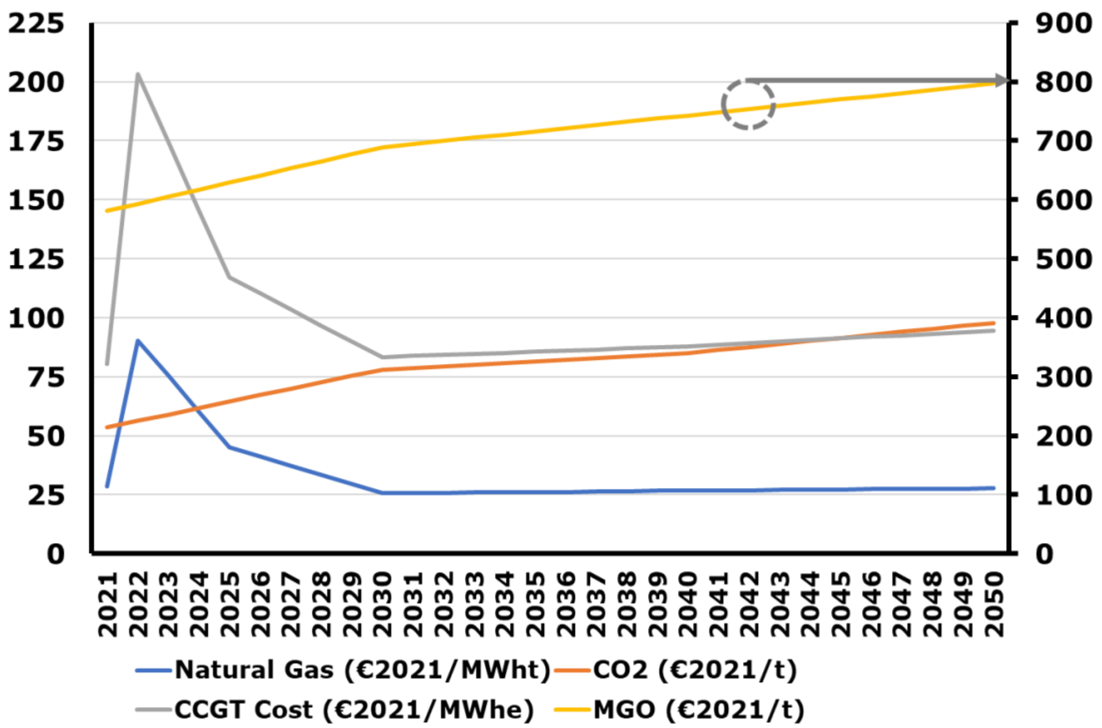

Figure 4. Air pollutant emissions and carbon emissions in case of on-board and onshore energy supply during the hotelling phase for a cruise ship.

2.2.2.6 Conclusion and Recommendations

The present work proposes the development of a pre-feasibility analysis of a cold ironing system for supporting the in-port operation of a cruise ship. Energy, environmental, and economic considerations are illustrated, and some conclusions can be derived, as reported in the following.

- The utilization of a cold ironing system determines a reduction of fossil fuel consumption by considering the current composition of the Italian power generation mix. Looking at the future evolution of the generation mix, the context should become even more convenient since more renewables are expected to enter in operation.
- The cold ironing system guarantees a substantial decrease of air pollutant emissions and greenhouse gases. This is relevant since in most cases cruise terminals are located in city centres thus emissions have a direct impact on the urban population. Cold ironing system can contribute to reduce the emissions locally, but also globally since the current configuration of the Italian power system determines an overall lower level of emissions with respect to on-board generation.
- The economic analysis of the cold ironing demonstrated its viability especially from the point of view of reduction in externalities. The substantial reduction in pollutant emissions has a strong effect in reducing the externality costs, thus cold ironing results more convenient for the community. In terms of operating cost, cold ironing determines an overall saving of 9 M€, but most of it is achieved in the long term.

The proposed estimations are affected by the different considered assumptions and by the uncertainty of many data. A further development of this study could be represented by the implementation of a scenario analysis to evaluate the impact of different fuel evolutions.

Furthermore, the switching from a deterministic to a probabilistic approach in the calculation would allow to estimate the risk connected with this investment in order to take more informed decisions.

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2.3 Polytechnic University of Valencia – Methodology to estimate the decarbonization potential at the neighborhood level. Case study: Benicalap

2.3.1 Executive Summary

The main objective of this case study is to quantify GHG emissions across sectors Figure 5 in the Benicalap district of Valencia in order to create a roadmap for the integration of renewable energy and the eventual achievement of carbon neutrality in the district. Through this analysis, it was possible to conclude that nature-based solutions (NBS), photovoltaic production, sustainable transport and efficiency in public lighting are the best strategies for a successful energy transition.

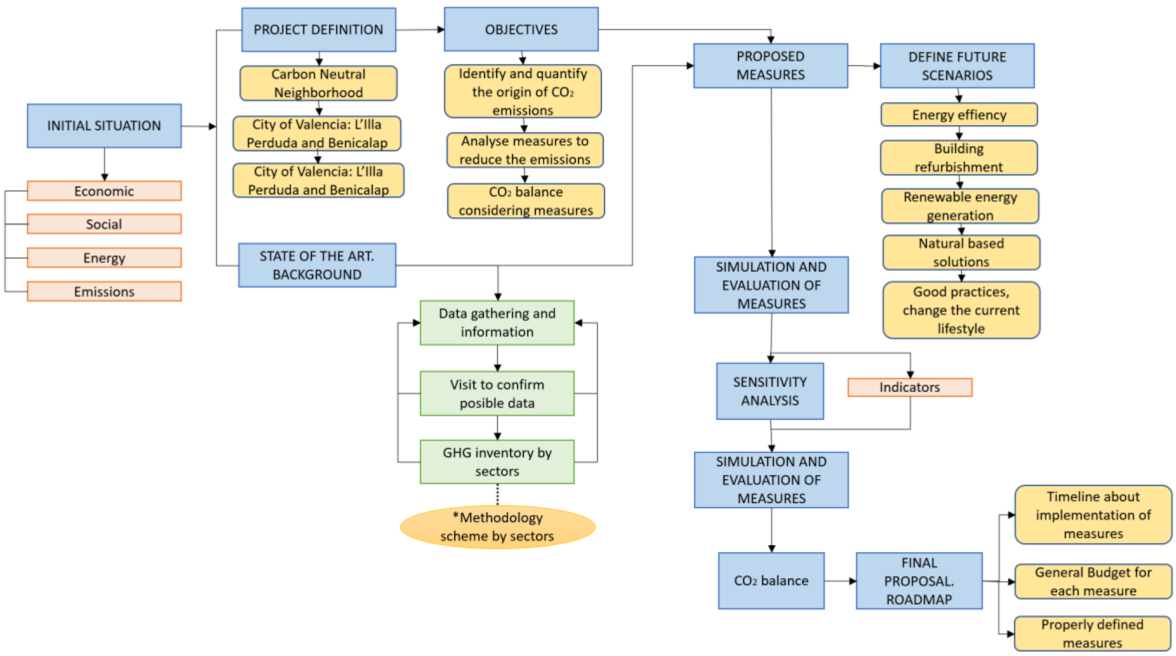

Figure 5. Summary of the Project Methodology

2.3.2 Case Study

2.3.2.1 Abstract

The Benicalap district is located on the outskirts of Valencia; it is among the city's top 6 most densely populated districts. It is mainly residential, with relatively old buildings and good public transport connections. However, private vehicle transit is also highly relevant. On top of that, Benicalap is expected to host a vital venue: the new football stadium, with the corresponding increase in transit, emissions, and services.

However, according to the City Hall, 12.465 neighbors are in a state of "vulnerability"; most of the population (69% of workers) are occupied in the service sector, and the unemployment rate is 34%. Thus, the energy transition in this district will accomplish an ambitious technical challenge while coping with a vulnerable population immersed in an expanding tertiary economy. Therefore, considerations of fairness and social innovation are mandatory for this project (Ajuntament de València, 2023).

The urban energy transition proposed for this district is a disruptive solution through district-based integration of renewable energy sources. The primary district resource is its solar potential of around 1.650 kWh/kWp. The strategy contemplates some actions: deployment of local energy communities, use of nature-based solutions, buildings' retrofitting programs, and transportation electrification. The impact of the solutions is measured regarding their energy savings and emission factors (European Commission, 2022c).

This case study shows how to exploit all the resources available in a district to accomplish a fair energy transition and to make them work together. Pilot experiences like this are essential to standardize processes and accelerate them.

This project aims to develop a methodology to estimate the decarbonization potential at a neighborhood level and the road map to achieve the decarbonization goals in the neighborhood of Benicalap.

To carry out the methodology, state-of-the-art is elaborated, based on the information obtained, an emissions inventory is worked on, and these emissions are quantified. The emissions inventory is carried out by analyzing sectors such as energy, transport, land use, and others. Subsequently, lines of action are proposed with their respective measures for neutralizing these emissions in the different sectors, developed and analyzed from a technical, economic, environmental, and social perspective (Roncero Tarazona, 2023; van den Dobbelsteen et al., 2018).

Once the lines of action are developed, an emissions balance is drawn up, evaluating the contribution that each of the focal points of action makes to the decarbonization of the neighborhood, assessing whether it is possible to achieve the objective of neighborhoods with zero emissions, or if not, including future guidelines to achieve it.

2.3.2.2 Introduction

Human-induced climate change has caused widespread adverse impacts and related losses and damages to nature and people.” That is the first conclusion of the sixth assessment report of the Intergovernmental Panel on Climate Change (IPCC): Impacts, Adaptation, and Vulnerability. Hence, experts report that the accelerated change we are witnessing becomes an impossible problem to avoid. We must focus on reducing their impacts and stopping the current trend. In this context, cities are crucial as they cause 70% of emissions worldwide. In addition, high population density in cities produces enormous social and economic impacts. Therefore, transforming cities and generating more sustainable urban ecosystems is both a challenge and an opportunity. It is necessary to develop strategies that reduce these impacts and consider the various factors involved in the sustainability of cities to achieve carbon-neutral cities (IPCC, 2023; United Nations, 2023).

A literature review is done to obtain a clear view of the work. On the one hand, a carbon footprint review highlights the methods and the general results for cities. On the other hand, a review of the leading carbon reduction strategies in cities and their connection with the different aspects of ecosystems in cities.

In the last few years, the European Union has been working hard on the GHG inventory, scope, data collection, footprint calculations, interpreting the results, and proposing and planning mitigation and reduction plans (IEA, 2021; Ministerio para la Transición Ecológica y el Reto Demográfico, 2023).

In terms of mitigation plans, much has been done in Scope 1 and Scope 2, which corresponds to direct emissions and indirect emissions through the generation of emissions, respectively. However, little has been said about mitigation actions for indirect emissions resulting from people's activities, scope

3. One of the reasons is that they are the most difficult to quantify in detail and are directly related to citizens' consumption habits (Fong et al., 2021; Ghaemi & Smith, 2020; Shan et al., 2018).

This project aims to develop a methodology to estimate the decarbonization potential at a neighborhood level and the road map to achieve the decarbonization goals in the neighborhood of Benicalap in Valencia City (Wieselblad, 2021).

This research study's specific main goals are:

- Develop a GHG emissions inventory considering the different activity sectors.
- Build a methodology to estimate and analyze the decarbonization potential in specific city zones.
- Search for and propose measures to reduce GHG emissions and quantify the impact of each step on the initial GHG inventory to analyze the final situation.
- Realize a carbon balance by years, considering the actions proposed.
- Analyze and detail future actions and directions to follow to improve and complete the carried-out study.
- Analyse and detail a methodology to determine the principal components of the scope three emissions inventory.
- Propose and analyze some mitigation plans for scope 3.

Several tools have been used to achieve a relevant, complete, consistent, transparent, and accurate methodology. Some of them are:

- QGIS: This tool has been used to estimate the building surface available to implement solar photovoltaic (PV) installations on the rooftops of the buildings.
- Datadis: This online platform has been used to obtain the daily and hourly electricity consumption values in the different neighborhoods.
- PVGIS: (Photovoltaic Geographical Information System) is an online tool developed by JRC (Joint Research Centre) of Ispra (Italia) from the European Commission, which has a database about solar resources.
- HOMER: (Hybrid Optimization Model for Multiple Energy Resources) is a software developed by National Renewable Energy Laboratory and improved and distributed by Homer Energy. It has been used to dimension and evaluates the neighborhood's photovoltaic potential as one measure to try to reduce emissions associated with electricity consumption.
- EXCEL: Organize, combine, and analyze information. Likewise, to make projections, graphs, and scenarios.

Based on the initial GHG inventory, four measures have been proposed for the decarbonization of the neighborhood: NBS, PV generation, sustainable transport, and efficiency in public lighting. Having developed all these measures, PV generation is the highest contributor to CO_2 emissions, followed by the measures proposed for transport. The electrification of vehicles reduces around 3% of the total initial emissions. The other two measures have a low impact on the total emissions, with a less than 1% reduction contribution.

As mentioned above, conducting a more in-depth investigation into the measurement and mitigation plans for Scope 3, corresponding mainly to the consumption of goods and services, is essential.

2.3.2.3 Description of Case Study

Develop a methodology to estimate the decarbonization potential at the neighborhood level and the road map to achieve it in a specific neighborhood of the city of Valencia: Benicalap—one of the city's most important and dense neighborhoods.

The specific steps to achieve the objective of this case study are:

- Develop a GHG emissions inventory considering the different activity sectors in the neighborhoods.
- Build a methodology to estimate and analyze the decarbonization potential in specific city zones, the neighborhoods.
- Search for and propose measures to reduce GHG emissions and quantify the impact of each measure on the initial GHG inventory to analyze the final situation.
- Realize a carbon balance by years, considering the actions proposed.
- Analyze and detail future actions and directions to follow to improve and complete the carried-out study.

Benicalap is one of the 87 neighborhoods of Valencia; it is located in the north and is part of one of the 19 districts named in the same way (Ajuntament de l'Hospitalet, 2017).

It is among the top 6 most densely populated districts of the city. It is mainly residential, with relatively old buildings and good public transport connections. However, since it is in the outskirts, private vehicle transit through Benicalap is also highly relevant.

- Has 41.483 habitants; 1,72 km2 of area; and density of population of 24.132.
- The majority of the population is between 30 and 50 years of age and are professionals.
- There are 18.968 buildings, most built between 1961 and 1980.
- Energy consumption is 77.085,33 MWh, of which 59% corresponds to the residential sector, 29% for the service sector, and 2% for the industry.
- The initial GHG inventory determines the total annual emissions are 18.4379, of which 66% corresponds to the consumption of goods, followed by transportation (18%) and natural gas consumption (5%).

2.3.2.4 Case Study Solution

Figure 5 details the methodology and process used for this project. The first step is defining the project and the planned objectives to achieve during the study. To determine the main project scope and objectives, it is important to plan some questions to bear in mind to define it, such as *"What do carbon neutrality plans in your city focus on? What does carbon neutrality mean for your city? What real benefits do you see for your city in implementing these plans? What are the main stakeholder groups the city needs to engage to implement those plans?".*

Having defined the project and the lines to follow, a detailed review of the state-of-the-art in different topics related to carbon neutrality was carried out. The documents included and reviewed in this step were of various types, research articles, check articles, government documents related to studies, statistics from the Valencia City Council or the Valencian Community, and reports from the European Community or other institutions (Ministerio para la Transición Ecológica y el Reto Demográfico, 2023).

Based on that, a good concept of carbon neutrality application in the cities was constructed. The main topics searched include carbon neutrality, sustainable cities, energy efficiency in buildings, natural-based solutions, circular economy, involving stakeholders in programs, PV generation on rooftops, etc.

With the information obtained from the elaboration of the state-of-the-art and the concepts clear, the next step is to analyze the initial situation of the place where the project will be applied. In the case of this specific study, a set of initial information was gathered and evaluated:

- Main characteristics of the neighborhood: total surface, use of the land, population, and characteristics of the population (age, gender, job, etc.), transport system, green areas, and other data that, with the progress of the study, has been considered important and useful.
- In some cases, a visit to the neighborhood was executed to understand the characteristics and evaluate the data collected from the different sources.
- Energy consumption is divided into residential, industrial, and services sectors.
- GHG inventory by sectors. Obtain data from the characteristics of the sectors in the neighborhood, the emissions per type of sector, and other aspects of developing this inventory.
- The transport system in the neighborhood.

Considering the initial situation of the neighborhood and using the concepts extracted from the development of the state-of-the-art related to the possible measures to reduce CO_2 emissions, a list of measures has been proposed to make a multilevel analysis of the economic, technical, social, and environmental impact on the initial situation.

The summary of the list of measures is as follows:

- Renewable generation based on PV generation.
- Evolution of the transport fleet for private and public transport to sustainable transport.
- Implementation of natural-based solutions.
- Energy efficiency measures in public lighting.

Considering the proposed measures is necessary to analyze the impact and contribution to the CO_2 reduction of the initial situation that each measure can produce. In that way, it will be possible to concrete which measure has a more significant impact as it is more important to develop, not only considering the CO_2 reduction, the economic impact, the social affection, etc. And with all these data priories the different measures in a temporal line.

With the previous results obtained from the simulation of the proposed measures, the sensitivity analysis for this study has been carried out. In this case, the variables or aspects considered changeable in this analysis and that have been included as important to evaluate the impact of this change in the project has been:

- Energy price.
- Increase in consumption.
- Increase of electric vehicles.

One of the main reasons for this study is to evaluate the impact of different measures proposed in the literature to achieve carbon neutrality in cities. For this, a CO_2 balance has been carried out. Starting from the initial situation and considering a curve estimated for the CO_2 emissions during the following years and considering the CO_2 reduction based on the proposed measures, a CO_2 balance has been presented in this document for the following years until 2030 (Furió et al., 2019).

In this work, the GHG Inventory has been developed by dividing all the emissions emitted today into diverse groups to calculate this in detail. The groups which are included in this document are buildings (electricity and gas consumption), transport, consumption of goods, waste, and public lighting.

A. Buildings

To estimate the emissions coming from the operation of the different buildings, the information on the total consumption of electricity and gas for the city of Valencia has been used. After that, this data was extrapolated according to the habitants of Benicalap.

B. Transport

To calculate the emissions generated by the different means of transport, transport has been divided into two groups: private transport and public transport.

To determine the current situation of private transport in Valencia and, more specifically, in Benicalap, the personal vehicles will be small trucks, passenger cars, two-wheelers, and bicycles.

First, the number of each type of private transport in Valencia was obtained from Dirección General de Tráfico (DGT) to evaluate the emissions. These vehicles are calculated based on the European Regulation that groups the vehicles in various groups depending on the year of matriculation (DGT, 2023).

Based on that regulation, the data used to calculate the emissions has been:

- Total of each mean of transport vehicles grouped due to the regulation in each neighborhood.
- Total kilometers traveled for each vehicle depending on the type and year.
- Emissions per kilometer depending on the type and year of the vehicle.

Another emission that should be considered due to the use of private transport is the ones coming from the vehicles that are not considered private vehicles in the neighborhood but pass through it and emit GHG in the area.

These emissions have been calculated using the IMD (Intensidad Media Diaria de Vehículos) available for the main streets in Valencia, the kilometer of each one of these avenues, and the general emissions per kilometer considered for this calculation.

On the other hand, the public transport of the city of Valencia comprises four main means of transportation: seven metro lines, four tram lines, a wide range of bus lines that will be detailed, and Valenbisi service, which is the bicycle-sharing service.

In the case of Benicalap, there is a metro, bus, and tram system. The activity of the public transport bus is calculated considering the distance of each line that passes through the neighborhood, the number of trips performed per type of day, weekday, weekend, and holiday and the emissions related to each means of transport.

On the other hand, there is the bicycle sharing service; in the city of Valencia, there are a total of 2.750 bicycles, divided into 277 stations in all the city and 5.502 locking points. Based on the map of all the stations in the city, the bicycles in Benicalap are 66.

C. Consumption of goods

The consumption of goods in society nowadays is very remarkable because it could be qualified as consumerist, and the purchase and use of a higher number of necessary goods, supposes an increment in the CO_2 emissions related to these processes that could be reduced by implementing good practices in the consumption of goods. The goods considered in this inventory are food, clothes, and other manufactured products like furniture and technology devices.

The previous inventory of food consumption is based on the “Informe del Consumo de Alimentación en España 2020” where a total of 27 food categories were estimated for Spanish society consumption. To calculate the emissions produced by this consumption is necessary to consider the CO_2 emission factors for each previous item included (Ministerio de Agricultura, 2020).

Combining the previous values, the CO_2 emissions per capita have been calculated and detailed.

How it was mentioned before, this is one of the points related to scope 3, and it is one of the most important in terms of consumption and emission relevance. Also, it is one of the points that are more difficult to calculate and generally is a gap in this kind of project.

This is one of the main motivations to deepen this project and type of research and thus to create a methodology that facilitates and reduces the uncertainty of this scope and, in turn, allows to evaluate of different mitigation options and plans in the changes in consumption of the inhabitants.

D. Waste

Other emissions that have been considered in this inventory are related to the generation and management of waste. First, the total waste generation in the neighborhood per waste type (Municipal solid waste, organic, glass, paper, plastic, vegetable oil, and batteries) and then scaled to the neighborhood using the downscaling factors.

After that, it is necessary to divide the waste type into management categories. In this case, the categories considered has haven landfilling, recycling, energy generation,n, and composting.

It is important to consider the emissions that are included in each of the waste management categories:

- Recycling: includes transport to a recycling facility and sorting of recycled materials at a material recovery facility.
- Landfilling: includes transport to landfill, the equipment used at the landfill, and fugitive landfill CH_4 emissions. Landfill CH_4 is based on typical landfill gas collection practices and average landfill moisture conditions.
- Composition: include transport to a composting facility, the equipment uses at the composting facility, and CH_4 and N_2O emissions during composting.

E. Public lighting

The public lighting installed in streets, gardens, parks, monuments, and other public elements are responsible for a part of the CO_2 emissions from the neighborhood.

Based on the statistic of the Valencia City Hall, the total consumption of electricity from public lighting is known. To adapt these values of the district to the selected neighborhood, the downscaling factors for Benicalap have been considered; in this case, the factors used and being more adequate due to the type of distribution of public lighting have been the area.

Having developed the GHG inventory of the current emissions, the next step of this project is to propose different measures to reduce carbon emissions and approach carbon neutrality. Some of the proposes are:

F. Natural Based Solutions

First, it is necessary to expose what Natural Based Solutions (NBS) are. There are means of bringing nature back into cities, following the example of natural ecosystems and achieving environmental, social, and economic benefits to improve urban sustainability.

Another aspect to consider in the analysis of natural solutions is the type of urban areas in which the project is proposed. Different zones are grouped into classes depending on a variety of characteristics such as land use, the type of buildings, etc. The urban zones are classified as urban zones with high density, urban zones with low density, urban zones of community equipment, and new development urban zones. Considering the characteristics of Benicalap, it can be regarded as an urban zone with high density that has a high surface occupied by buildings and a low surface with vegetal zones, been in the majority alone trees or small garden. The recommendation in a wide range of studies is to increase the vegetation in buildings, focusing on court blocks, terraces, roofs, and facades. In the case of Benicalap, an area in the north of the neighborhood can be included in the group of urban zones with low density because the size of green zones is larger than in the rest. And the plan in this area is to increase the density of the current green zones with autochthonous species, apart from creating new green zones in accessible spaces.

To propose a solution based on natural solutions, it is necessary to determine the base and current situation of this solution in the neighborhoods. Using the Geoportal of the city of Valencia, there is one section with information about the green zones in the city of Valencia, including the name of the green zone, the neighborhood to which it belongs, and the surface in square meters. Working with this data, it is possible to calculate the total green zone area of the neighborhood.

In the case of Benicalap, there are 39 green zones in all the areas, including parks, gardens, green zones on sidewalks, etc. The total area that covers these zones is 135.228 m^2, representing 7,87 % of the entire surface of the neighborhood.

G. PV generation

PV systems on the neighborhoods' roofs have been proposed as one measure to decarbonize the city's electricity consumption.

The energy generated by the potential PV installations has been calculated using the software Homer.

Plenty of simulations, have been developed, considering different percentages of the functional area and different inclinations. After this first filter, the final selection has been based on the higher production of photovoltaic energy and comparing the payback between the options.

H. Sustainable transport

One of the main sectors responsible for GHG emissions in the neighborhoods is the transport sector, and more precisely, the private and commercial transport, including the measures in public transport.

Therefore, the basis on that and the necessity to reduce these emissions, a series of measures will be proposed based on the “Plan de Movilidad Urbana Sostenible” of Valencia (Ajuntament de València, 2013). One of these objectives that will be presented and developed are:

- Apply measures with the objective of the decarbonization of the transport system.
- Enhance the pedestrian's movements when the distance allows it.
- Increase the cycle paths and the number of public bicycles available to promote cycle movements.
- Promote public transport instead of private transport, with the analysis of the current system and the potential of zones with the worst connections.
- Promote the increase of electric vehicles both in public and private transport.
- Increase the use of electric cars.
- Increase the participation of hybrids and electrical buses.

I. Public lighting

Another planned measure is related to public lighting, a straightforward measure that the Ayuntamiento de Valencia can develop to reduce emissions.

The current situation of public lighting in different spaces, such as parks, streets, etc., is based on a wide range of lighting, mainly: high-pressure sodium led, LED lights, metal halogen lights, and others less frequent.

One of the measures that the city of Valencia is planning is substituting the luminaries for others more efficiently to reduce the consumption of public lighting and, consequently, CO_2 emissions. Also, flux reductors and astronomic clocks will help reduce electricity consumption.

Subsequently, a detailed technical analysis is performed. A social and economic analysis follows this to determine a roadmap of the actions and the estimated reduction percentages.

2.3.2.5 Results and Discussion

With all the information mentioned above and following the methodology explained. The following preliminary results are obtained regarding the emissions inventory (Figure *6*).

In the project's first phase, approximate emissions for the neighborhood of 184,380 tons of CO2/year were determined. Of these, 77% of the emissions correspond to Scope 3, 66.39% being due to the consumption of goods, especially food and cloth. This is followed by private transportation emissions, which account for 18% of total emissions with 33.128 Tons of CO2/year.

This was followed by electricity consumption in the residential, services, and industrial sectors, totaling 13,259 tons of CO2 equivalent and corresponding to 7.2% of total emissions. Next is the consumption of natural gas, especially for the residential sector, with a 4.87% share.

GHG Inventory (OPEX):

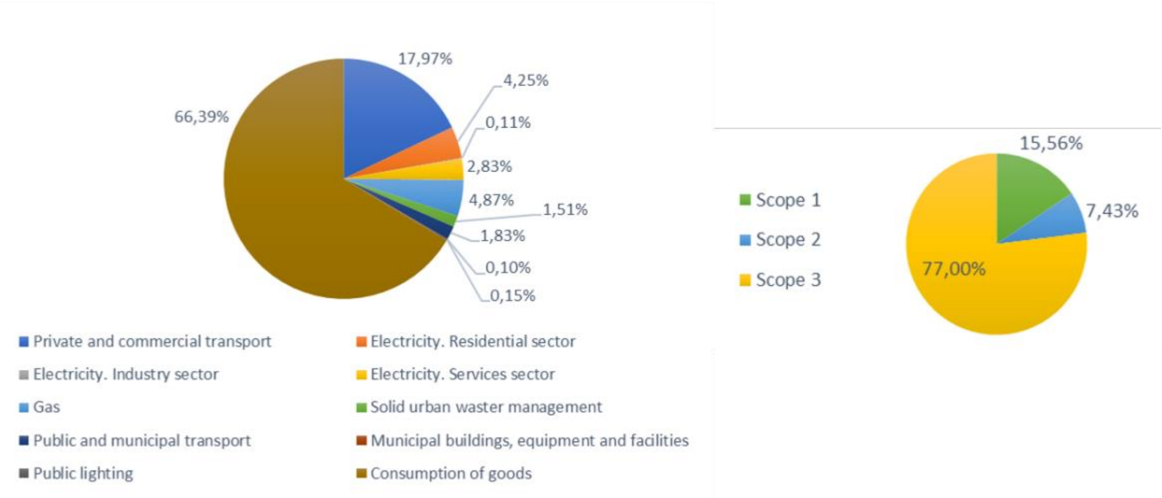

Figure 6. GHG Inventory Benicalap Valencia

The project's initial phase aims to analyze scopes 1 and 2 in more detail, so these results will be further explored. After a detailed technical analysis and considering each proposed initiative's social, environmental, and economic considerations, a proposed scenario and a road map for its implementation are given.

RESULTS FOR BENICALAP

Initial CO_2 SCOPES 1 & 2 — 42399 tCO_2/year

Percentage of CO_2 savings			
YEAR	**2020**	**2025**	**2030**
NBS	0,051%	0,082%	0,152%
PV GENERATION	0,0%	14,53%	24,87%
PUBLIC LIGHTING	0,0%	0,15%	0,28%
SUSTAINABLE TRANSPORT	0,0%	12,7%	25,39%
TOTAL	0,051 %	27,46 %	**50,69 %**

Final CO_2 SCOPES 1 & 2 — 22515 tCO_2/year

Figure 7. Comparison with the initial and proposed situation

An estimate is made of the achievable achievements in reducing emissions of these Scopes due to each of the mitigation proposals, where self-generation and a more sustainable transportation model are the most relevant measures, achieving a 50% reduction of emissions by 2030 and starting from 42.399 TonCO2 year and reaching 22.515 TonCO2 year. In the mitigation proposals, and as mentioned above, the change of public lighting and the creation of green spaces are also considered.

Figure *8* shows the proposed road map for each mitigation measure in more detail.

1. Natural-Based Solutions

   Nowadays, green area spaces represent de 7,87% of the area of the Neighborhood. The recommendation in a wide range of studies, such as (Gutiérrez et al., 2016), in these zones is to increase the vegetation in buildings, focusing on court blocks, terraces, roofs, and facades. The plan is to increase the density of the existing areas and create new green zones in free spaces, with a proposed execution of 40% of the scope by 2025 and 100% by 2030.

2. Public lighting

   The current situation of public lighting in different spaces, such as parks, streets, etc., is based on a wide range of lighting, mainly: high-pressure sodium led, LED lights, metal halogen lights, and others less frequent. The recommendation is to make the changeover so that all public lighting is LED technology.

3. Sustainable transport

   A series of measures are proposed for the transport sector based on the "Plan de Movilidad Urbana Sostenible" (Ajuntament de València, 2013). The diagram shows in more detail the implementation percentage for each measure from 2022 to 2030:

   - Implement measures with the objective of decarbonization of the transport system.
   - Promote pedestrian travel when distance permits.
   - Increase bike lanes and the number of public bicycles available to encourage bicycle commuting.
   - Promote public transport instead of private transport by analyzing the current system and the potential of the worst connected areas.
   - Promote the increase of electric vehicles in both public and private transport.

4. Photovoltaic

   This proposal consists of installing self-consumption photovoltaic systems on the roofs of buildings. Using Homer, PVGIS, and Google Earth software. It is determined to install 50% of the power calculated for the year 2025 and reach 100% of this, with a total value of 49,000 kW in 2030.

Throughout the project period, it is proposed to carry out awareness campaigns to involve and provide greater knowledge to the community about the responsible use of energy, recycling, the importance of proximity consumption and other elements that seek a change in the habits of people in favor of sustainability.

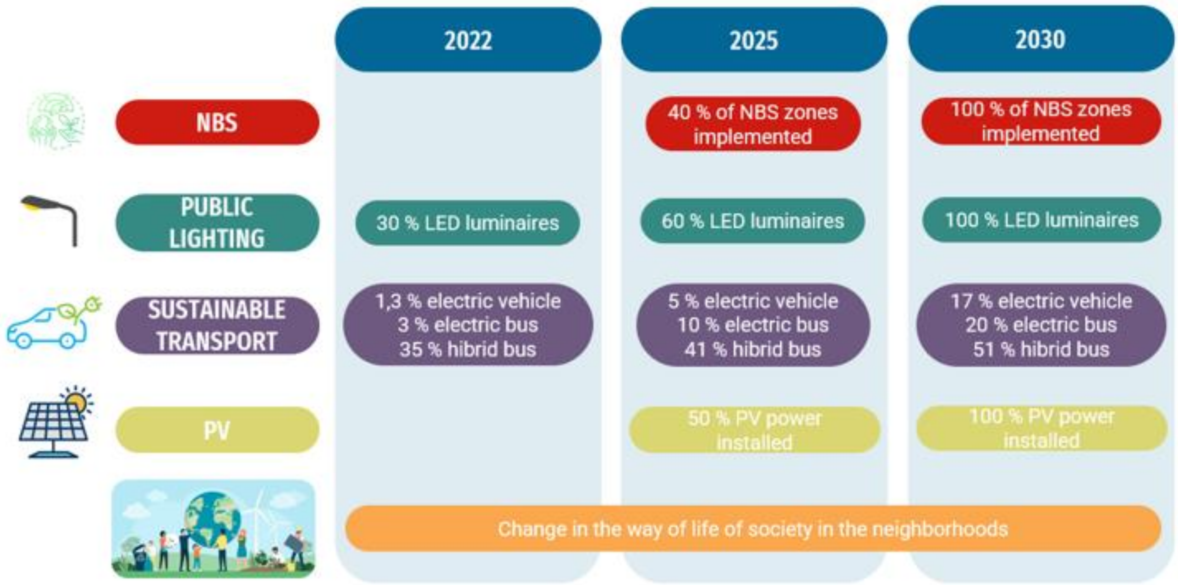

Figure 8. Roadmap of the proposals

If it is wanted to comply with the agreed-upon environmental commitments, working on this type of project is essential. A clear methodology to determine emissions and abatement potentials will allow us to focus mitigation efforts on the sectors that generate the most significant impact.

Likewise, this type of project can be scalable and replicable, which encourages us to continue working on them and begin to generate a cascading effect.

Finally, it is essential to understand that this type of new proposed project, in this case, the development of a carbon-neutral neighborhood, is not only a work that concerns the technical part to achieve it but different non-technical factors should be analyzed. It is a new concept that implies a change in a huge aspect of life that today is planned in a direction that all these new projects will modify.

The main non-technical factors that will be evaluated and modified to adapt to the new conditions are policy, legal, social, and economic factors.

2.3.2.6 Conclusion and Recommendations

The world and mainly the cities, should change the urban areas to mitigate the effects and adapt to climate change challenges. Sustainable plans, new policies, actions, and projects or initiatives like the one presented in this document can play a fundamental role in helping cities and governments hit different points and solve these problems, considering the results obtained in these studies (European Commission, 2023; Gronkiewicz-Waltz et al., 2020).

In this project, one methodology to estimate the decarbonization potential was developed to create a roadmap to achieve the planned situation and approach to carbon neutrality.

The GHG emissions inventory was developed for both neighborhoods, and it is remarkable to say that the majority of data available is not specific to communities and is accessible at the city level or even at the country level. This lack of data supposes an error in the calculation that, probably in the future, with more precise information, can reduce and have more realistic results.

Apart from the previous indications, the values obtained in this inventory show that the consumption of goods is the highest responsible for emissions. The third scope in some studies is not considered is the more emitted part of the mix. For this, it is important to consider this scope in the analysis. Following this sector, private transport is the second sector with more considerable emissions, and electricity consumption is the third one, with a vast difference from the rest of the sectors, with a minority representation.

Based on the initial GHG inventory, four measures have been proposed for decarbonizing the neighborhoods: NBS, PV generation, sustainable transport, and efficiency in public lighting. Having developed all these measures, PV generation is the highest contributor to CO2 emissions, followed by the measures proposed for transport.

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2.4 University of Grenoble Alpes – Advance controls of storage and use of waste heat from a nearby industry

2.4.1 Executive Summary

This case study presents the heating network in Grenoble, including its stakeholders and the different power plants involved (). The results show that among the three scenarios presented, the most realistic is the scenario with 25% wood pellets and 75% wood consumption. In fact, the construction of a new power plant is not useful since this plant would only operate half of the time foreseen.

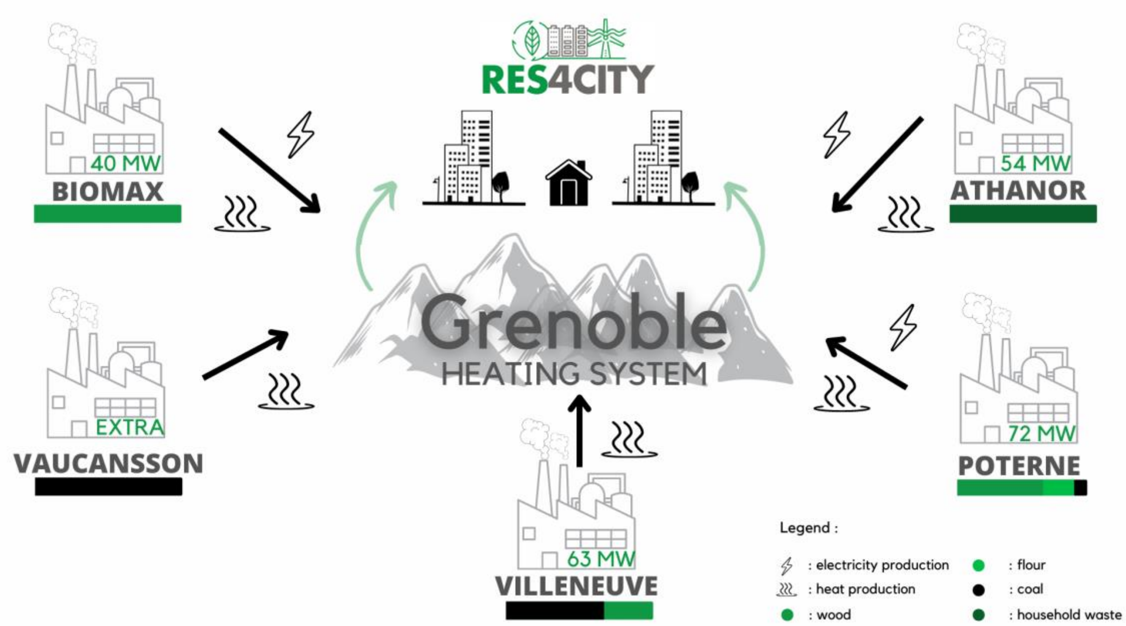


Figure 9. Advance controls of storage and use of waste heat from a nearby industry – Graphical Abstract

2.4.2 Case Study

2.4.2.1 Abstract

Because of its concern for eco-development and alpine environment, Grenoble has made energy transition and the development of renewable energies its priority and was named European Green Capital in 2022. The limited available space made dense public transport and heat networks more profitable and then earlier and more developed than elsewhere which provides us with many application cases of interest for the Renewable Energies System for Cities (RES4CITY). The Metropolitan heat network of Grenoble provides heat, some others allow to provide also cold, to one or more consumers. In the case of Grenoble, all types of consumers are connected: hospitals, industries, services, public building, private dwellings, which covers most of the cases of use and interactions that can be thought about, this connection is called district heating. The energy feeding the network has been shifting progressively away from the original fossil fuels. Waste incineration heat retrieval was first set up, then biomass was added, and now industrial heat recovery technologies are increasing the volume of renewable calories used. The goal of the lighthouse case study is to transfer to students the inspiration, action, and solutions, by showcasing how renewable and innovative technologies are integrated in the Grenoble metropolitan area. The proposed lighthouse case will provide a better understanding of such a system from three different points of view.

i) First, the technological aspect is presented in terms of design of the grid (sources, tubes and potential storages), operating and maintenance principles as well as the operation of the grid, its sources and eventual storages for short-term and long-term periods.

ii) Second, from the economic standpoint, the aim is to understand the optimal control of the available resources. On the one hand, the short-term economic benefits (related to operation) of resources and grid optimization were analyzed. On the other hand, over the long term, given the level of uncertainty over the decisions of many actors, such as connection of new customers or new sources, how the optimal planning of the energy resources potentially available in the local system can be carried out was explored. In this sense, we propose various technical-economic modeling scenarios for the complete decarbonization of the network.

iii) Third, heat networks connect many different categories of stakeholders: designers, builders, operators, customers, users that are all needed but have different levels of understanding of the system and potentially opposite interests. The lighthouse case will improve their understanding of the system, its interest for a better environment, and their role in its development and governance.

2.4.2.2 Introduction

Just a while ago, on 30th March 2023, the European Union has sent a very strong signal for its energy policy, planning to double the share of renewable energies by 2030s in the energy mix of the 27 countries (EC,2023). Among other strategies, this acceleration from the current level (around 22%, Eurostat (2023) to 42.5 % of renewables in consumption will necessarily have to go through the massive deployment of additional renewable heat sources, as a tool for the energy transition. In Europe, there is a diversity of heating sources for reasons related to the historical context, to the choices of energy policy or to the climatic conditions conditioning the amount of heat consumed. When the conditions are favorable, the heating systems[1] can have important benefits by using local renewable energies and by contributing to the energy transition of territories in the long term.

- Problem to be addressed and its relevance.

District heating networks are now in operation in most of the major cities in France. In France, consumption for heat production (all modes combined) represent 741 TWh and the energy mix is mainly fossil, with 61% of the heat produced from natural gas, oil and coal. Only 21% of this heat comes renewable and recovered energies. District heating networks make it possible to provide 3.5% of national heat consumption. They have the advantage of providing energy mainly produced from renewable and recovered energies.

The city of Grenoble has made significant progress in sustainable development, especially in the energy sector. With a focus on research and development, the city has become a hub for innovation, particularly in the fields of energy, nanoelectronics, and biotechnology. In recent years, Grenoble has prioritized sustainable development, with a focus on reducing pollution and greenhouse gas emissions.

One major success story in this regard is the city's heating network, which spans 177 km and is 80% powered by renewable energy sources (Grenoble’s Urban Heating, 2022). This makes it the second-

[1] A heating network is a collective technical solution to deliver heat to users from a given territory from a centralized production point.

largest heat network in France, and the city has been working for years to further decarbonize and improve the network. Grenoble has set a goal of reducing its emissions by 80% over the next 30 years, and the success of its heating network has made it a model for other cities to follow. Overall, Grenoble's focus on sustainable development and its success in implementing renewable energy sources in its heating network make it an excellent model for other cities looking to reduce their carbon footprint and prioritize sustainability.

- Challenges and expected benefits from the work

As part of the RES4CITY project, this lighthouse case study aims to gain a comprehensive understanding of the intricate heating network in Grenoble, including its stakeholders and the different power plants involved. Given that data collection is a crucial part of this work, one of the main challenges is the unavailability of easily accessible data, particularly regarding the heating network technologies and its stakeholders. The aim of this study is to contribute to the development of the RES4CITY project and support the city of Grenoble in its ongoing efforts towards sustainable development. By providing detailed and convincing calculations related to the decarbonization of the heating network, this project aims to help policymakers and stakeholders make informed decisions that would benefit the environment and the local community. Furthermore, our work is intended to be widely disseminated, making it accessible to anyone who is interested in the topic of sustainable energy and heat networks. Additionally, sharing our findings and recommendations can be helpful for other cities and communities looking to implement similar measures, especially in the context of the global transition towards a low-carbon economy. Ultimately,

- Literature review and gaps

There is a wide literature on urban heating networks, including academic research, textbooks, and different annual reports from related entities. There are currently 5 plants producing heat in Grenoble, 3 of them operating in cogeneration, but one has not been operating since 2012 (CCIAG, 2023). The impact of the construction of a new plant, BIOMAX, in Grenoble in different technical reports. Bureau Veritas Exploitation, Ingevalor and (2017) detail the environment of the selected site in Grenoble and explain all the analysis of the impact that this plant could have on its environment. It also details the way the parcel could have evolved without this project. All the dangers linked to the creation of this plant have also been studied and the exploitants have applied for the authorization to operate. This more technical document explains the operation of the plant, following every step of the process. It also details the way this plant will become a part of the heat network, comparing the actual situation with the potential future situation with the plant. Rossi & Petit (2021) provide the elements to consider when it comes to CO2 computations of a heat network: the life-cycle analysis, the direct emissions and the emissions avoided thanks to the cogeneration. A study has been done to add more industrial heat recovery in the network, with the National Laboratory for Intense Magnetic Fields (LNCMI) (Hodencq, 2019). This laboratory works on magnets, and product heat as a byproduct. Currently, they are using the Drac's river cold water to cool their process, so a connection to the heat network could be profitable to prevent the waste. But this heat source would be intermittent because it depends on the experiment schedule. An example of the expansion of the heat network to link all 100 university's buildings has been studied, to reduce the CO2 emissions of the university, and to be less dependent on fossil fuels (L'université Grenoble Alpes (Uga) et al., 2021). The technologies of thermal energy storage for heat networks are presented by Martinelli (2018). A dynamicl modeling and management of heat networks is proposed by Giraud (2016). Finally, a connection of waste heat sources located near or in dense urban areas to heat networks is studied by Chiche (2020).

- Objective of the work

Our work aims to present an extended overview of the technologies, the stakeholders and the economic optimization of the heating network as stated in Figure 10.

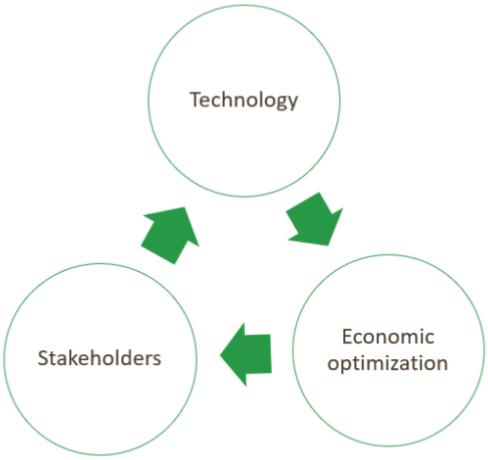


Figure 10. Main objectives Source: Own elaboration

This case study aims to answer the issue of what needs to be done to reach 100% of renewable and recovered energies in the heating network by 2033, by offering different possible options. Our methodological approach will be based on scenarios (incorporation of short-term uncertainties related to the operation issues and long-term uncertainties associated with changes in market prices or financing costs influencing investments). This question raises the issue of the primary energy sources used to produce heat, and the variable availability of some of these sources, such as the wood or the city's waste.

2.4.2.3 Description of Case Study

The heating network in Grenoble is the second biggest heating network in France, and the heat delivered corresponds to 100 000 housing equivalents. It provides heat to the city's Hospital, its different museums, the university, the town hall, various sport centers and many private housings (Grenoble's Urban Heating, 2022). This heat network is owned by the Metropolis of Grenoble, and it is exploited by the CCIAG under a contract of public services delegation as stated in Figure 11.

The network consists of 178 km of pipes spread under the public road in 7 cities of the Agglomeration (Grenoble, Echirolles, Eybens, Gières, La Tronche, Le Pont-de-Claix and Saint-Martin-d'Hères). The heat is provided by 5 plants (Athanor, Biomax, Poterne, Villeneuve and Vaucanson, which doesn't produce anymore) and 1 unit of heat recovery. There is 1200 m^3 of thermal storage located in the sites of 2 production units. These storages help to have better flexibility and to smooth the production during peak hours. All the power plants operate with the principle of incineration: the water of the network is heated thanks to the incineration of fuels. Amongst the five thermal units, three of them work in cogeneration, meaning they produce both electricity and heat.

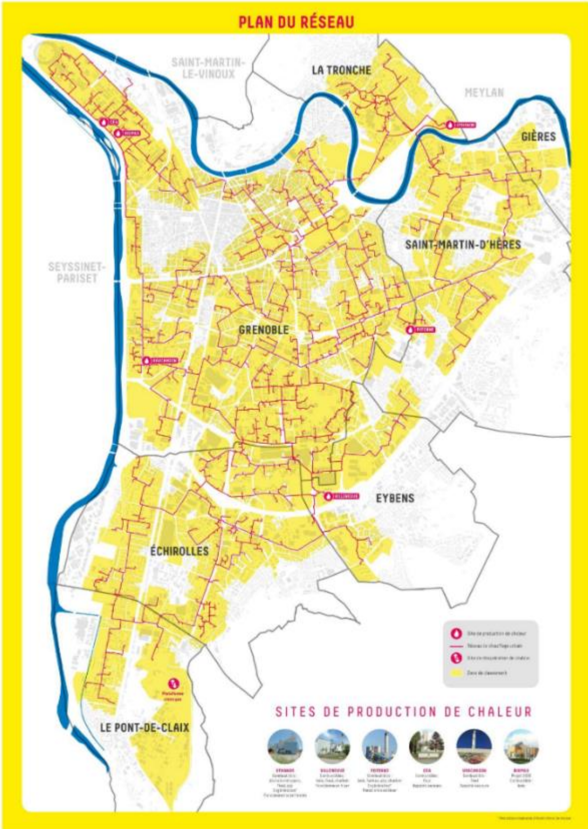


Figure 11. Map of the Network - Source: (Grenoble's Urban Heating, 2022)

As shown in Figure 12, the main fuels used are wood (35.2%), household waste (43.8%), coal (5.4%), fuel oil (0.2%), bone meal (1.0%) and natural gas (14.3%) for the year 2022 (Grenoble's Urban Heating, 2022). Due to the contract between Grenoble's metropolis and the CCIAG, the wood sources must come from a radius of maximum 50 km, and at least 11% must come from sustainable sources. The "waste" wood comes from the department and a neighboring department, as the town alone does not provide enough. The repartition of each source in the plants is presented in Table 5.

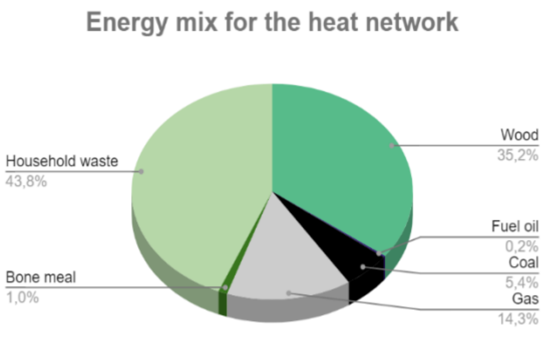


Figure 12. Energy mix of the network - Source: (Grenoble's Urban Heating, 2022)

Table 5. Raw Materials for each plant - Source: (Grenoble's Urban Heating, 2022)

Heat production sites	Raw materials
Poterne (Cogeneration)	Wood (forestry chips)
	Wood (end-of-life packaging)
	Bone meal
	Natural gas
	Coal
Villeneuve	Wood (forestry chips)
	Wood (end-of-life packaging)
	Fuel oil
	Coal
Athanor (Cogeneration)	Fuel oil
	Natural gas
	Household garbage
Biomax (Cogeneration)	Wood (forestry chips)
	Wood (end-of-life packaging)
	Natural gas
Vaucanson	Heating oil
Solvay (Pont-de-claix)	plant activity (8MW) (hydrogen)
	plant activity (24MW) (hydrogen)

The heat recovery unit is located in the Chemical Platform of Le Pont-de-Claix, the project is Solcia, by Solvay and consists of heat exchanges in a year (Solvay, 2023). During summer, the power plant Athanor produces too much heat from city waste, so Solvay consumes heat from the network for its industrial activities, which allows them to consume less natural gas. During winter, Solvay produces its own heat for the industrial activities, and sells the waste heat to the network, which helps the CCIAG to have a greater flexibility during peak hours. Overall, 3.3% of the heat produced in 2022 came from industrial heat (Grenoble's Urban Heating, 2022).

The network uses 80.1% of renewable and recovered sources. The project of the CCIAG is to reach 100% by 2033, see Figure 13 below. The BIOMAX plant is relatively new (2021) and only renewable sources, while some are older but have refurbishment projects, like Poterne, that plans to stop using coal by 2026, to replace it with renewable sources.

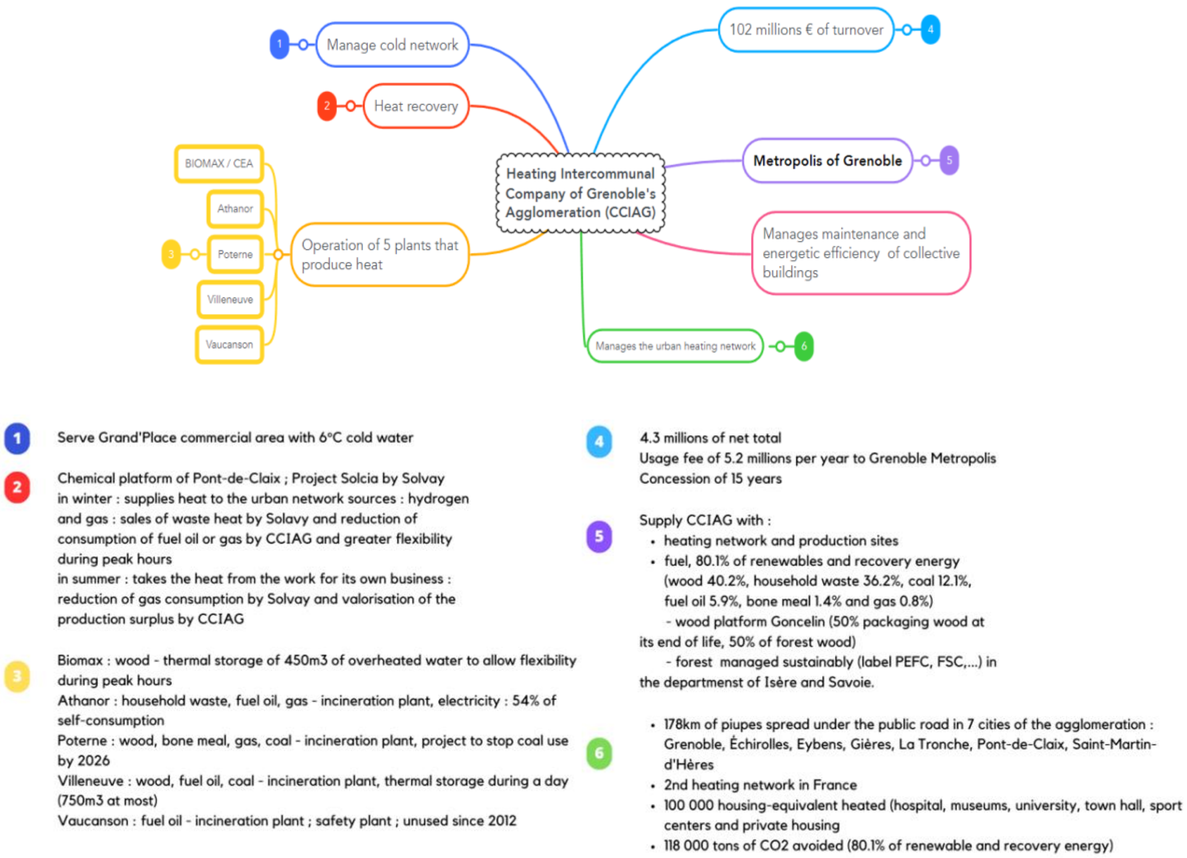


Figure 13. MindMap of Grenoble's heat network

2.4.2.4 Case Study Solution

- Definition of the strategy with illustrations

The Grenoble Urban Heating Utility has an existing portfolio of five assets with associated sources of production and is considering its extension to other types of sources to address the fluctuating demand and the environmental constraints. This work aims to address these different aspects. Analytical software is used to assess various scenarios for decarbonizing the network and evaluate their technical, economic, and environmental feasibility. First, we assess the technologies of the heating network in Grenoble. Then, an economic model is developed. We searched in the literature for information regarding the installed power, and then we made hypotheses on the operating time in the year, to compute the energy produced. The cost to produce this energy is also computed. Then, we model the CO_2 content of the network, depending on how much of each primary source is consumed, and whether this production is made in cogeneration. The CO_2 must be computed considering the life cycle and the direct consumption.

The main goal of this case-study is to reach 100% of renewable energies to produce heat for Grenoble's network. Different alternatives can be used to attain this goal. Three different options are studied: the first scenario is to build another plant similar to Biomax, the second scenario is to refurbish all existing plants to use renewable sources rather than the current fossil fuels, and the third scenario is to use new biomass sources, such as walnut shells, as the region is well-known for its production of walnuts. Regarding the active period of the plants, the assumptions made are that all plants are active 50% of the time except the one that burns household waste that is active all year. All

following studies are made compared to the actual situation, meaning a new plant will have new paid workers, while a refurbished plant will have no new workers and therefore no OPEX.
The first option is to build a new plant, very similar to Biomax, the latest plant constructed in Grenoble. When it comes to building a new plant, the decision belongs to the metropolis, and the concessionaire works on the necessary studies. Most of the time, this process is 'bottom up': the concessionaire presents the idea to the metropolis, and they decide on the investment. The origin of this idea can be linked to a need to develop the renewable energies rate according to the contract. For this scenario, it is considered that all engineering studies have already been carried out.
The second study considers the refurbishment of a plant in use to make it possible to use renewable sources in these fossil fuels plants. Poterne and Villeneuve are the two plants using the most fossil fuels, mainly coal and gas. Wood pellets are compatible with any coal-burning unit. They are a way to suppress the coal from the mix without huge modifications of the plants, which would be expensive and difficult, depending on the type of equipment used. In this scenario, all the coal will be replaced by wood pellets.
The last scenario focuses on the replacement of fuel oil by walnut shells. Walnut shells are compatible with any wood-burning plant. It is a resource mainly present in Grenoble's area, but the main issue is that the production is very limited. The sector of walnut shells is not developed, there are a lot of small producers, but it is not well-organized. For these reasons, it is not possible to consider a replacement of all fossil fuels by walnut shells. The Grenoble region produces enough walnut to supply the plants and replace fuel oil use.

- Identification of the models and methods implemented (mathematical, simulations, etc.)

The modelling framework is based on the literature regarding the installed power, and then include assumptions on the operating time in the year to compute the energy produced. To compare different scenarios, economic and environmental tools, such as the Net Present Value (NPV) of the project, the levelized cost of energy (LCOE) and of the CO_2 contents of the different networks are used. First, the CAPEX, or initial investment, of each scenario is computed or estimated. This economic indicator is interesting because collectivities tend to invest on less expensive solutions, even if the maintenance costs will be more expensive. Then, the OPEX, or maintenance and operation costs, is computed. It includes wages for the employees and maintenance costs. The benefits for each year are estimated, considering the savings from not paying for fossil fuels but renewable sources, but also the possible subsidies available for such projects. The benefits from the clients that consume the heat is not considered as each scenario produces the same quantity of heat, and therefore sells the same quantity. The objective here is to compare the scenarios. To know if the project is profitable, the Net Present Value (NPV) is calculated with the formula:

$$NPV = \sum_{t=0}^{T} \frac{Benefits_t - Costs_t}{(1+r)^t} \quad (6)$$

Where T is the number of years, r is the discount rate, and the $Benefits_t$ correspond to the above benefits and the $Costs_t$ to the CAPEX for the first year and the OPEX for the following years.
A project will be profitable (and therefore feasible) if the NPV is superior to 0. Then, the Levelized Cost of Energy (LCOE), is computed, to know how much it costs to produce a quantity of heat:

$$LCOE = \frac{\sum_{t=0}^{T} \frac{Cost_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{Energy\ Produced_t}{(1+r)^t}} \quad (7)$$

Where $Energy\ Produced_t$ is the energy produced each year.
Finally, the CO_2 content of a network is computed, depending on how much of each primary source is consumed, and whether this production is done through cogeneration. The CO_2 must be computed

considering the life cycle and the direct consumption (C_{lca}, C_{direct}), as well as emissions avoided thanks to cogeneration. The CO_2 content is the most complex parameter to compute. The methodology of Rossi & Petit (2021) is used. The total CO_2 emissions are given as follows:

$$C = C_{direct} + C_{lca} \quad (8)$$

The direct emissions are computed with:

$$C_{direct} = \frac{q_{CO_2,prod} - q_{CO_2,coge}}{L} \ (kg_{CO_2}/kWh) \ (9)$$

where L is the total energy produced over the year, $q_{CO_2,prod}$ is the quantity of CO_2 emitted by the facilities of production and $q_{CO_2,coge}$ is quantity of CO_2 saved using cogeneration, simultaneously producing electricity and heat. It is considered that the production of one kilowatt hour of cogenerated electricity saves 356 g of CO_2 compared to separate production of heat and electricity.
More precisely, $q_{CO_2,prod}$ is expressed as follow:

$$q_{CO_2,prod} = \sum_i^n E_i \times \alpha_i \times \frac{C_{HCV,i}}{C_{LCV,i}} \ (10)$$

where E_i is the amount of energy for the input i used for heating, α_i is the direct emissions coefficient that depends on each source, n the amount of sources and $\frac{C_{HCV,i}}{C_{LCV,i}}$ is the conversion ratio applicable to the entered quantity for the fuel i (HCV-high calorific value,LCV-low calorific value).
The quantity of CO_2 saved using cogeneration, simultaneously producing electricity and heat is given by the following equation:

$$q_{CO_2,coge} = \sum_i^n P_{e,coge,i} \times 0.365 \quad (11)$$

where $P_{e,coge,i}$ is the electrical power produced thanks to cogeneration. It is estimated that producing 1kWh of electricity through cogeneration avoids the emission of 356g.co2 compared to separated productions.
Then, the life-cycle CO_2 emissions are computed, with

$$C_{lca} = \frac{\sum_i^n E_{ch,i} \times DES_i}{L} + a \ (kg_{CO_2}/kWh) \ (12)$$

where DES_i is an environmental coefficient that considers the specific impact of each source, and a a fixed value, corresponding to the operation of the plant and the network.

- Identification of the field of implementation (building, industry process, etc.)

Our study is a demonstration of the importance of collaborative projects such as RES4CITY, which bring together various stakeholders, including students, researchers, and industry experts, to work towards a common goal of sustainable development. By combining knowledge, expertise, and resources, it is possible to make significant strides towards creating a more sustainable and equitable future for all. The companies listed below have show a great interest to the current study, Table 6.

Table 6.Main interested stakeholders

Company	Relevance	Needs & Interests
Grenenoble Alpes Metrople	Local Authorities	The lighthouse case will improve their understanding of the system, their interest for a better environmental, and their role in its development and governance.
CCIAG	Heating Company – main local player	
LNCMI Grenoble	National High Magnetic Field Laboratory – different ongoing projects for the electro-intensive installation and opportunities for waste heat recovery into the nearby district heating network	
Tenerrdis/AURA-EE	Local energy and environmental hubs already involved in similar projects such as RES-DHC, SDH-p2M	

The study would help them to better understand the economic behind storage and use of waste heat and the networking issues.

2.4.2.5 Results and Discussion

Table 7 presents the main parameters used in the computations. Some of these values were obtained through interviews, and others were taken from technical reports or in the literature.

Table 7. Main parameters

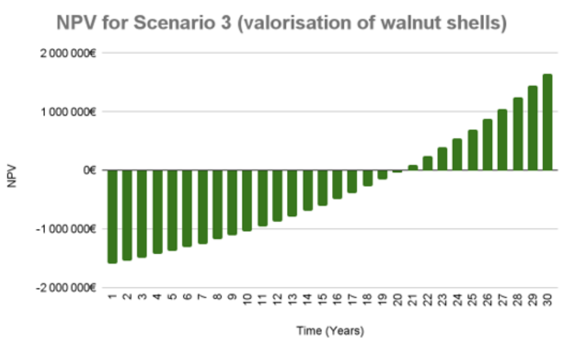
Average Annual Inflation from 2017 to 2023 (INSEE, 2023)	1.87%
Number of Annual employees on the Biomax site	20
Annual maintenance cost of Biomax Site	1 M€
Cost of a new wood boiler	20 M€
Cost of a new fuel oil boiler	2 M€
a (fixed value, corresponding to the operation of the plant and the network)	4/1000 $kgCO_2/kWh$
Overall efficiency of the Network	80%

For scenario 1, the 2017 CAPEX is discounted with the inflation and used for 2023 CAPEX, and the OPEX is computed with the wages of the annual workers for the plant, the maintenance cost and the wood supply. The operating costs are computed thanks to values found online for the fuel costs. For scenario 2, the CAPEX is to renovate the coal plant and there is no OPEX because the plants already operate and already have their workers and maintenance. There is a need for investment of 7 Millions euros in order to change the burners because wood doesn't need the same burners as coal. For scenario 3, the CAPEX is to renovate the coal plant and there is no OPEX because the plants already operate and already have their workers and maintenance. Two different discount rates are used, to model the faster deprecation of fossil fuels compared to wood. Indeed, the price of these energy sources will not vary in the same way. The cost of fossil fuels is more likely to rise rapidly, while the cost of wood will surely increase but slowly. The NPV and payback period are computed with (6) and the CO_2 emissions are computed with (7), (8) and (12) and resumed in Table 8.

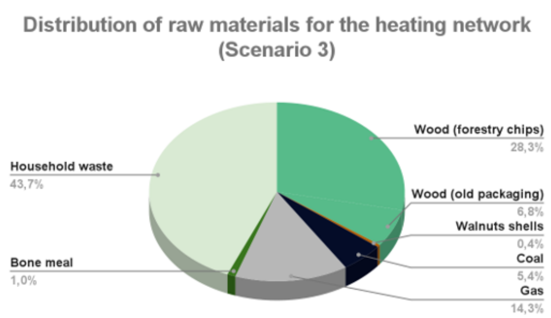
Table 8. Summary of each scenario

	Notation	Scenario 1	Scenario 2	Scenario 3	Current Situation
CAPEX	CAPEX	61 M€	7 M€	2 M€	/
OPEX	OPEX	1.96 M€	0€	0€	/
NPV (30 years)	NPV	395.5 M€	-112.5 M€	1.65 M€	/
Payback Period	Payback period	12 years	36 years	21 years	/
CO_2 direct emissions	C_{direct}	-179 gCO_2/kWh	-188 gCO_2/kWh	-133 gCO_2/kWh	-142 gCO_2/kWh
CO_2 Life-cycle emissions	C_{lca}	23.5 gCO_2/kWh	24.2 gCO_2/kWh	77.1 gCO_2/kWh	78.5 gCO_2/kWh
Total CO_2 emissions	C	-156 gCO_2/kWh	-163 gCO_2/kWh	-55.5 gCO_2/kWh	-63.1 gCO_2/kWh

For the first scenario, the payback period is 12 years, with a discount rate for fossil energies of 5% and of 1% for wood. The values for the discount rate on different sources of energies could have been evaluated a little bit higher but it is the discount rate normalized of the standard discount rate. The investment costs are 61 million of euros (2023) without considering the engineering process (already done for the first site). The cost of wood is increased by 20% to keep a supply coming from the area (around 120 km) and from eco-certified forests.



(a)



(b)

Figure 14. a) NPV and (b) Energy mix for Scenario 2

As the supply network of walnuts is mainly made of small producers, there is no organization for a re-use of walnut shells. Another option could be to buy full nuts, to separate the shells from the walnut kernel and to sell the kernels. This would be a way to ensure the supply of walnut shells, but a lot of work would be needed on the separation work.

- Discussion on Variable Values

More than 40% of the heat produced comes from household waste produced by the inhabitants of Grenoble's area (Grenoble's Urban Heating, 2022). This source is never constant as it directly depends on the inhabitants, but it doesn't vary too much. On the Sinoe website, it is possible to observe variations from 633 thousand tons to 657 thousand tons between 2009 and 2021, but there is no clear increase or decrease. The rate per inhabitant decreased, but there are more and more inhabitants, so the general values do not have too much variation.
The two first scenarios are mainly focused on the use of wood as the main source for this network. The study of the availability of wood in the Grenoble area is necessary to ensure the viability of these projects. will be enough wood to supply the network. The Auvergne-Rhône-Alpes region is one of the regions with the most forests (IGN, FCBA, 2019), and the wood stock in this region is the one that experienced the most significant increase between 1976-1994 and 2012-2017. The quantity of forests available is hence sufficient for the supply of the network.
The wood recovered from waste has to be class A or B. Class A wood has never been treated, while Class B wood has been slightly treated with paint or varnish in general. Class C wood is a dangerous waste wood because of their treatment that involves lead paint, preservation products or glue. These chemicals cannot be separated from the wood, so it must be burnt in very special units. Compared to forest wood, the waste wood has the advantage of being two times less expensive.
Another possibility would be to connect new industrial plants to the network. Some options are studied every 5 years approximately, but the irregularity of these heat sources is often an issue, as a consistent production is better for the network's efficiency. In these cases, an option would be to think of a possible thermal storage solution. Another frequent issue is the temperature needed to heat the water of the network, because in many cases, the temperature reached by the industries is too low to be used with a heat exchanger to heat the network. A portion of the network, that is close to many industrial or research sites, is in study to use low pressure, which would allow industries that produce lower temperature heat to connect to the network.
Regarding the CO_2 content of the network, it includes only the CO_2 emitted by the plants. The heat recovery unit located in Le Pont-de-Claix emits CO_2 by producing heat during the winter, but these CO_2 emissions are attributed only to the products of the industrial activity, as it is considered that this heat recovered would have been wasted if it were not used in the heat network. Another option would have been to attribute a certain proportion of the CO_2 emission to the heat network, but the CCIAG decided to not take the emissions of the heat recovery unit into the CO_2 content.

2.4.2.6 Conclusion and Recommendations

The lighthouse case study has presented the heating network in Grenoble, including its stakeholders and the different power plants involved. One originality of this work is regarding the data collection which can be considered as the main challenges to propose sufficient calculations related to the decarbonization of the heating network in Grenoble.
The model presented has been applied to three scenarios regarding the use of wood as one main source to the heating network in Grenoble. The results show that among the three scenarios presented, the most realistic would be the second, with 25% of wood pellets and 75% of wood consumption as discussed previously. Indeed, the construction of a new plant is not useful, as this plant would only operate half of the designed time, because of its important capacity. The walnut shell option is interesting for this area but as the industry of walnut shells is not developed, replacing fuel oil by walnut shells does not seem doable, and the low availability of this resource makes it impossible

to replace all fossil fuels. However, the use of this material must not be sidelined as its characteristics are interesting.

The objective of the heat network is not to spread further but to reach more people within the network that already exists, i.e. to densify the network. In the end, reaching more people will balance the reduction of consumption, and the heat network will continue to always produce the same amount of heat. Working on a partnership with local producers for bringing an import of walnut shells could be beneficial for Grenoble's heat system. With that, other partnerships could be worked on to bring import of other burning materials for power plants and develop a local economic and energy system.

2.4.2.7 References

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2.5 National University of Ireland Maynooth – Electric Vehicle Battery Analysis: Insights for Recycling and Second-Life Use

2.5.1 Executive Summary

The case study examines the growth potential of used electric vehicles in the UK market, addressing industry trends, the factors influencing second-life electric vehicle battery expansion, and opportunities and challenges in the reconditioned electric vehicle market. Results emphasize the importance of expanding charging infrastructures and establishing battery repurposing/recycling facilities to stimulate the second-hand electric vehicle market. Recommendations include collaboration with major manufacturers, strategic planning for popular car models, continued analysis of market trends, and the adoption of battery recycling and health assessment practices to capitalize on the expanding used electric vehicle market.

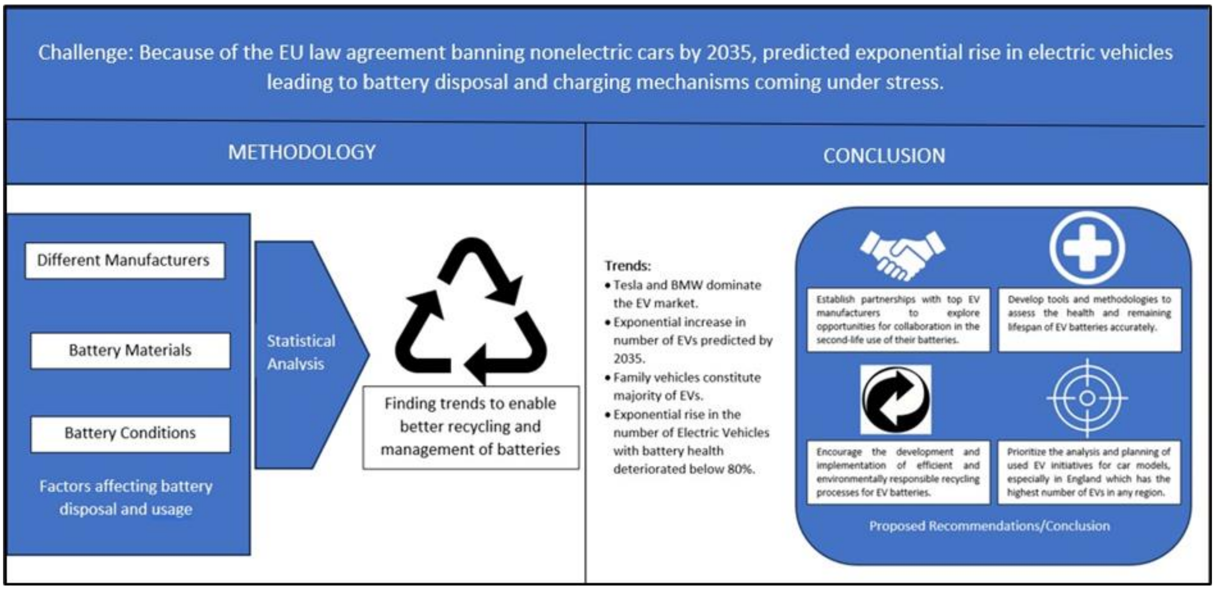

Figure 15. Electric vehicle battery analysis: Insights for recycling and second-life use - Graphical Abstract.

2.5.2 Case Study

2.5.2.1 Abstract

This executive summary provides an insightful overview of a comprehensive survey assessing the prevalence and potential growth of used electric vehicle (EV) batteries in the UK market. The investigation explores industry trends, factors influencing second-life EV battery expansion, and opportunities and challenges in the reconditioned EV market.

The analysis employed a robust system, examining EV market trends, battery advancements, and government policies, drawing data from reputable secondary sources and the UK vehicle registration database. To estimate the prevalence of used EV batteries in the UK, various forecasting methods, including regression analysis and pattern extrapolation, were utilized. However, it is crucial to acknowledge the inherent risks and assumptions involved in forecasting based on existing market patterns. Nonetheless, the application of these approaches enabled a comprehensive understanding of the potential appearance of used EV batteries in the UK market.

Findings project a promising 87% increase in the second-hand EV market from 2022 to 2025, driven by EV adoption, government incentives, and interest in sustainable transportation. The regulatory environment in the UK, characterized by cash incentives, tax reductions, and substantial investments in charging infrastructure, emerged as a crucial catalyst in supporting the growth of the used EV industry. Furthermore, technological advancements in battery innovation and recycling methods were identified as pivotal factors contributing to the viability and appeal of used EVs. These advancements are anticipated to lead to longer battery life spans and reduced environmental impact, rendering used EVs an attractive and eco-friendly alternative for users.

The study also highlighted the escalating demand for affordable EVs within the used car market, offering users a cost-effective option to embrace sustainable transportation. The growth of charging infrastructure and the establishment of battery repurposing and recycling facilities were identified as instrumental drivers behind the expansion of the second-life EV market. Furthermore, there are ongoing efforts to further enhance the charging network and promote eco-responsible practices throughout the entire EV lifecycle, reinforcing the sustainability of the used EV industry.

In conclusion, this study offers valuable insights into the emerging used EV battery market in the UK, addressing market size, battery diversity, utilization, and lucrative second-life EV prospects, guiding stakeholders towards a sustainable automotive landscape.

2.5.2.2 Introduction

The primary objective of this research paper was to forecast and estimate the influx of used electric vehicle (EV) batteries into the rapidly growing UK market. The study delved into current industry trends and the various factors influencing the growth of second-life EV batteries, with a particular focus on providing valuable insights into the expected trends and opportunities within the country's expanding market for used EVs.

In this context, Battery Cycle emerges as a leading company that specializes in the management, repurposing, and recycling of EV batteries. As the demand for EVs continues to surge in the UK market, the need for efficient and sustainable battery solutions becomes increasingly critical. Battery Cycle plays a vital role in addressing this need, offering innovative and responsible battery lifecycle management services. The significance of EV batteries within the context of the UK's transportation sector cannot be overstated. As the country makes strides toward reducing greenhouse gas emissions and advancing the transition to a low-carbon economy, the proper handling and utilization of EV batteries become paramount. Battery Cycle's approach aligns seamlessly with the UK government's commitment to sustainability, as their services contribute to the circular economy, promoting responsible resource utilization. Through their battery repurposing and recycling initiatives, Battery Cycle not only extends the useful life of EV batteries but also ensures their proper disposal at the end of their lifecycle. By doing so, they actively minimize the environmental impact of these batteries, further bolstering the UK's efforts to promote a greener and more sustainable future. As the demand for EVs continues to rise, the responsible management and utilization of second-life EV batteries will play a crucial role in shaping the future of the UK's electric mobility landscape. Battery Cycle's innovative approach to battery lifecycle management underscores their commitment to advancing sustainability and contributing to a cleaner and more environmentally friendly transportation sector.

The UK market for EVs has experienced remarkable growth in recent years, driven by various factors, including government incentives, advancements in battery technology, and a rising environmental consciousness among consumers. According to the Society of Motor Manufacturers and Traders (SMMT, 2021), the sale of EVs in the UK reached a record high in 2020, with over 100,000 new registrations, signifying a substantial increase compared to previous years. As the quantity of EVs on UK roads continues to rise, the management of EV batteries becomes a basic concern. However, despite their limited lifespan for essential vehicle use, EV batteries still hold a significant measure of energy storage capacity, making them important for secondary applications. The Battery Cycle plays a crucial job in broadening the existence of EV batteries by repurposing them for different purposes, such as stationary energy storage systems (Y. Wang et al., 2020). The repurposing of EV batteries offers several benefits, including cost-effectiveness, an increased energy storage capacity, and a reduced ecological footprint (Dunn et al., 2015). Through battery repurposing, Battery Cycle addresses the growing demand for energy storage solutions in the UK, facilitating the integration of renewable energy sources into the system and promoting a more sustainable energy infrastructure. As a sustainable and environmentally friendly transportation option, the transition to electric cars (EVs) has gained significant momentum in recent times. The breakthroughs in battery innovation, which are essential for increasing the driving reach, decreasing charging times, and eventually reassuring the mass reception of EVs, are at the core of this shift. This case study examines the present status of batteries used in electric vehicles, featuring significant technologies, problems, and prospective solutions. The case study opens with a careful clarification of the battery innovation frequently used in electric vehicles. It addresses lithium-particle (Li-particle) batteries, the most well-known choice because of their high energy density, lightweight, and exceptionally low self-discharge rates. Also, it looks at state-of-the-art innovations that could totally disrupt the EV industry, such as lithium-sulfur batteries, solid-state batteries, and other non-traditional energy storage methods.

Two central concerns in the realm of EVs are their driving range and the infrastructure for charging. This section thoroughly examines the current state of battery innovation and its implications for the scope of EVs, covering essential aspects like battery capacity, energy density, and thermal management. Additionally, it delves into the challenges of expanding the ongoing charging infrastructure to meet the surging demand for fast and efficient charging options. Consumer confidence is profoundly influenced by the performance and durability of EV batteries. Thus, this segment of the case study assesses the long-term reliability of batteries by scrutinizing factors such as temperature, charging cycles, and depth of discharge that impact battery health. Moreover, it explores various methods to extend battery life and mitigate capacity fading, including the implementation of battery management systems and cutting-edge charging algorithms.

2.5.2.3 Description of Case Study

The ecological impact of battery manufacturing and disposal should not be overlooked, even as EVs help reduce greenhouse gas emissions during their use. To address waste and recover valuable materials for future battery production, this section investigates the environmental effects of battery manufacturing. Despite the benefits of EVs, their widespread adoption is hindered by battery costs. The case study examines the economics of battery production, analyzing cost-influencing factors such as raw material costs, production methods, and economies of scale (Etxandi-Santolaya et al., 2023). Additionally, it explores potential strategies to reduce battery costs and make EVs more affordable for consumers.

Moreover, Battery Cycle's commitment to EV battery recycling ensures the recovery of valuable raw materials and minimizes the environmental impact of the automotive industry. The recycling process involves the extraction and reuse of materials such as lithium, cobalt, and nickel, which are crucial components of EV batteries (Gaines, 2018). By employing environmentally responsible recycling practices, Battery Cycle helps reduce the reliance on mining for these essential materials, contributing to resource conservation and sustainability.

In conclusion, Battery Cycle plays a pivotal role in managing, repurposing, and recycling EV batteries in the UK market. With the ongoing rise in EV demand, Battery Cycle's services contribute significantly to the sustainability and efficiency of the transportation sector. By maximizing the value and lifespan of EV batteries, the company actively supports the circular economy and fosters responsible resource utilization. Battery Cycle's innovative approach aligns perfectly with the UK government's environmental objectives, highlighting the importance of sustainable battery solutions in the ever-evolving automotive landscape.

2.5.2.4 Case Study Solution

The research project forecasts second-life electric vehicle (EV) numbers in the UK, evaluating economic, environmental, and technological aspects of second-life EV batteries. Data was collected from diverse sources, including the government's vehicle registration database, industry reports, and expert consultations. The methodology involves statistical analysis, regression, and trend extrapolation. Advanced tools assess energy consumption, emissions, and economic viability. Performance evaluation of battery technologies and a comprehensive market study were conducted. The research aims to provide valuable insights for policymakers and stakeholders, promoting EV adoption, enhancing performance, and sustainability in the UK's dynamic market landscape.

Data Collection

The data collection process for this research project was extensive and involved gathering information from various primary and secondary sources. One of the primary data sources was the UK government's vehicle registration database, which provided essential data on the number of electric vehicles currently registered in the country (GOV.UK, 2023). This dataset was crucial for establishing a baseline and understanding the current state of the EV market in the UK.

In addition to official government data, the study also relied on secondary sources such as industry reports, research papers, and government publications. These sources offered valuable insights into the trends, challenges, and opportunities within the electric vehicle industry. Industry reports provided valuable market intelligence and predictions for the future growth of EV adoption in the UK.

To enhance the accuracy and applicability of the study's findings, the research team conducted consultations with industry experts, battery providers, and other automakers. These interactions allowed the researchers to gain practical insights into the real-world performance of EV batteries and understand the challenges and opportunities in the electric vehicle market. Feedback from customers and end-users provided valuable information on battery types, capacities, charging infrastructure, and driving range, which further enriched the dataset.

Furthermore, the research project aimed to collaborate with leading electric vehicle and battery manufacturers, as well as pertinent governmental organizations. This collaboration was crucial for accessing current and reliable data related to battery chemistry, energy storage capability, degradation trends, and safety requirements. By tapping into the expertise of these industry leaders, the research team could ensure that their analysis was based on up-to-date and accurate information.

Methodology

The research methodology followed a systematic and structured approach, starting with a comprehensive analysis of the collected data. During the analysis phase, the data underwent both statistical and qualitative analysis to provide a comprehensive understanding of the subject matter.

Statistical techniques were used to identify trends and correlations within the data, while qualitative analysis helped to interpret and contextualize the findings.

To ensure the accuracy and reliability of the input data, the research team employed advanced forecasting methodologies, including data pre-processing and cleaning. Data pre-processing involved identifying and addressing potential outliers and inconsistencies within the dataset, ensuring that the subsequent analysis was based on reliable information (Colarullo & Thakur, 2022). By carefully handling the data, the researchers aimed to minimize the impact of data noise and improve the robustness of their analysis.

Regression analysis, a powerful statistical tool, was then applied to establish relationships between various variables and to derive meaningful insights regarding the arrival of used EVs in the UK market. This technique allowed the research team to model the relationships between different factors and understand how they might influence the growth of the second-life EV market.

Additionally, trend extrapolation was incorporated into the analysis to extend the findings into the future. By identifying historical patterns and trends, the researchers could project potential growth patterns in the industry. However, the research team acknowledges that forecasting inherently involves uncertainties and assumptions based on prevailing market trends and conditions. As such, the results should be interpreted with caution, considering the dynamic and ever-changing nature of the market landscape.

Technology Employed

The research project leveraged sophisticated data gathering and analysis tools to gain valuable insights into the energy consumption, pollutant emissions, and economic viability of second-life EV batteries. Advanced software and mathematical algorithms were employed to process and analyze the vast amount of data collected from multiple sources.

Moreover, the research included a performance assessment of various battery technologies used in electric cars. This evaluation involved analyzing several important metrics, such as energy effectiveness, driving range, charging speed, and temperature sensitivity. By assessing these performance indicators, the research team could determine the strengths and weaknesses of different battery technologies and their applicability in various electric vehicle types and driving situations.

The environmental impact of EV batteries was also a significant component of the study. A comprehensive examination was conducted, encompassing the entire lifecycle of the batteries - from the extraction of raw materials to the manufacturing processes, the usage phase, and eventual recycling. Understanding the environmental implications of EV batteries was vital for assessing their sustainability as a green transportation alternative.

Furthermore, the research incorporated a thorough market study to comprehend the current trends and potential futures for the use of electric vehicles. This analysis considered various factors, including government regulations, incentives, customer preferences, and infrastructural advancements that could influence the growth of EV battery technologies in the UK market. By understanding these market dynamics, the research team aimed to develop a comprehensive forecast of the second-life EV market's potential growth and the challenges it might face.

In conclusion, the research project utilized a diverse array of data sources and advanced tools for data analysis, including sophisticated software and mathematical algorithms. The methodology employed a structured approach, involving statistical and qualitative analysis, regression analysis, and trend extrapolation to forecast the number of second life EVs in the UK market. The technology employed encompassed a performance assessment of EV batteries and a comprehensive market study to understand current trends and potential growth opportunities (Illa Font et al., 2023). By combining these elements, the research team sought to provide valuable insights and well-informed recommendations for policymakers and stakeholders in the automobile sector, contributing to the adoption and improvement of electric vehicles in the UK.

2.5.2.5 Results and Discussion

The main aim of this project was to forecast and get an idea of no of EVs that will be available for second life use in the United Kingdom. For this purpose, we used a step-by-step procedure. We started analyzing them from the basics and worked our way towards the goal.

Analysis: It helps to gather knowledge about the possible effects of introducing second-life EV batteries, the data collected was statistically and qualitatively analyzed. This research focuses on the economic, environmental, and technological elements of SLBs to examine the possibilities for integrating them into the UK market. Due to its favourable environmental effects and decreased reliance on fossil fuels, EV adoption has been gradually rising in the UK. But as the EV industry expands, a problem with second-hand electric vehicle batteries (SLB) appears.

Market analysis: The present situation of the UK EV market was examined, including sales data, EV models, and charging infrastructure. Data about SLB's accessibility and market integration were also looked at. With more EV models readily available to customers, the EV market in the UK has grown significantly over the past several years. SLBs are now more widely available as a result of breakthroughs in battery technology and recycling procedures. SLBs are a desirable alternative for energy storage applications since they are often less expensive than new batteries. Battery leasing, remanufacturing, and recycling are just a few of the several pathways via which SLB revenue streams might be produced.

In this the first analysis was based on which are the top 10 EV manufacturers in the United Kingdom. For this we used our main dataset from DVLA (Driver and Vehicle Licensing Agency).

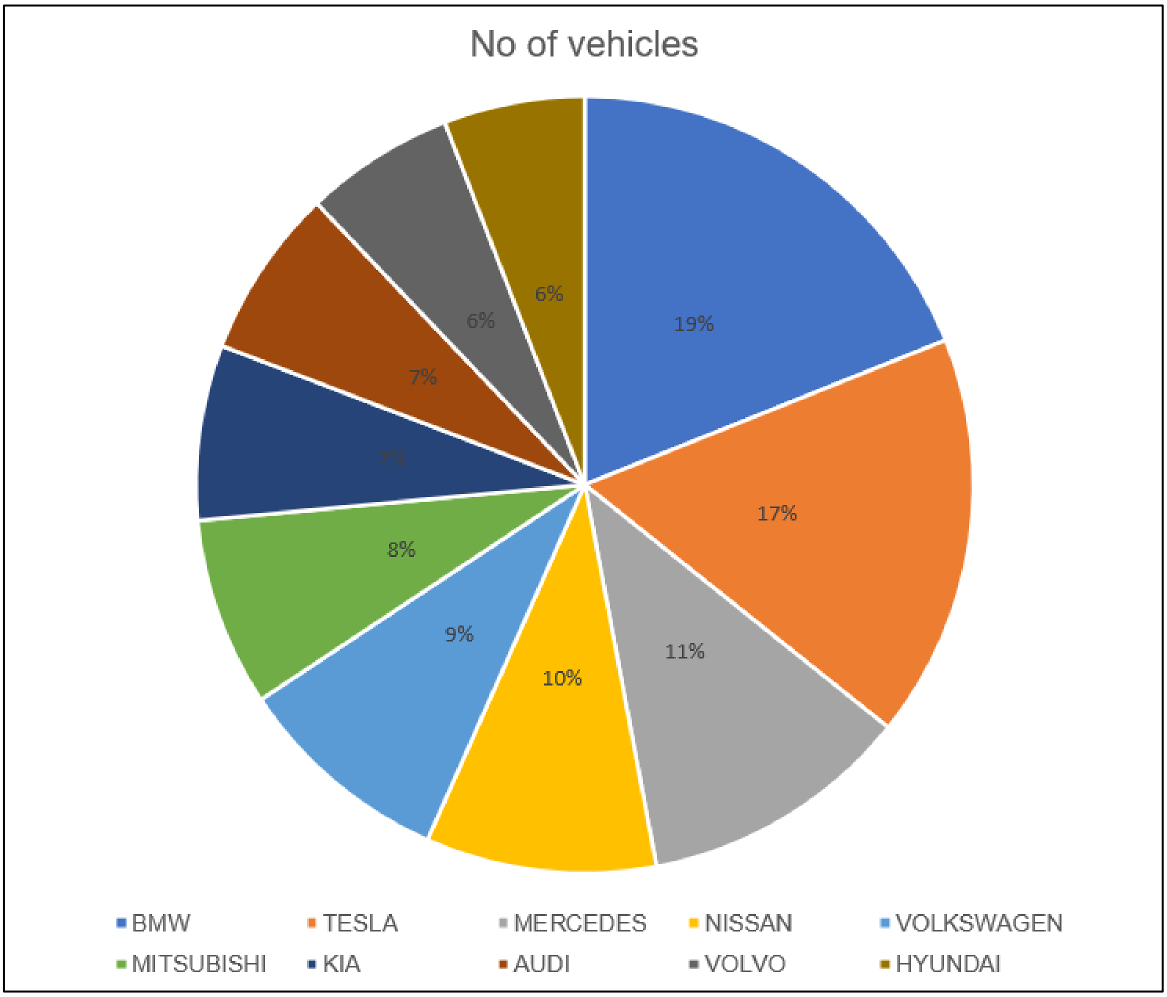

Figure 16. A presentation of EV market share by brands

From Figure 16 we can see that BMW is currently dominating the EV market with 17% of the total EVs in the United Kingdom being manufactured by them which is followed by Tesla which is 17 %, which being a new company in the market is giving reliable results. Since our main aim is second life use of batteries this data is important because different EV manufacturers use different battery chemistry. This could even be useful to form partnership with top manufacturers to collaborate on second-life use of these batteries. To solidify this learning on the top manufacturers we next focused on forecasting this data towards 2030 and as we expected from Figure 17, we can see that Tesla overtook BMW in the EV race. For this analysis we used a linear regression model. This graph helps us to focus on the future top manufacturers according to the trend.

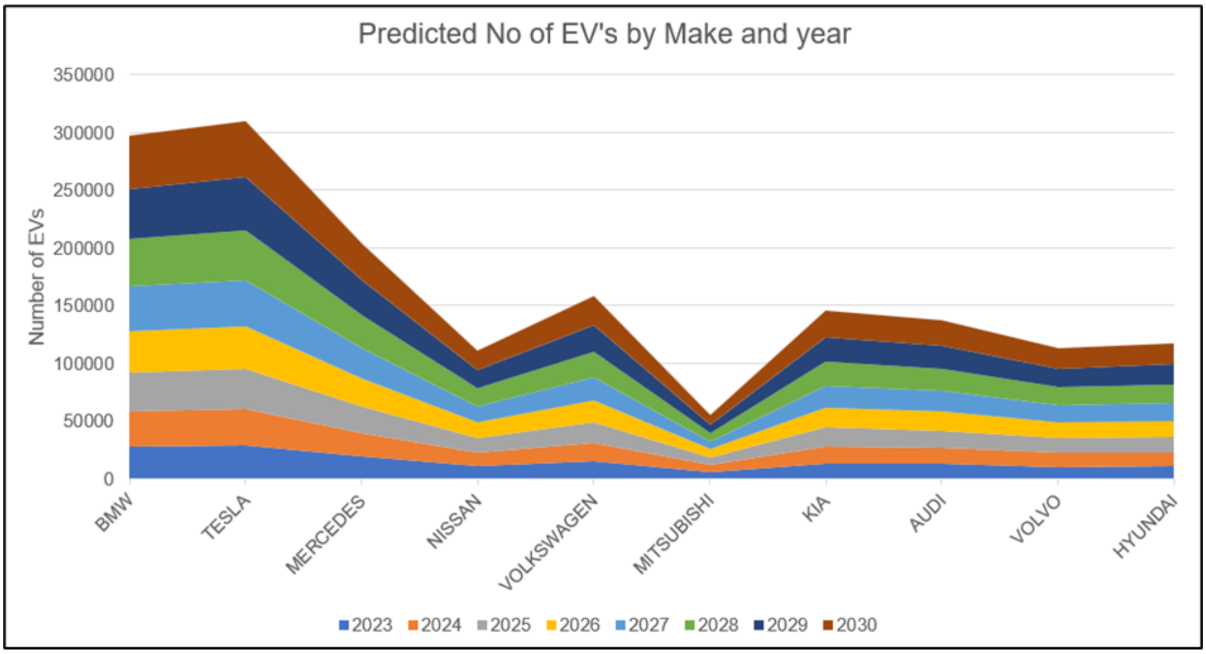

Figure 17. A representation of predicted number of EVs by make and year

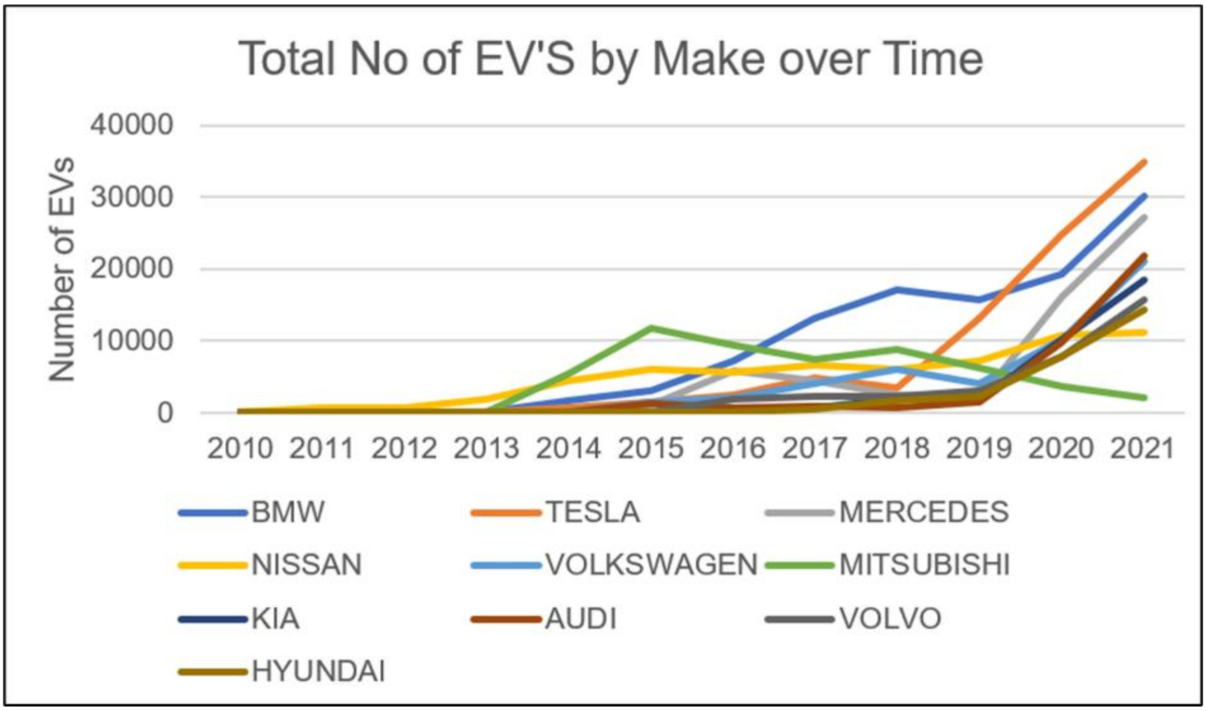

Figure 18. A representation of number of EVs by make over time

According to manufacture and year, Figure 18 breaks down the total number of Electric vehicles on the market. Considering the exception of Mitsubishi, whose sales are declining, we can observe that all EV manufacturers are helping the growth. In the EV industry, Tesla saw a startling upswing in 2018 that just continued to grow. As seen in Figure 3, all EV manufacturers had a sharp increase in EV registrations in 2019 notwithstanding Covid's impact. This is in addition to how other manufacturers turned their attention to EVs after TESLA's success.

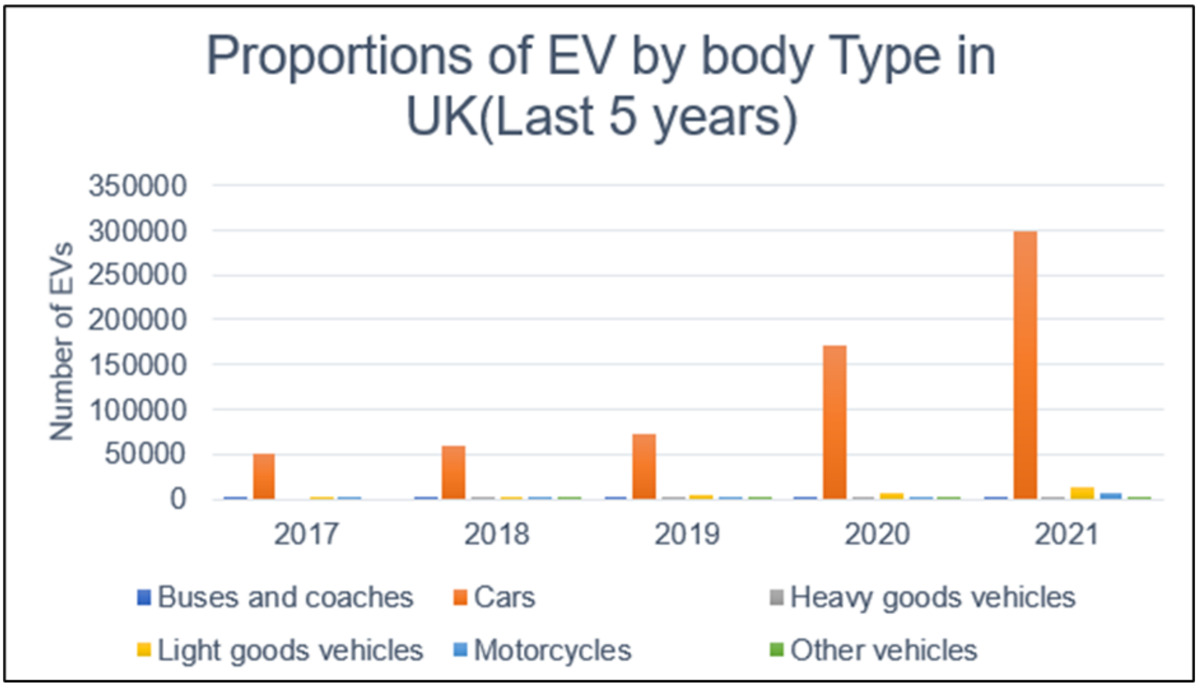

Figure 19. A representation of number of EVs by body type in the last 5 years

The car type that has dominated the EV market in the UK during the past five years is seen in Figure 19. Cars are certainly dominating to a significant degree, as can be shown. These forces need to concentrate more of the research on automobiles, and as there are far less of the other kind of vehicles, one could even try to discount them from it. Assessing whether second-hand EV batteries are appropriate for a particular use case is going to be made easier by understanding the body type.

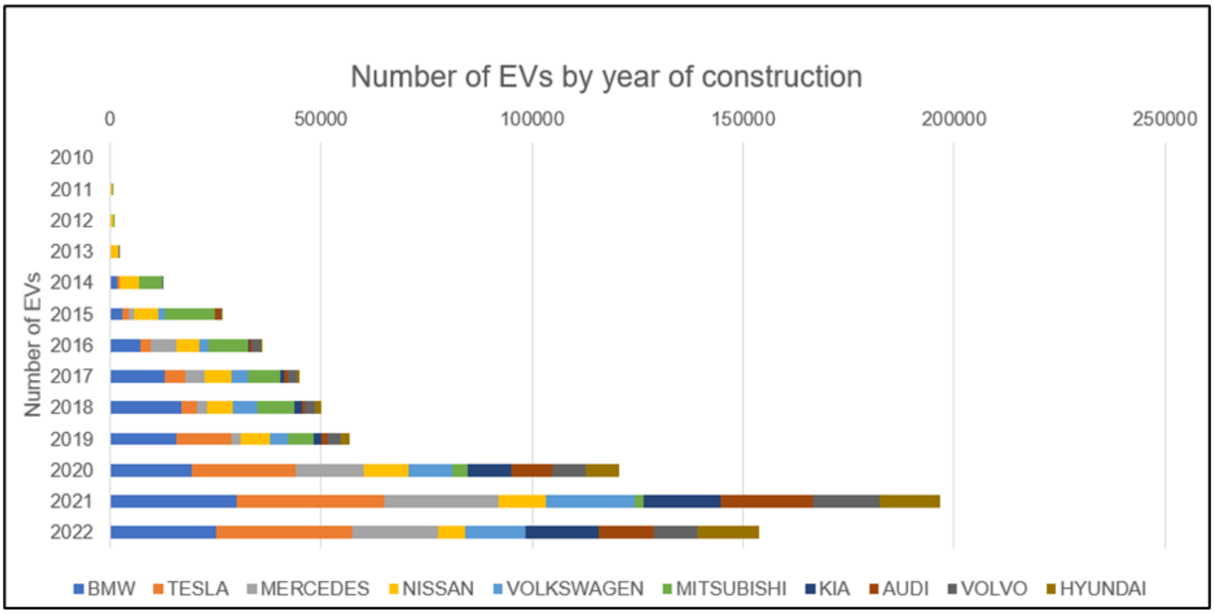

Figure 20. A representation of number of EVs by year of construction

The number of registered EVs overall is shown in Figure 20 by year. Up to 2018, one should expect a continuous rise. A major shift in the EV industry is anticipated after 2018. As the tendency continues to rise, the overall number of dead batteries is going to increase in the upcoming years, as can be seen from the trend (Y. Wang et al., 2020). To understand market trends and make appropriate plans, use this data. As only facts up to the third quarter of 2022 are taken into account, the year might be judged as having less potential.

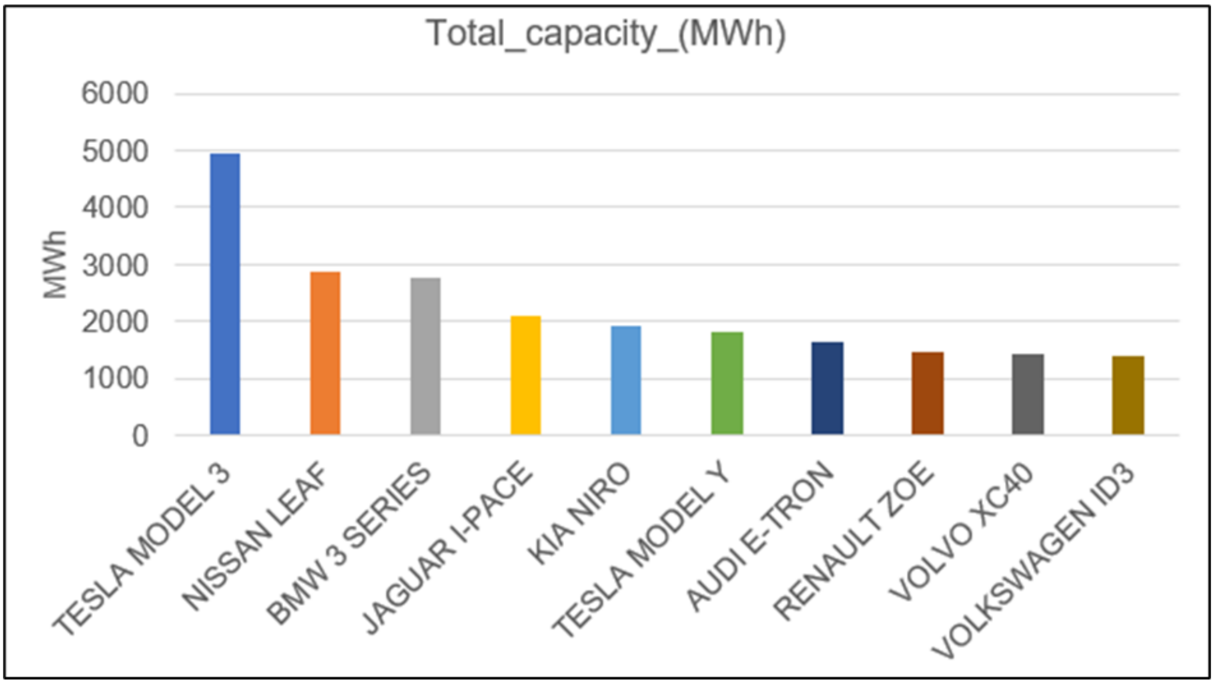

Figure 21. A representation of the cumulative battery capacity of different models

The total battery capacity of the various EV models now on the UK market is shown in Figure 21. To understand the raw resources that are accessible, this information is helpful. MWh is the battery's capacity. One can see that the Tesla Model 3 currently on the market has a capacity of 5000MWh. Depending on the kind of battery, this information can later be transformed to determine the raw components.

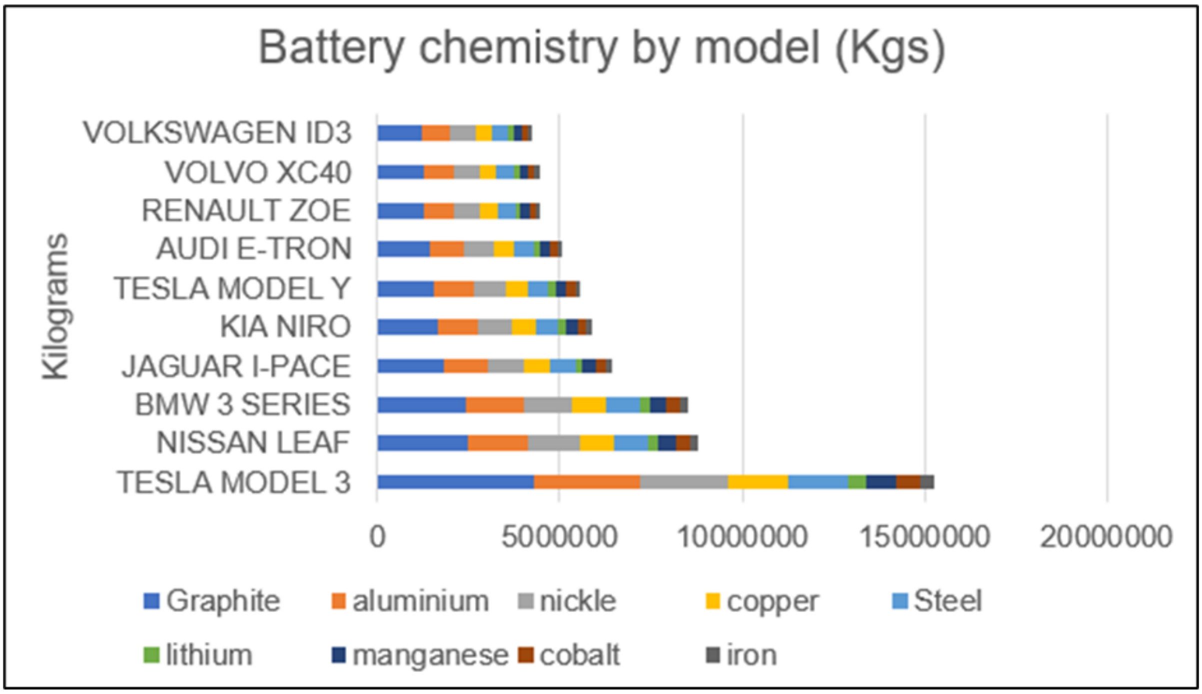

Figure 22. A representation of the composition of different materials in batteries of electric vehicles

Now, one can see in Figure 22 how the raw materials are split by the EV model in kilograms. This information is crucial since it aids in properly planning the recycling process. Additionally, it is going to encourage the recovery of valuable materials and help decrease waste (Dunn et al., 2015). Graphite has the highest concentration, followed by lithium, as can be shown. Knowing the battery's economic worth can also be aided by this. For this, we used a conventional ratio of 185 kg of minerals to 60 kwh of battery power.

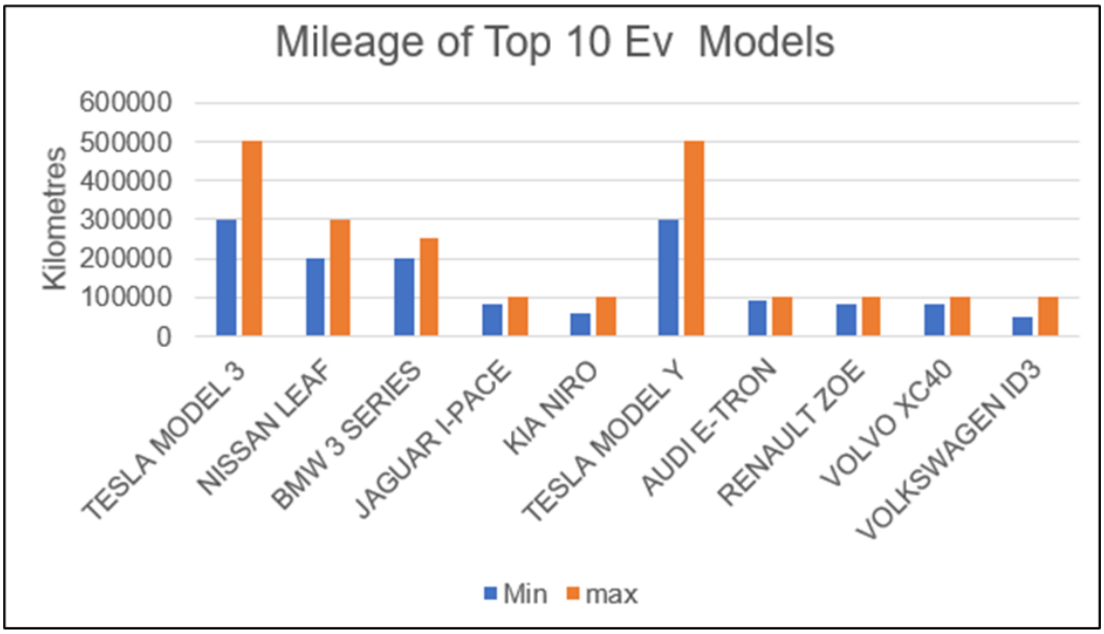

Figure 23. Total distance driven for the top the 10 EV models

The lowest and highest mileage values for the top 10 EV vehicles are displayed in Figure 23. Depending on the current mileage, this information might be used to evaluate the condition of the vehicle. They used years as a criterion for determining the State of health because we lacked access to any form of mileage data.

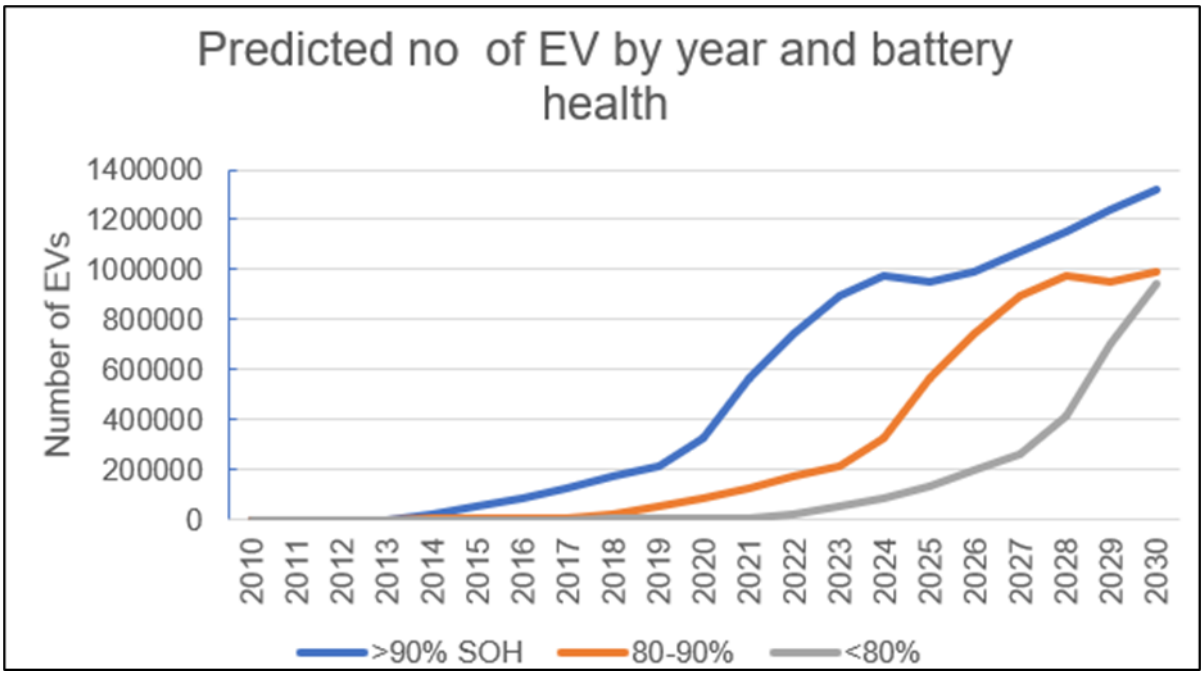

Figure 24. A representation of predicted number of EVs by year and battery health

The Predicted State of Health and the number of automobiles is shown in Figure 24 for each year. The battery is regarded as dead and frequently requires replacement if the state of health (SoH) is less than 80%. In light of this, we can estimate the number of EVs that will be available for usage in aftermarket applications by 2030. One million EV batteries would be accessible in the UK alone for reuse, according to the estimates. To forecast this, we employed a linear regression model. We started with an 80% SOH level and worked our way up to higher than 90% by considering the typical battery life of EVs, which is 8 years.

Researchers looked at a variety of factors in this study, starting with the fundamentals of leading manufacturers and ending with the State of health. The batteries for electric vehicles that are now on the market and those that are no longer suitable for use in vehicles but still have some powers were also a major emphasis. In this study, researchers looked at the UK market's size, the various EV battery types that are offered, and the use of repurposed EV batteries (Thorne et al., 2021). The EV battery's capacity, lifespan, and deteriorating process were also considered.

2.5.2.6 Conclusion and Recommendations

Recommendations

The market for used electric vehicles offers substantial opportunity for vehicle manufacturers, dealerships, and other stakeholders to capitalize on the growing desire for inexpensive and sustainable transportation options. These suggestions are meant to help your company be ready for the arrival of second-life electric vehicle (EV) batteries, including looking into partnerships, making infrastructure investments, and thinking about marketing plans.

To handle the growing influx of old electric vehicle (EV) batteries, the company needs to invest in the creation of a strong infrastructure for battery recycling. The company should create recycling facilities with cutting-edge technology so that it can safely remove valuable materials and safely dispose of dangerous waste.

An alternative to recycling old batteries is to reuse them in order to extend their usable life. Energy storage systems are among the main areas where used batteries are put to use. The extra renewable energy produced by sources like solar or wind power can be stored in large-scale storage systems made from the combined use of these batteries. These systems can offer electricity at times of high demand and also help to smooth out variations in the power supply by storing extra energy.

In order to increase economic benefits, it is imperative to create an infrastructure for an electrical grid based on EV rapid charging stations and second-life battery energy storage devices. The infrastructure for electric vehicle charging can be supported by repurposed EV batteries. These batteries can be used for energy storage to regulate peak charging demand, balance power loads, and ease the burden on the electrical grid.

We encourage cooperation with EV producers to make it easier to recycle and reuse second life batteries. EV manufacturers should develop collaboratively effective and standardized battery collection, testing, refurbishing, and recycling procedures. Encourage automakers to assume accountability for the end-of-life management of their goods.

We recommend that EV manufacturers should support activities in research and development that are centred on battery recycling and other second-life uses. Investigate novel applications for retired EV batteries, such as stationary power sources, energy storage devices, or grid stabilizing techniques. To promote innovation in this area, establish collaborations with research facilities, academic institutions, and business leaders.

The company should create standardized techniques to evaluate the state of used EV batteries and their remaining capacity. Adopt stringent testing techniques to evaluate battery performance, deterioration rates, and appropriateness for reusing in other applications. It is advised to use cloud-connected storage solutions to monitor battery aging during the whole life cycle.

The organization can work with the government to disseminate information to the general public about the value of recycling old EV batteries and disposing of them properly. Convey the possible economic and environmental advantages of recycling activities. To promote sensible battery management, provide information about collection locations, recycling facilities, and accessible aftermarket applications.

In addition, EV manufacturers can establish recycling facilities and pickup stations for used EV batteries in cooperation with local authorities. Make sure there are handy and easily accessible sites where customers may return their batteries. Start local awareness campaigns to encourage battery recycling and repurposing efforts.

The company can participate in global partnerships and knowledge-sharing forums to share top battery recycling and repurposing techniques. Utilize the knowledge of nations with well-established battery recycling programs and learn from them to help the UK advance more quickly.

The organization should keep an eye on the success of activities for recycling and reusing batteries. Analyse the effectiveness and efficiency of various strategies. Review and revise your strategies frequently in light of new developments in technology, market trends, business prospects and new possibilities (Cusenza et al., 2019)c.

Used batteries can be incorporated into off-grid power systems, which are useful in places like isolated or rural areas without access to dependable electrical networks. For off-grid communities or installations, these batteries can provide a sustainable and dependable power supply by storing renewable energy produced from sources like solar or wind power.

The company should keep up to date with regulatory and policy changes related to EVs and second life batteries in the UK. This can include changes to tax incentives, grants, and subsidies, as well as environmental regulations that may impact battery recycling and refurbishing processes.

The UK government should roll out financial rewards and assistance programs to promote recycling and reusing old EV batteries. Companies engaged in battery recycling or repurposing projects should be offered grants or tax incentives (Hossain et al., 2019). Donate money to research and development projects aimed at increasing the effectiveness of battery recycling and reusing.

For the smooth processing, recycling, and disposal of second-life EV batteries, specific rules and regulations need be established by the UK government. There must be measures in place to ensure that environmental regulations are followed at all stages of the battery life cycle, including collecting, transportation, and processing.

The company can manage the influx of used EV batteries, reduce environmental effects, advance the circular economy, and realize the potential value of these batteries beyond their primary use in EVs by putting these ideas into practice (Iqbal et al., 2023). In order to build a general economic model, it is advised that consideration be given to future price inflation, correct battery market pricing, and net metering rates.

Conclusion

Based on an examination of market patterns and available data, the research predicts that the arrival of used EV batteries in the UK market will expand steadily over the next five years. The increased adoption of electric vehicles in the UK is likely to increase demand for used EV batteries. Furthermore, rising demand for energy storage solutions, especially in the renewable energy industry, has resulted in a developing market for used EV batteries. By incorporating these recommendations into strategic planning and decision-making processes, stakeholders can leverage the findings from the project to maximize the potential of the second-life EV market, contribute to sustainability goals, and establish a robust and circular economy in the EV sector.

Collaboration with Leading Manufacturers: Establish partnerships with top EV manufacturers, such as BMW and Tesla, to explore opportunities for collaboration in the second-life use of their batteries. This can involve repurposing partnerships, joint research and development projects, and resource sharing.

Geographic Focus: Concentrate efforts and resources on England, the region with the highest concentration of EVs. Develop tailored strategies and initiatives to promote second-life EV programs, charging infrastructure expansion, and recycling facilities to maximize impact and benefits.

Strategic Planning: Prioritize the analysis and planning of second-life EV initiatives for car models, considering their dominance in the market. Develop specific use cases and applications for second-life EV batteries in the automotive sector, such as electric vehicle fleets or ride-sharing programs.

Market Trend Analysis: Continuously monitor market trends and industry developments to adapt strategies and forecast future demand for second-life EV batteries accurately. Regularly update forecasting models based on updated data and industry insights.

Recycling and Resource Recovery: Encourage the development and implementation of efficient and environmentally responsible recycling processes for EV batteries. Promote the recovery of valuable raw materials, such as graphite and lithium, to minimize waste and maximize resource utilization.

Battery Health Assessment: Develop tools and methodologies to assess the health and remaining lifespan of EV batteries accurately. Consider factors beyond mileage, such as years of use, to determine the State of Health (SoH) and identify batteries suitable for second-life applications.

In conclusion, we highlight the need of keeping an eye on market trends and adjusting strategy as the industry changes.

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2.6 University of Sassari – Promoting Sustainability in Urban Areas through the Use of Green Materials and Recycling in Building Construction – A case study in Sardinia (Italy)

2.6.1 Executive Summary

Focusing on the building sector, this case study analysed the renovation potential of a complex of abandoned urban industrial buildings in Sassari, Italy, considering embodied energy and carbon related to existing materials and their potential recovery. The results reveal a substantial material recovery potential, ranging from 25%-35% to 65%-75%. In addition, the type of insulation material used showed a relevant impact on embodied energy and carbon recovery rates, with cork having the potential to reduce overall embodied energy and carbon, Figure 255.

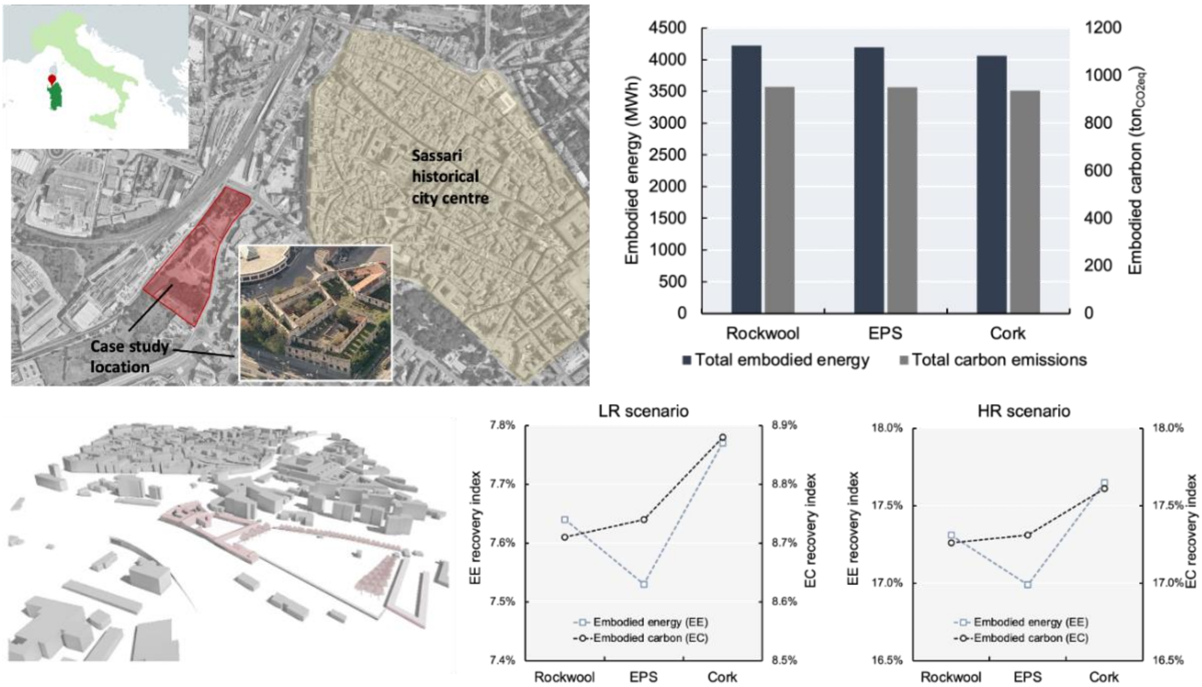

Figure 25. – Promoting Sustainability in Urban Areas through the Use of Green Materials and Recycling in Building Construction - Graphical Abstract

2.6.2 Case Study

2.6.2.1 Abstract

The European economy relies heavily on the consumption of non-renewable resources such as minerals, metals, concrete and wood, as well as fossil fuels and land to meet the demands of its citizens. As a result, a significant amount of waste is generated, with an average of six tons of waste per person annually. Currently, 51.5% of this waste is disposed of, with only 43.6% being recycled. With Europe importing a large quantity of raw materials, there is a growing need to optimise the use and management of waste materials.

In this context, the building construction sector can play an important role in reducing the raw materials demand by implementing the reclamation, reuse and recycling approach on the huge quantity of stock material typically abandoned along the building lifetime. This is particularly relevant considering the large number of abandoned buildings or buildings which require refurbishing and energy retrofitting in Europe. The implementation of rational and efficient design and construction policies and practices aimed at supporting the recycling and reuse of building construction waste – including the use of abandoned buildings as materials quarry – and the adoption of green construction practices, based on green materials and renewable energy, can lead to a number of benefits, such as: the reduction of raw material extraction, transportation and processing, energy and carbon emission savings, a reduced volume disposal in landfills, and the potential of reducing costs and increase health and life quality in the affected urban areas.

Generally, recycling in the building construction sector specifically involves the collection, processing, and reuse of materials from building construction and demolition sites. Common practices include recycling concrete and asphalt for use in new building projects, using reclaimed wood for flooring and other building components, recycling metals such as steel and copper, the adoption of sustainable and environmental-friendly materials for building elements, such as insulation, flooring, panelling, etc. However, the potential for reusing a large amount of abandoned material in the building process requires a comprehensive life-cycle approach that encompasses everything from the selection of the construction site to the selection of building materials and design elements, from the construction to its operating life and decommissioning. The present case study explores several methodologies and strategies for recycling and reuse of raw materials in the construction sector, with reference to several existing buildings/urban areas in Sardinia (Italy).

2.6.2.2 Introduction

A growing recognition of the environmental, economic, and social benefits of sustainable construction practices has led to implementing policies for the recovery and reuse of existing buildings. Nowadays, there is an even greater emphasis on the environmental impact of the construction sector and a growing recognition that material recovery of existing buildings is essential for maximizing sustainability (Yang et al., 2022). By reusing materials that already exist in the built environment, we can reduce the environmental impact of new construction and minimize material waste. This is particularly important given the finite nature of many of the resources used in construction, such as minerals, metals, and wood. Furthermore, the recovery and reuse of existing buildings may also lead to economic savings (Kylili & Fokaides, 2017), due to the reduction of new materials needed for new construction, and social benefits - such as preservation of historical structures and local architectonical character, as well as to revitalise communities and neighbourhoods (Iacovidou & Purnell, 2016).

Various possible degrees of intervention can be employed when it comes to working with existing buildings, and each requires a unique set of skills and knowledge. These interventions can become increasingly complex and intertwined with environmental concerns, requiring not only an understanding of the immaterial connections between people and place, but also of the physical and bioclimatic properties of the building envelope. Additionally, knowledge of the adaptability of existing structures to new uses is crucial to ensure that they can continue to serve as functional and valuable components of the built environment. According to a residual performance-based approach for technical elements and components (Monsù Scolaro & De Medici, 2021), to minimize material flow and waste creation, a refurbishment intervention should ideally be carried out by conserving and reusing as much material as possible while also minimizing the addition of new material. At the same time, the technical design choices should be compatible (from a physical-chemical and mechanical standpoint) with the existing material and meet the criteria of disassembly, ease of maintenance, and recoverability of the materials and construction solutions adopted, preferably using dry construction technologies where possible.

Over the last decade, the life cycle analysis has raised a lot of interest among the research community since it allows to evaluate the environmental impact of a product or service throughout its life cycle, from raw material extraction to end-of-life disposal. In the building sector, LCA can provide valuable information about the environmental impact of different retrofitting solutions and material reuse options (Chau et al., 2015), including potential savings from the energy and carbon emission points of view (Schwartz et al., 2018). In addition, the concept of embodied energy and embodied carbon has been introduced to quantify the energy consumption and carbon emissions associated with the entire life cycle of a building material, from extraction and processing to transportation and installation. Evaluating both the energy and carbon life cycle enables a comprehensive assessment of the material and system performance in terms of primary energy and carbon savings (De Rosa & Bianco, 2023).

This approach enables the optimization of insulation layer design, such as thickness, based on energy and carbon payback (Azari & Abbasabadi, 2018). Numerous authors have successfully tested this methodology in the building construction and renovation industry. For example, (Braulio-Gonzalo & Bovea (2017) studied the environmental and cost performance of insulation strategies for building envelopes by conducting a life-cycle assessment of the insulation materials. Roberts et al. (2020) investigated the sustainability of building components in terms of life-cycle carbon emissions and developed a trade-off methodology for decision-making purposes. Similarly, Abd Alla et al. (2020) examined the impact of embodied energy and carbon on energy efficiency measures in the building sector, highlighting the significance of a full life-cycle analysis in determining the performance of insulation layer deployment.

Generally, to adopt a comprehensive and sustainable approach to building retrofitting that promotes material reuse and recycling to optimise refurbishing costs, embodied energy and carbon, the underlying methodology should include several phases (Figure 26):

- Phase 1: preliminary assessment of the existing building's end uses, architectural configuration, existing material and structures, and potential retrofitting solutions. The assessment will consider the building's current condition, its history, and its potential for adaptive reuse. The evaluation will also identify the most promising retrofitting solutions that consider the building's environmental impact, energy efficiency, and the well-being of its occupants.
- Phase 2: a preliminary control and verification of material flows of the retrofitting solutions, by analysing the architectural constraints and determining the potential for preserving the existing material and structures, as well as identifying opportunities for material reuse, recycling, and disposal. This involves conducting a preliminary control and verification of material flows during the construction phase.
- Phase 3: assessment of technological performance of both existing and new materials, as well as analysing their embodied energy and embodied carbon to evaluate the potential impact of retrofitting solutions and identify opportunities for energy and carbon savings. In addition, the phase considers factors related to well-being and safety to ensure that the retrofitting design not only improves the building's energy efficiency but also creates a healthier and safer environment for its occupants.
- Phase 4: optimization of the retrofitting solutions designed to reduce waste and costs, promote the use of sustainable materials with low embodied energy and low embodied carbon, as well as the requalification and integration of the building in its local context. This phase aims to achieve the best possible balance between environmental, economic, and social sustainability, and to identify and evaluate the potential benefits of each design option. It also involves ensuring the

compliance of the retrofitting solutions with all applicable regulations and standards, as well as the proper coordination with stakeholders and contractors involved in the project.

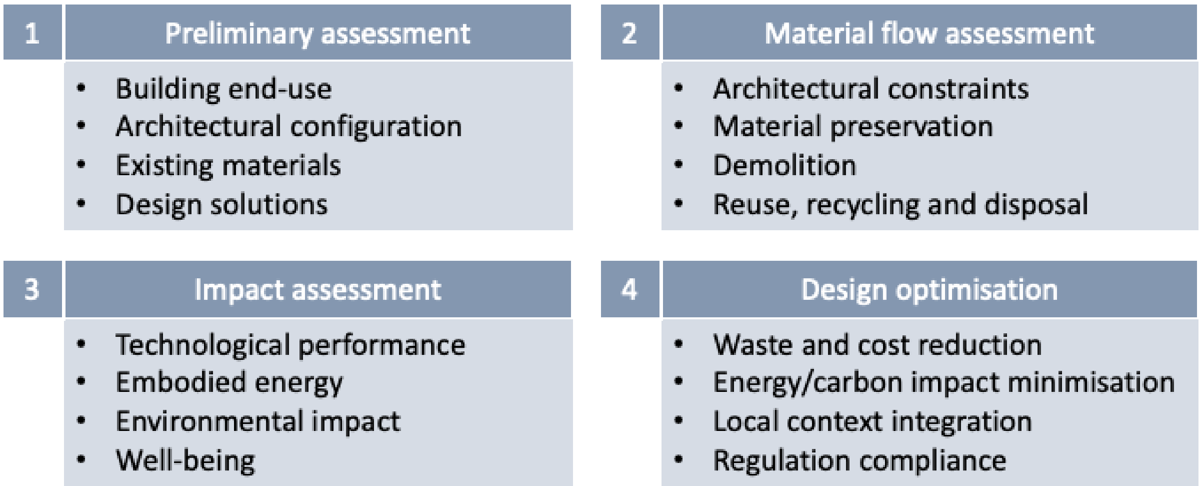

Figure 26. Building retrofitting design promoting material reuse and recycling.

In this context, the present case study outlines the potential renovation of a former urban industrial area located Sassari (Sardinia, Italy). The area, inserted in the urban context of the city close to the city centre and well connected with the main road and rail junctions, is abandoned since the early ‘80s and in an advanced state of decay. Starting from the assessment of the current condition of the different buildings located in the complex, aimed at analysing the different structures, the constituent materials, their condition and remaining performance, the potential material flows are identified. Then, potential reuse and recycling of the existing material and new material components are assessed and evaluated in terms of embodied energy, embodied carbon and costs. Different solutions are analysed to determine the optimal material flow configurations to minimise the raw material consumption.

2.6.2.3 Description of Case Study

The case study relates to a redevelopment and reuse intervention of the "Ex Concerie Costa", an industrial complex located in the urban area of Sassari in Sardinia, Italy (Figure 27).

The building complex was built starting from 1859 and expanded over several decades, which represents an interesting example of industrial archaeology in Sardinia (Italy). The building was used for leather processing until the early 1950s, then rented as a furniture factory, and eventually abandoned in 1982 due to a fire that made it unusable. The current complex floor plan is due to the numerous changes of use from 1859 to 1936. The first expansion phase involved adding some volumes to the first three factory buildings for the installation of powerful steam engines. Subsequently, two more factory buildings were added, which configured two new internal courtyards (originally used as a city fruit and vegetable market). The main building was built in 1899 and gave the entire complex a stately and imposing appearance: the expansion process, at least until 1910, was based on a unitary project whose floor plan articulation was influenced by the nearby railway, built in 1872. The last growth phase of the complex coincides with the addition of the last internal courtyard in which the power plant for the production of electricity for the building was located.

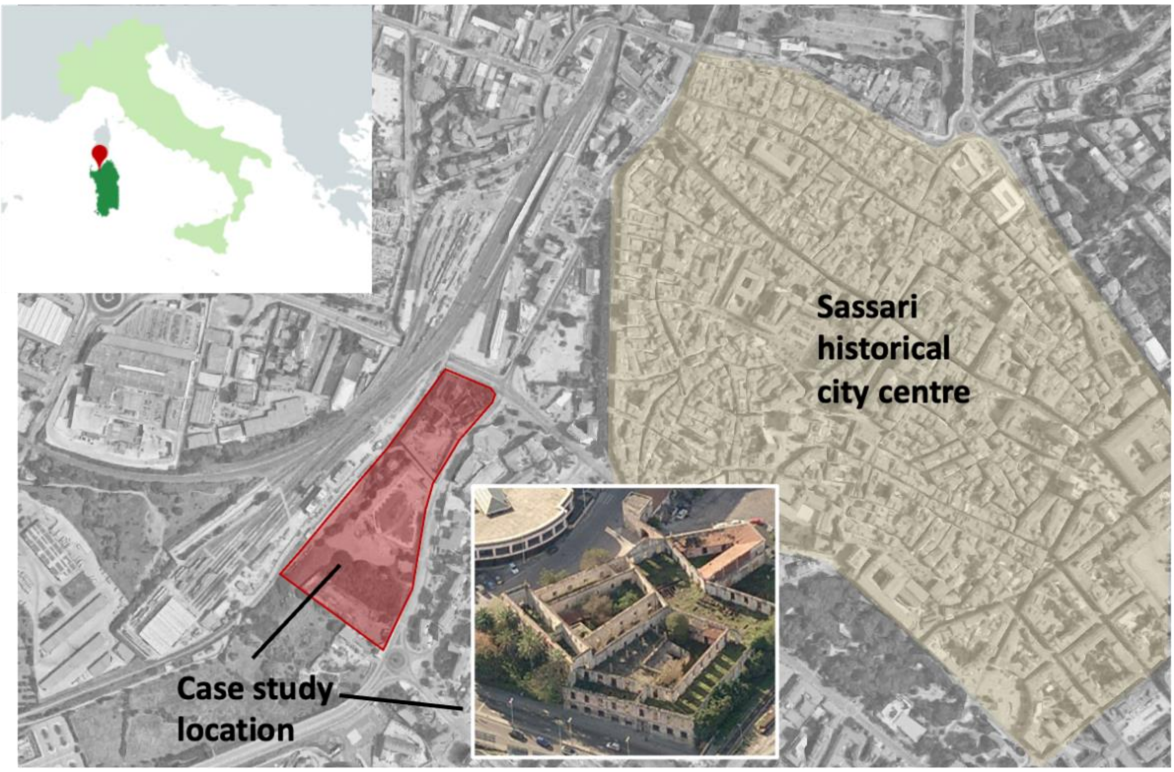

Figure 27. Location of the case study.

Currently, the building complex is abandoned, and the remaining structural components are in an advanced state of decay. Being located near both road and rail junctions, easily accessible on foot or by car, and thanks to its proximity with Sassari's city centre (Figure 26-27), the area has a high potential for redevelopment and renewal. Its strategic location and accessibility, together with the large courtyard area available and a certain flexibility in the use of spaces, make it an ideal location for a variety of new uses, such as commercial or residential spaces, cultural centres, or educational institutions.

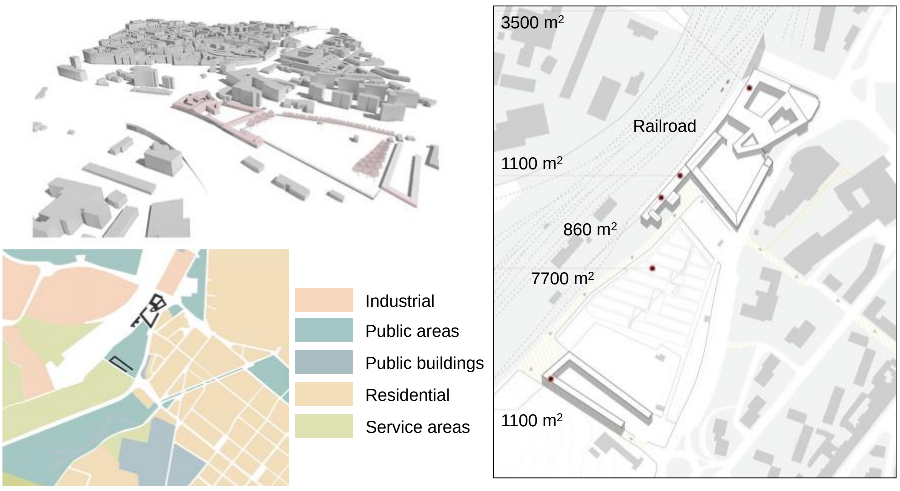

Figure 28. Case study features and its integration in the urban district (Costa, 2013)

The main complex consists of a 3 floor building with about 1543 m^2 per floor and it was constructed with load-bearing masonry in squared blocks of local limestone, double T steel beam floors, and brick vaults supported by cast iron columns. The external and internal walls are about 98.33 m^3 and 73.83 m^3, while the roofs (where still in place) are gabled or hipped and are supported by a structure consisting of wooden trusses, crosspieces, and battens (Figure 29, Figure 29).

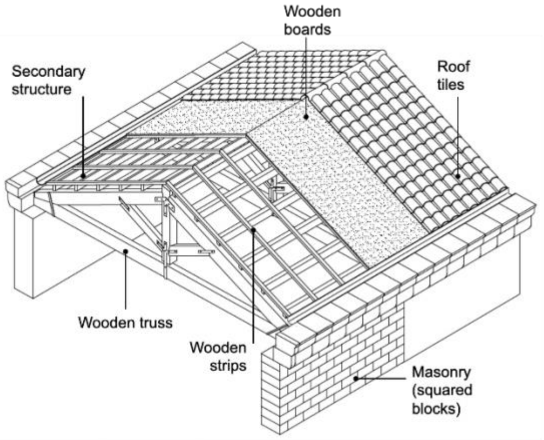

Figure 29. Construction details of the main building complex (Costa, 2013)

2.6.2.4 Case Study Solution

The experimental methodology proposed in this study is founded on the interdependence between building process and spatial features of a structure. It is based on the notion that the way a building is constructed shapes its spatiality, and vice versa. In this particular case, the methodology explores the idea of a symbiotic relationship between the building process and spatiality, emphasizing the crucial role of reuse, recycling, super-use, and other connected practices. The goal is to investigate a unique concept of "spatiality of recycling," which highlights the potential of repurposing existing materials and spaces in a building. By focusing on recycling and repurposing, this methodology aims to create sustainable solutions for requalification and reuse of existing buildings by recovering materials and their embodied energy and carbon content. Since the building can be reused in its entirety or in parts, with consideration given to its spatial quality, the spatial and technological quality of certain construction elements, or the quality of the materials, the adopted procedure can be divided into three main phases (Scolaro, 2018):

- Building structural and material assessment: the evaluation of the building's planimetric and spatial configuration is carried out to identify the main architectonic and structural features, which allows to identify refurbishment strategies and the consequent modifications required, such as demolition and preservation.
- Refurbishment strategy: the constituent materials are broken down and analysed in relation to their technological characteristics, conservation status and residual performance. This allows to evaluate the material flows which can be recovered, reused and recycled during the refurbishment process.
- Refurbishment optimisation: this phase assesses costs, embodied energy and carbon contents of the identified material flows in order to detect the optimal refurbishment strategies to minimise new material consumptions and related carbon emissions.

Embodied energy and carbon

The redevelopment of a building depends on its state of decay and may require technically replacement interventions or reuse and implementation of existing building components. Embodied energy can therefore split into three main components (Dixit et al., 2010):

- Initial embodied energy: accounting for 75-80% of the total embodied energy of a material, it accounts from the primary energy consumed for the extraction of the raw materials, their processing and transportation and the energy used during the construction phase.
- Recurring energy: it refers to energy consumed during the recurrent maintenance of the building as well as any subsequent retrofitting.
- Disposal embodied energy: it includes the energy consumption due to demolition and final disposal of the building material.

Therefore, the quantification of the embodied energy is a complex task which adopts a cradle-to-gate approach. In the present work, the Inventory of Energy and Carbon (ICEN) (Dixit et al., 2010) was used to estimate the values of the initial embodied energy of the building constituent materials of the case study under analysis. The ICEN (Inventory of Carbon and Energy) contains average embodied energy data for 30 main categories of materials, referring to the cradle-to-gate phase, from the extraction of raw materials to their transformation and transport to the construction site. Minimum and maximum EE values are provided in accordance with the literature referenced in the inventory, which takes into account specific operating conditions that could affect the variations in the EE value of each individual material on a case-by-case basis. The data are shown in the following table.

Table 9. Construction details of the main building complex (Costa, 2013)

	Material	Function	Density (kg/m³)	Dimension (cm)	Embodied energy (MJ/kg)
Wooden truss	Wood	Structural	640	20 x 20	378.9
Secondary structure	Wood	Structural/Support	640	12 x 12	68.2
Wooden board	Wood	Support	640	3	142.8
Wooden strips	Wood	Support	640	2 x 2	39.8
Roof tiles	Terracotta clay	Finishing	1500	45 x 14	354.8
Masonry blocks	Masonry	Structural	2000	62	1426.0
Plaster	Lime	Finishing	1500	3	52.2

Starting from the values of embodied energy shown in Error! Reference source not found., given the total mass of the construction material i ($m_{i,tot}$) in the building complex, its embodied energy is:

$$EE_{i,tot} = m_{i,tot} \cdot EE_i \tag{13}$$

Since not all the material can be effectively reused or recycled during the refurbishment phase, the recovered embodied energy for material is:

$$EE_{i,R} = m_{i,R} \cdot EE_i = \left(m_{i,rcy} + m_{i,reu}\right) \cdot EE_i \tag{14}$$

where $m_{i,rcy}$ and m_{reu} are respectively, the total mass of material *i* recycled in the production process of other components and the reused total mass (i.e., not demolished).

The ratio between the total embodied energy $EE_{i,tot}$ and the recovered embodied energy $EE_{i,R}$ of material *i* is called "EE recovering efficiency":

$$\eta_{R,i} = \frac{EE_{i,R}}{EE_{i,tot}} \tag{15}$$

Generally, the value of the EE recovering efficiency depends on the status of the existing materials in terms of residual technical performance - which can be of various nature depending on the original purpose of the building component (e.g., structural, energy efficiency, hygrometric performance, acoustic insulation, etc.) – on health and safety constraints, the specific refurbishing project under development and on the costs associated with recycling and reuse phases. Following the identification of the initial embodied energy and its potential recovering, the total initial embodied energy of all building components is defined as:

$$EE_{tot} = \sum_{i=1}^{N} m_{i,tot} \cdot EE_i \tag{16}$$

Similarly, the total embodied energy recovered is given by:

$$EE_{tot,R} = \sum_{i=1}^{N} m_{i,R} \cdot EE_{i,R} \tag{17}$$

and the overall EE and EC recovery indexes are:

$$\eta_{EE} = \frac{EE_{tot,R}}{EE_{tot}} \tag{18}$$

The calculation of the embodied carbon emission related to the production process of each existing component requires the knowledge of the energy flows used in the production process, which ideally should be obtained from a detailed case study on the life cycle carbon emission (You et al., 2011). However, due to the complexity and variety of materials, together with the lack of information and data for all countries and materials, retrieving these information could be challenging, and overall because pre-existing old materials and building components impede to precisely calculate the environmental impacts associated with the former production processes To tackle this challenge, a simplified approach was presented in De Rosa & Bianco (2023) where the authors used the energy fuel mix of the material or component production country.

Knowing the embodied energy of the material *i*, its embodied carbon emission is:

$$EC_i = \zeta \cdot EE_i \tag{19}$$

where is the average carbon intensity of the considered country (i.e., Italy) which is determined based on the country average fuel mix of the industry sector. Based on the authors' work De Rosa & Bianco (2023), the present analysis assumes a constant carbon intensity of 107.3 kg_{CO2}/MWh for Italy.

Scenario analysis

Recovering existing materials in the construction site for its refurbishing allows the reduction of the consumption of new materials. In order to analyse the potential impact of material recovering for the case study described before, a baseline scenario (BS), which consists of the demolition of the entire building complex and its reconstruction without any recycling or reuse of existing material was defined. Starting from the baseline case, two different scenarios were identified:

- Low recovering scenario (LR): the building structures with a high residual technological performance are reused (i.e., vertical walls), while the others are demolished and disposed. The refurbishment of the unrecovered part is made by using new materials and components.
- High recovering scenario (HR): the buildings are refurbished by keeping all structures with a good residual technological performance, while the others are dismantled and recycled where feasible.

Table 10 and 11 outlines the main assumptions of the two scenarios highlighting the structural elements reuse, which refers to the components which are conserved and refurbished, and demolitions. Since part of the raw materials obtained by the dismantling of the existing structures can be recycled to reduce the amount of new raw materials required for the building complex refurbishment, the tables also report the share of materials recycled and disposed in landfills.

Table 10. Description of the Low Recovery Scenario (LR) assumptions

Building elements	Structural element reuse	Dismantling	
		Material recycling	Landfill disposal
External walls	~25% of the external walls are conserved. The remaining walls are demolished and reconstructed.	~30% of the raw material from the demolished walls is processed and reused onsite.	The unused or recycled materials are processed and disposed in landfill.
Internal walls	~20% of the internal walls are conserved. The remaining walls are demolished and reconstructed.	~30% of the raw materials from the demolished walls is processed and reused onsite.	The unused or recycled materials are processed and disposed in landfill.
Basement and floors	No structural elements are recovered and reused.	~30% of the material is processed and reused onsite.	~70% of the material is transported offsite and disposed in landfills.
Roof	No structural elements are recovered and reused.	~30% of the material is processed and reused onsite.	~70% of the material is transported offsite and disposed in landfills.

Table 11. Description of the High Recovery Scenario (LR) assumptions

Building elements	Structural element reuse	Demolition	
		Material recycling	Landfill disposal
External walls	~50% of the external walls are conserved. The remaining walls are demolished and reconstructed.	~50% of the raw material from the demolished walls is processed and reused onsite.	The unused or recycled materials are processed and disposed in landfill.
Internal walls	~50% of the internal walls are conserved. The remaining walls are demolished and reconstructed.	~50% of the raw materials from the demolished walls is processed and reused onsite.	The unused or recycled materials are processed and disposed in landfill.
Basement and floors	~25% of basements and floors are conserved. The remaining walls are demolished and reconstructed.	~50% of the material is processed and reused onsite.	The unused or recycled materials are processed and disposed in landfill.
Roof	No structural elements are recovered and reused.	~50% of the material is processed and reused onsite.	~50% of the material is transported offsite and disposed in landfills.

All considered scenarios aims to fully refurbish the building complex in line with the energy efficiency regulation in place. To this purpose, insulation layers are installed in all scenarios where relevant, and different insulation materials are considered – namely, EPS, Rockwool and cork. Thermo-physical properties, embodied energy and carbon of the insulation materials, Table 12, are taken into account in the calculation (Hammond & Jones, 2008).

Table 12. Insulation materials data

Insulation material	Density (kg/m^3)	Thermal conductivity (W/mK)	Embodied energy (MJ/kg)	Embodied carbon (kg$_{CO2}$/kg)
Rockwool	92	0.047	16.80	0.501
EPS	16	0.036	88.60	2.641
Cork	180	0.041	4.00	0.119

The LR and HR scenarios are then compared with the baseline scenarios (BS) in order to evaluate the potential impact on embodied energy and carbon on different shares of recovered materials.

2.6.2.5 Results and Discussion

Based on the structure surveys outlined in the previous section (see Table 12) the assessment of the existing materials was carried out in order to determine the current embodied energy and carbon emissions of the pilot site. Table 13 reports the results of the analysis grouped based on the building structures still in place. Despite the poor conservation status of most of the building elements, a total embodied energy and carbons of about 938 MWh and 226 ton$_{CO2eq}$ was computed for the pilot site, with the largest share accounted for basements and floors, followed by external walls. On the other hand, the embodied energy and carbons of the roof elements showed the lowest share, mainly due to the fact that part of the roof structure has been destroyed and/or demolished for safety reason.

Table 13. Available materials, embodied energy and carbon for different structural element

Structures	Volume (m^3)	Mass (ton)	Embodied energy (MWh)	Embodied carbon (ton$_{CO2eq}$)
External walls	295.0	590	159.3	38.2
Internal walls	222.6	443	104.7	25.1
Basements and floors	1234.4	2469	582.9	139.9
Roof	-	109	91.8	23.4

The next stage of the analysis involved the definition of the baseline scenario (BS) which consists of the demolition of the entire building complex and its reconstruction without any recycling or reuse of existing material, which is then processed and disposed in landfills. First, the impact of the dismantling/demolition and disposal process in terms of embodied energy and carbon has been estimated, based on the procedure suggested by Wang et al. (2018). Considering the processes of demolition, collection and sorting, residual transports and landfill disposal, a total of 513 MWh of primary energy consumption and 54.9 ton$_{CO2eq}$ of carbon emissions are expected (Table 14). This energy and carbon "costs" are then taken into account in the definition of the baseline scenario and added to the overall energy/carbon assessment for the subsequent analysis.

Table 14. Primary energy and carbon emissions related to a full demolition and disposal of the building structures of the case study

Phases	Embodied energy (MWh)	Embodied carbon (ton$_{CO2eq}$)
Demolition	170	18.2
Collection and sorting	292	31.3
Transport and disposal	51	5.5
Total	513	54.9

The next step involved the definition of the structures of external and internal walls, basements, floors and roof for the new building complex. To maintain consistency, it was assumed to keep the same layout of the complex, but new materials were considered for the structural elements (i.e., vertical walls, basements and floors), Moreover, thermal insulation layers with a thickness of 15 cm were added where relevant to meet the current energy efficiency regulation in place. The different insulation materials outlined in Table 9 were considered separately to investigate their influence on energy and carbon emissions. The new structure layouts are:

- Vertical walls: structure made by a layer of 38 cm made by bricks and 15 cm thermal insulation added at the external side (for external walls only). A 2-cm finishing later made by plaster was also considered.
- Floors and basements: concrete slab with structural I-beam and steel joints with a total thickness of 25 cm and finishing layers with plaster and/or tiles based on the specific application. Thermal insulation was also added in the basement where relevant.
- Finally, the roof was assumed to be replaced entirely while keeping the same structural layout and materials, as shown in Figure 29.

Table 15 reports the result of the new embodied energy and carbon obtained for the baseline scenario for each different building element and insulation material used. It can be observed that the horizontal floors accounts for the largest share of embodied energy and carbon, followed by the external walls, basement and internal walls, while the roof is the building element with the lowest impact on energy consumption and carbon emissions.

Table 15. Embodied energy and carbon of the new building in the baseline scenario

Elements	Total surface (m^2)	Embodied energy (MWh)	Embodied carbon (ton_{CO2eq})
Internal walls	1108	449	113
External walls	1475	Rockwool 692 EPS 684 Cork 642	Rockwool 161 EPS 160 Cork 155
Basement	1543	Rockwool 639 EPS 631 Cork 586	Rockwool 153 EPS 152 Cork 148
Floors	3086	1157	290
Ceiling	1475	Rockwool 678 EPS 670 Cork 624	Rockwool 156 EPS 155 Cork 150
Roof	-	91	24

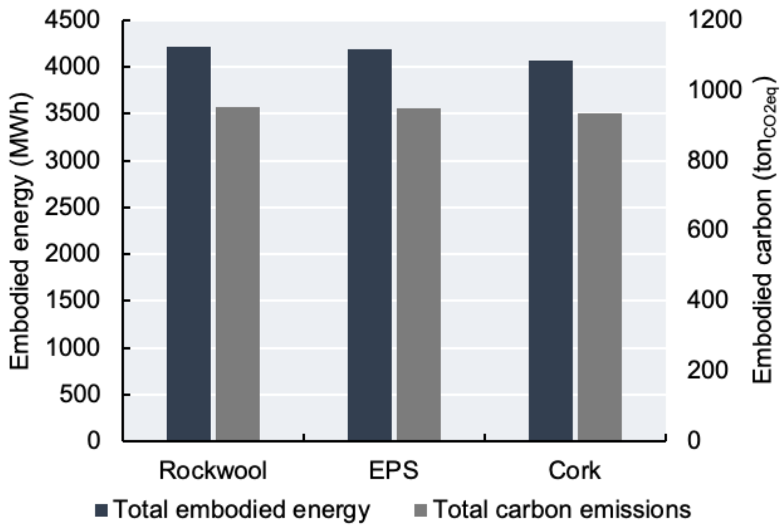

Figure 30. Total embodied energy and carbon of the baseline scenario for different insulation materials (Rockwool, EPS, Cork)

Regarding the different insulation material, the results showed that cork allows a reduction of the embodied energy and carbon compared to EPS and rockwool in all structural element where insulation was required. However, these differences can be considered limited related to the overall new embodied energy and carbon, mainly due to low amount of insulation material required compared to the main building structures (i.e., bricks) and to the similar values of the thermophysical properties and embodied energy/carbon of the different materials (see Table 12). This is confirmed by observing Figure 30where the total embodied energy and carbon resulting from the demolition, treatment and disposal of the old building and its reconstruction by using new material one can be estimated is illustrated.

Figure 30 and 31 shows the results of the analysis on the embodied energy and carbon associated with the existing materials of the case study in case of low and high material recovery rates respectively, based on the current structure conditions. For each scenario, the figures illustrate the share of the structural elements already present onsite which are conserved (i.e., reused), the share of the materials recycled after demolishing the remaining structures and the share of the material disposed in landfills. While the recycling process is assumed to be carried out onsite, the share of disposed material also includes the embodied energy and carbon associated with material processing, transportation and final disposal. As expected, the LR scenario shows low percentages of materials reused and recycled, with percentages below 25% and 35% of the embodied energy and carbon recovered. However, the HR scenario demonstrates that high shares of embodied energy and carbon can be recovered, depending on the element characteristics and conservation status, with percentages up to 65% and 75% respectively.

Both Figure 30 and Figure 31 illustrate that, in this specific case study, most of material which can be recovered and/or recycled are related to vertical walls (external and internal), while a limited recovery rate can be obtained by basements/floors and roof structures, due to their poor conservation status. This is particularly true for roof elements, since most of the structures collapsed or are in a highly degraded status, which makes their reusability unfeasible for safety reason.

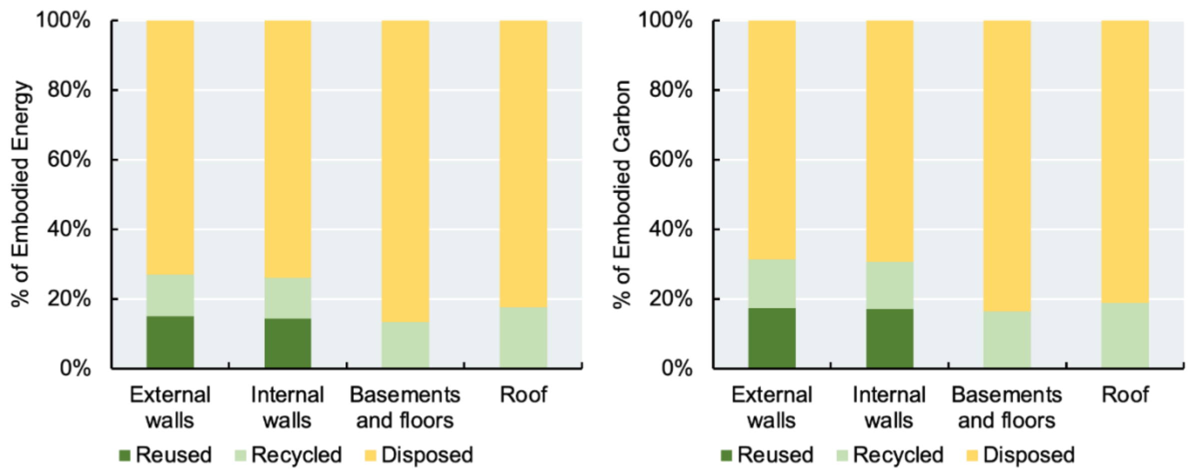

Figure 31. Share of embodied energy and carbon related to the materials reused (conserved structural elements), recycled and disposed in landfill for the Low Recovery (LR) scenario

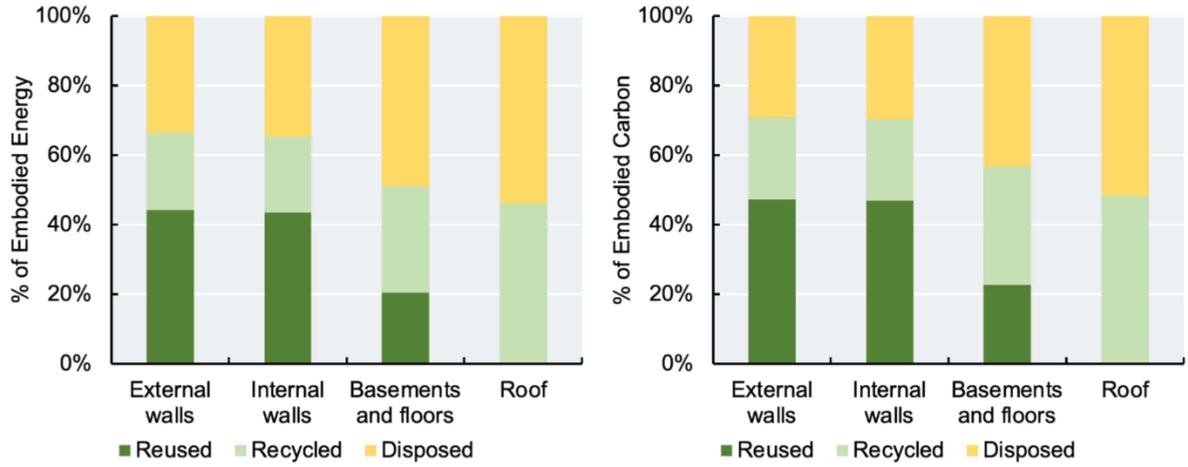

Figure 32. Share of embodied energy and carbon related to the materials reused (conserved structural elements), recycled and disposed in landfill for the High Recovery (HR) scenario.

Figure 33 shows the recovered embodied energy and carbon obtained in the two analysed scenarios for the three different insulation materials adopted. Firstly, it can be noted that the recovery indexes values in the range 7.5%-8.9% and 17%-17.8% for the LR and HR scenarios respectively were obtained for the specific case study under analysis. For both scenarios, the use of cork as insulation material allows to reduce the total embodied energy and carbon, and consequently increasing the recovery indexes, resulting from the refurbishment of the building complex under analysis, thanks to its lower specific embodied content (Table 12). On the other hand, rockwool shows the lowest recovery index for both scenarios. However, low variations in terms of energy carbon recovery indexes can be spotted as function of the insulation material used. As explained previously, this is related to the relative limited impact of the insulation quantities compared to the overall material requirements for the entire building refurbishment.

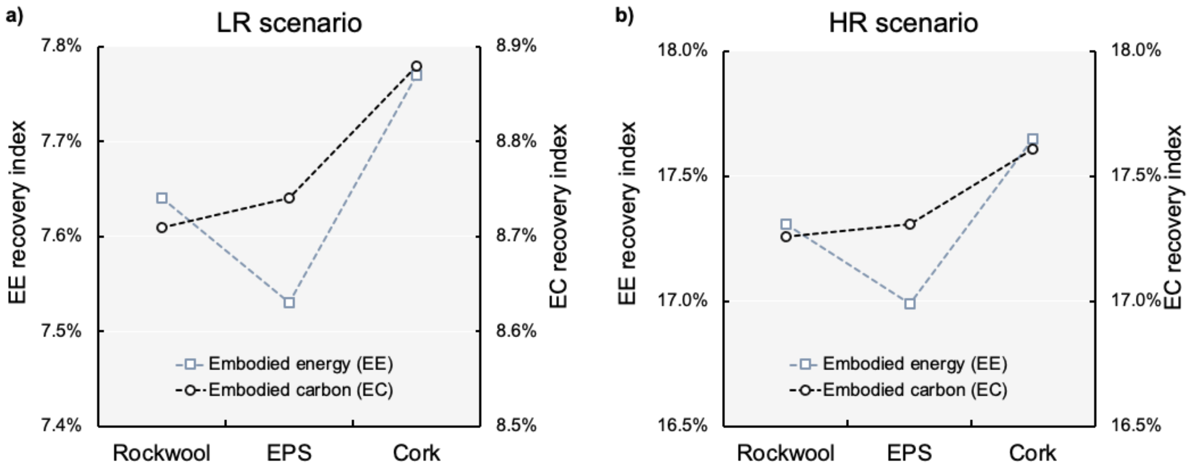

Figure 33. Recovered embodied energy and carbon indexes for different insulation materials (rockwool, EPS, cork) in case of (a) low-recovery (LR) and (b) high-recovery (HR) scenarios

2.6.2.6 Conclusion and Recommendations

Recycling in the building construction sector specifically involves the collection, processing, and reuse of materials from building construction and demolition sites and it represents a fundamental phase which can contribute significantly to the reduction of new material consumptions and related energy and carbon costs. Generally, the potential for reusing a large amount of abandoned material in the building process requires a comprehensive life-cycle approach that encompasses everything from the selection of the construction site to the selection of building materials and design elements, from the construction to its operating life and decommissioning.

In this context, the present case study analysed the potential renovation of a former urban industrial building block, named "Ex Concerie Costa", inserted in the urban context of the city close to the city centre of Sassari, Sardinia (Italy). The main complex, which consists of a 3-floor building with about 1543 m^2 per floor, was built starting from 1859 and expanded over several decades and eventually abandoned. Currently, the building complex is in an advanced state of decay, although its location close to the city and to the main roads and railway makes it an ideal location for a variety of new uses, both commercial and industrial. The analysis was carried out in terms of embodied energy and embodied carbon related to the existing materials on-site and the assessment of their potential recovery for the building complex refurbishment. The refurbishment of the entire complex was assumed to be carried out by maintaining the same building complex layout and characteristics.

A preliminary analysis was performed on the building elements, which showed that a relative large amount of available material, and therefore embodied energy and carbon, is available onsite (Table 5). Then, two different scenarios were defined based on the estimated amount of structural element reuse and material recycling potential (i.e., low-recovery and high recovery scenarios). The embodied energy and carbon estimation - related to demolition, material transportation and landfill disposal costs – were also considered. The results showed that a large potential of material recovery (and consequently embodied energy and carbon contents) is present, ranging from 25%-35% for the low-recovery scenario to 65%-75% for the high-recovery scenario, with the highest share for vertical external and internal walls. Generally, the dismantling scenario is the most preferable, but it depends fon the state of conservation of the pre-existing buildings materials.

Furthermore, the analysis was extended to investigate the influence of using different insulation materials (i.e., rockwool, EPS and cork) on the embodied energy and carbon recovery indexes for the specific building complex. The results showed that cork allows to reduce the total embodied energy and carbon, and consequently increasing the recovery indexes. Notwithstanding, low variations in terms of energy carbon recovery indexes can be spotted as function of the insulation material used, due to the relative limited impact of the insulation quantities compared to the overall material requirements for the entire building refurbishment.

2.6.2.7 References

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2.7 Technical University of Denmark – Decarbonisation of the heating sector: A multidimensional approach mixing centralised and decentralised heating systems in Lyngby Municipality, Denmark

2.7.1 Executive Summary

This case study explores technical, economic, and social aspects for the municipality of Lyngby to achieve 98% district heating access by 2030, figure 34. The case study concludes that transitioning to district heating requires better stakeholder communication, integration with neighbouring systems, and attractive business models. Collaboration and strong political support are necessary for successful implementation.

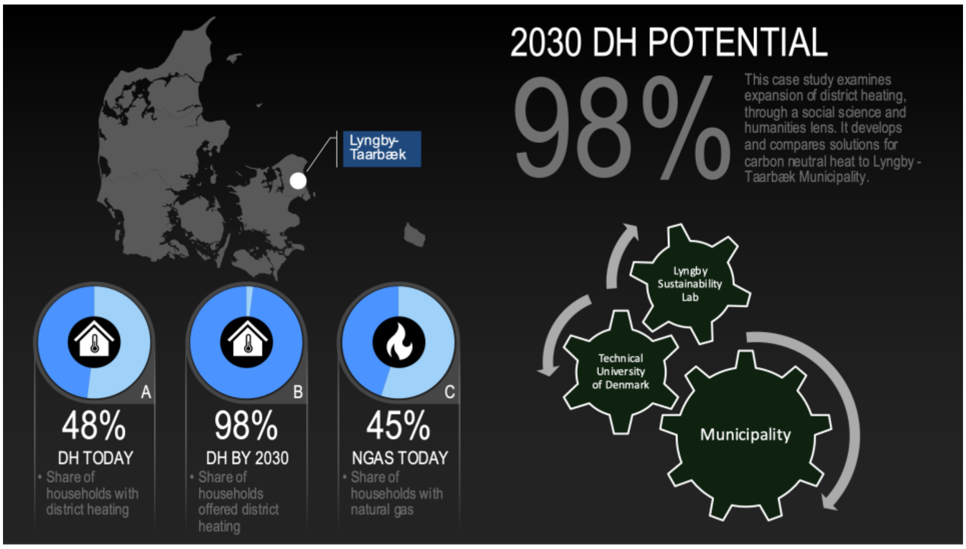

Figure 34 - Decarbonisation of the heating sector: A multidimensional approach mixing centralised and decentralised heating systems in Lyngby Municipality, Denmark – Graphical Abstract

2.7.2 Case Study

2.7.2.1 Abstract

Denmark has set out its objective to achieve a 70% reduction in its greenhouse gas emissions by 2030 compared to the 1990 level with the Climate Change Act of June 2020. This is the primary milestone before the country becomes a net-zero emitter in 2050. In the heating sector, the target is to reach full decarbonisation by 2035.

Measures include expanding district heating networks. However, there are also areas in Denmark where houses are too scattered for district heating, and individual households will have to consider other options for decarbonised heat. In this context, Danish municipalities such as Lyngby need to obtain a concrete assessment of the situation.

The district heating in Lyngby still relies on gas-fired facilities and many of the community's residents live scattered and far from the current network. Yet, the city aims to have 98% of district heating access by the end of 2030. That is a dramatic increase from 65% today. Lyngby is therefore looking for both centralised and decentralised solutions which can help them achieve the outcome at an affordable cost.

The problems to be addressed are technical, economical, and social, both at individual and district heating levels.

The project focuses on different technical, social and economic aspects of achieving the 98% coverage but also on sustainable solutions for the remaining 2%, which will not be connected to the main grid.

2.7.2.2 Introduction

Context and motivation: Denmark has set out to achieve a 70% reduction in its greenhouse gas emissions by 2030 compared to the 1990 level with the Climate Change Act of June 2020 (Ministry of climate, 2020). This is the primary milestone before the country becomes a net-zero emitter in 2050. By 2021, Denmark had managed to reduce its emissions by 38%. This represents a significant achievement, but it also stresses the difficulty ahead. Today, 96 of the 98 Danish municipalities have developed strategic energy planning to reduce their carbon emissions. In that respect, the government’s recently published "Danmark kan mere II" (Denmark can more II) (Danish Government, 2022) stresses the urgency to accelerate gas independency in the current geopolitical context. Measures include expanding in priority the district heating networks and allocating more than DKK 3 billion to subsidise the replacement of oil and gas boilers. However, there are also areas in Denmark where houses are too scattered for deploying district heating, and individual households will have to consider other options for decarbonised heat.

In 2022, the Danish government explicitly established the responsibility of the municipalities to draw up plans for green heat in the currently gas-supplied areas and to guide households' energy choices towards heat sources compliant with national policy. Therefore, municipalities need to obtain a concrete assessment of the situation.

The municipality of Lyngby-Taarbæk (LTM) is an excellent example of the current constraints on the supply of carbon-neutral heat in Denmark. First, most of its district heating supply still relies on gas-fired facilities. Second, many of the community's residents live in homes supplied by individual natural gas boilers. LTM is therefore looking for both centralised and decentralised solutions which can help them achieve the outcome at an affordable cost for the inhabitants while ensuring social equity.

The problems to be addressed are technical, economical, and social, both at individual and district heating levels. Which sources of heat can be found? What are the costs going to be? How many will accept the offer to connect to district heating? The 98% potential coverage may not necessarily mean that 98% in fact will use the heat from the district heating network.

Research gaps: Most residential energy consumption is today attributed to heat consumption – see Figure 35. This makes the decarbonisation of heat production critical to reaching our emission reduction targets.

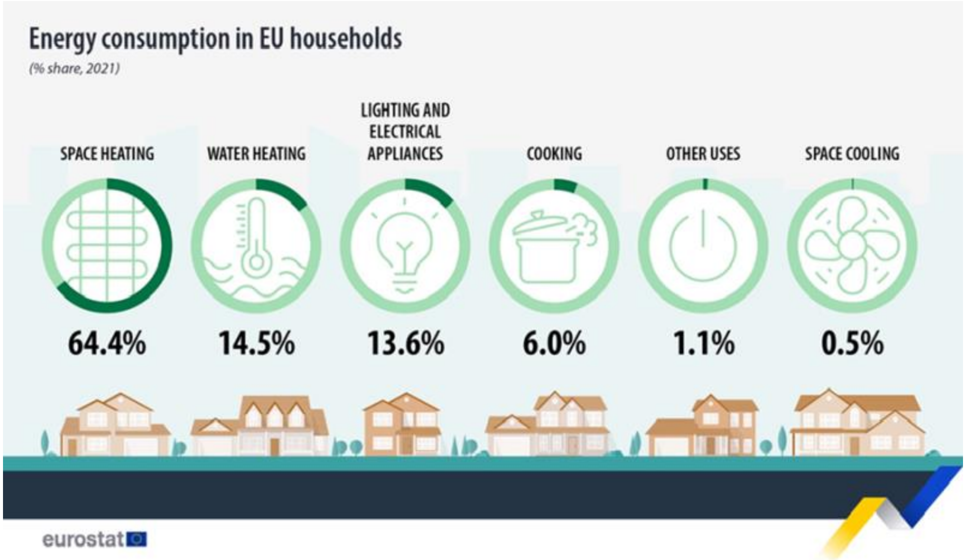

Figure 35- Energy consumption in EU households (Eurostat, 2023).

The issue of access to heat is particularly intertwined with the development of cities (IRENA 2020, Arabzadeh et al. 2020). City and energy planners have a central role in steering the low-carbon transition at the local level with the decarbonisation policies, (Bloess et al. 2018, Heendeniya et al. 2020) in concert with energy companies and city stakeholders.

District heating is a clear path for decarbonising the heat sector in Denmark and achieving EU transition targets (Hast et al. 2018). District heating presents multiple technical solutions to produce heat. Additionally, the centralised nature of district heating embraces economies of scale, leading to lower heating costs for end-users. However, legal or geographical restrictions often stand in the way of building new DH, requiring users to adopt individual decentralised heating sources such as heat pumps. DH is energy capital-heavy infrastructure requiring long investment horizons. Unlike e.g. electricity grids, DH as a technology is subject to competition with other types of heat supply. Households have a wide range of individual heating types and fuels to select between. This introduces risk to DH systems, as investment certainty is key for the deployment. For the end-user, investment in a new heat source is a large expense that households may be unwilling or unable to make. Households are, however, often unaware of their heat sources' long-term economic and environmental impacts, which imposes further challenges on city planners and policymakers to guide and support adoption choices, beneficial to individuals and society.

Objective: The objective of this case study is to examine the expansion of district heating in Lyngby municipality, through a social science and humanities lens, and to develop and compare appropriate solutions, to guarantee carbon neutral heat to all in the municipality.

Expected benefits. Lyngby hopes that the studies will help identify strategies for achieving the municipality's goal of 98% district heating coverage by 2030. The experiences from this development can be deployed in other cities and communities.

2.7.2.3 Description of Case Study

The goal of the Heating Plan 2022-2030 (Lyngby-Taarbaek Municipality, 2022) is that 98% of households in Lyngby-Taarbæk have been offered district heating by the end of 2030. The plan, therefore, involves a crucial shift from primarily gas to almost exclusively district heating - in no more than eight years. An ambitious project that requires cooperation and will shape the cityscape for years to come.

Today, 59% of the buildings in Lyngby-Taarbæk municipality are supplied by natural gas. However, since 2013, LTM has started an extensive district heating expansion plan to phase out the gas supply for heating in the city. The plan targets priority areas where the building stock is dense, and heat consumption is high. Recently, a sensitivity study of the conversion to DH included the recent price hikes in raw materials and labour, showing societal-, business- and end-user economic viability in district heating expansion to 70% of the municipality's heating needs by 2030. Regardless of the share of DH, the remaining share of the buildings not connected to district heating will need to switch to alternatives – such as heat pumps or local heat networks. Finally, there still exists pockets of consumption showing limited connectivity potential to district heating and equipped with recent fossil fuel-based boilers. These may have incentives to extend their operation beyond 2030.

The heat plan's (Lyngby-Taarbaek Municipality, 2022) map, figure 36, shows districts (blue) that are scheduled for conversion to DH. Areas outside DH supply (yellow and orange), are not socio-economically viable for district heating. Instead, these areas will be supplied by alternative heat sources.

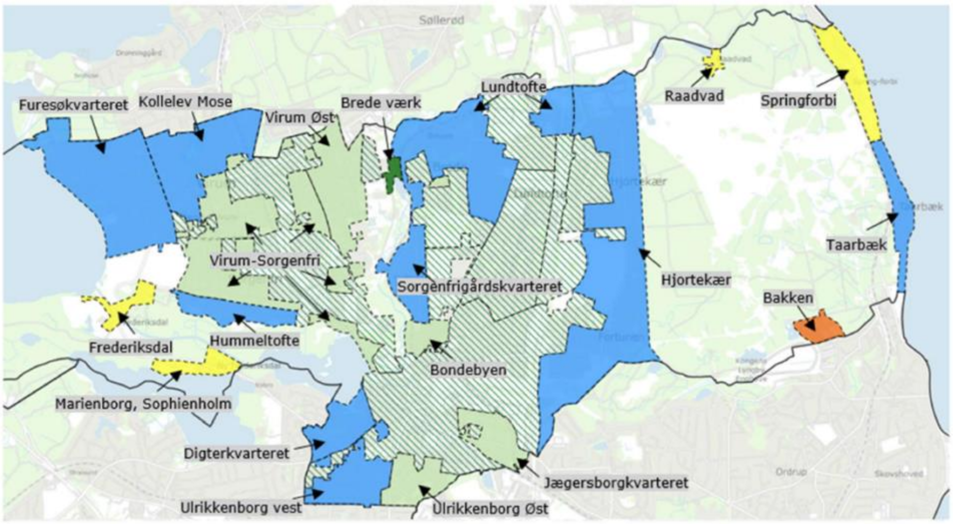

Figure 36 - Heat Plan Map

The case study focuses on the deployment of the district heating network in the medium term.

Lyngby-Taarbæk Municipality is atypical in the sense that 27% of residents have MSc-level or above. This is the highest in Denmark. The municipality has noted that in terms of communicating complex challenges and projects, this is an advantage, as people tends to grasp complex planning issues easily. This also requires well-prepared municipal authorities since residents are prone to challenge initiatives with in-depth questions and insights. Occasionally, residents even develop alternative solutions in self-established groups.

2.7.2.4 Case Study Solution

Such a task (heat planning for a new area) is usually conducted by a consultancy in a process combining techno-economic analysis of the heat supply (e.g. modelling in tools such as the energyPRO software), GIS-analysis (to determine demands + network length) and some degree of stakeholder engagement (e.g. information meetings). The current case deviates somewhat from the typical district heating development, as the scope is solely focussed on the stakeholder aspects. The process and methods LTM are explained in the following.

We leave the "classic parts" of heat planning and development (demand mapping and modelling) to the consultants. Instead, we focus on social acceptance and energy poverty. We analyse these topics through engagement of stakeholders as explained in the following.

Data collection is conducted as follows. Literature is reviewed for similar cases (e.g. heating area developments or studies of the same geography as the current case). Furthermore, grey literature is explored, as this field may contain aspects not yet found in scientific literature.

Building on the literature review, a workshop is conducted. The workshop includes the municipal energy planner and the city's Sustainability Lab. The municipality brings experience on heat planning (e.g. the types of consumption, the inhabitants, the available capital). The Sustainability Lab brings insights on how local solution-providers can enable the transition, thereby mapping the project's local commercial potentials.

The outcome of the review and workshop is a mapping of what local stakeholders need and what they can offer regarding the new heat supply. It will be explored whether the characteristics can be classified according to social science and humanities methods (energy acceptance/justice/poverty), and subsequently how to address these in developing the solution.

The solution will target development of end-user engagement models (e.g. communication, co-ownership or representation), business model (e.g. profit/non-profit) and finance solution (e.g. arrangements with local banks).

2.7.2.5 Results and Discussion

The objective of this case study is to examine the expansion of district heating in Lyngby municipality, through a social science and humanities lens, to develop and compare appropriate solutions, and to guarantee carbon neutral heat to all in the municipality. The following results are based on dialogue and a workshop with LTM. Solutions are based on the workshop, and supplemented with literature on the subject.

Needs and solutions

Stronger communication

- Need: The municipality sees a major potential in improved stakeholder engagement through communication on energy planning and transition. Particularly, in helping the utilities improve communication to enable better understanding of strategies and plans among residents.
- Solution: Typically, there is limited engagement from DH end-users when they have been connected and the supply is stable and affordable (Janssen et al., 2023). But in the period of deployment, there is an increased need for visibility, local engagement and establishment of trust in DH (Verstraten et al., 2021). The municipality has had successful stakeholder meetings, both physically and online, informing about their energy transition initiatives. These meetings have been over-subscribed and with large public interest. The municipality ascribes part of the success to the professional production of the online event. Here, a studio was rented, and a professional production crew and equipment elevated the event from regular "talking head and slides" to a more television-like experience. Continuing the path of physical and virtual meetings is sensible, as this has already proven successful. To address the need for more engagement between the utilities, LTM and end-users, LTM can facilitate brief, but frequent updates from the utility. Furthermore, everyday online presence is important (especially social

media) (Verstraten et al., 2021). As this is a significant task, and since the utility is typically fully engaged with the transition process, it may be beneficial to delegate it to service providers

Neighbouring district heating

- Need: The municipality sees benefit in collaboration with neighbouring municipalities, e.g. Rudersdal. Heat supply should not be constrained by municipal borders, meaning that Lyngby's DH company can supply nearby municipalities' areas that are hard to reach for neighbouring DH utilities. Vice versa, Lyngby's hard-to-reach areas for DH, may be close to neighbouring DH networks. These potentials need mapping.
- Solution: LTM can facilitate contact with neighbouring municipalities and their utilities (Verstraten et al., 2021). In the present case, there is already a well-established collaboration on energy- and heat planning in the Danish capital region, so dialogue can happen bilaterally or through the network. LTM can also contribute to driving the process and brokering an agreement, as utilities may be averse to expand into new areas, particularly those with lower heat density.

Diversified district heating

- Need: More excess heat from more sources. This is necessary to transition from the current fossil-based shares of DH supply.
- Solution: Two steps are necessary. Firstly, a mapping of potential sources. Second, engaging and contracting with the suppliers. LTM and the utility has initiated the mapping with the recent heat plan. Sources in neighbouring municipalities should also be surveyed, to ensure use of low-hanging fruits. Supply of excess heat is typically challenged by three issues (Sieverts et al., 2022): 1) Limited awareness among suppliers, as this is a secondary product to their primary product. 2) Perceived administrative complexity in establishing agreements. 3) Low profit motive for the supplier, as the DH utility must use the least cost heat source. This limits the payable amount to the supplier. Regarding 1, LTM and Lyngby's Sustainability Lab can map potential suppliers and organise events that raise awareness and opportunities. The utility and LTM, in collaboration with other utilities and municipalities, may benefit from a streamlined approach. Here, the contracts can be standardised to fast-track the agreements.

Certainty in heat supply

- Need: By 2022, the municipality informed all residents on the prospects of DH supply. As this deployment is a major infrastructure project, it cannot happen all at once. Instead, the deployment is spread over the period until 2028. According to the municipality, residents who can get DH within a brief period are inclined to do so. Those with DH scheduled multiple years into the future may be more inclined to find alternative solutions. This can, in turn, undermine the business case for DH deployment in these areas, leading to a societally sub-optimal solution. Certainty is a double challenge, as the DH utility needs a certain level of subscribers to have positive business case. For end-users, certainty also concerns the energy (typically gas) prices until they can get DH.
- Solution: The utility offers a non-profit service agreement to gas customers, enabling maintenance and replacement of the gas boiler until the DH arrives. This addresses

technological risk for the end-user. Price risk remains, as the customer is still responsible for the gas purchase. To address the latter, the utilities can explore the legal options for providing *heat as a service* i.e. providing heat regardless of technology. This includes providing long-term gas contracts for customers, in exchange for a legally binding obligation to connect to DH. or to provide and service a supplementary air-air heat pump that can reduce gas consumption and thereby reduce gas price risk. Reducing risk on the DH company's side includes the provision of a "cold plug", offer end-users with e.g. new heat pump or gas boiler a distribution pipe. At the end of life (typically 15 years) of the current technology, the end-user can be connected to DH.

2.7.2.6 Conclusion and Recommendations

Lyngby-Taarbæk Municipality, its inhabitants and district heating supply utility stand in front of a large task. They must collectively find solutions to transition the largely gas-based heating system to district heating. In this study, we have mapped the needs of the stakeholders, and we provide corresponding solutions based in the stakeholder dialogue, existing practice and literature.

Needs include stronger communication among stakeholders, better integration with neighbouring district heating systems, diversified and decarbonised heat supply and long-term certainty in heat supply among end-users and district heating utility. Clear and persistent communication is an overlapping solution for all these, with the municipality as a well-placed liaison. Further, attractive business models need to be developed for the supply of district heating from neighbouring utilities, provision of excess, carbon free heat to the district heating system, for the end-users to connect to district heating and for the district heating utility to responsibly deploy district heating according to the municipal plan.

These are substantial tasks that requires broad collaboration and coordination from the municipality. Large infrastructure projects like this takes time, so it is necessary to simultaneously initiate local action – i.e. the deployment and communication efforts within the municipality – and the municipality-external dialogues on heat supply and development of business models. The latter is relevant for municipalities and utilities across the country, so a collaborative effort is relevant. But it should not become an excuse for inaction. Conversely, the planning department in Lyngby-Taarbæk Municipality must receive strong political and budgetary support, for the politically enacted plans to become pipes in the ground, and not a pipe dream.

2.7.2.7 References

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2.8 University of Coimbra – Smart manufacturing in urban areas with carbon sequestration systems

2.8.1 Executive Summary

This case study underscores the promise of partnerships between universities and industries to propel the shift towards cleaner energy, reduced carbon emissions, and intelligent manufacturing (Figure 37). These collaborative efforts extend beyond just financial feasibility, bringing a range of advantages such as enhanced energy reliability, competitiveness, and diminished emissions.

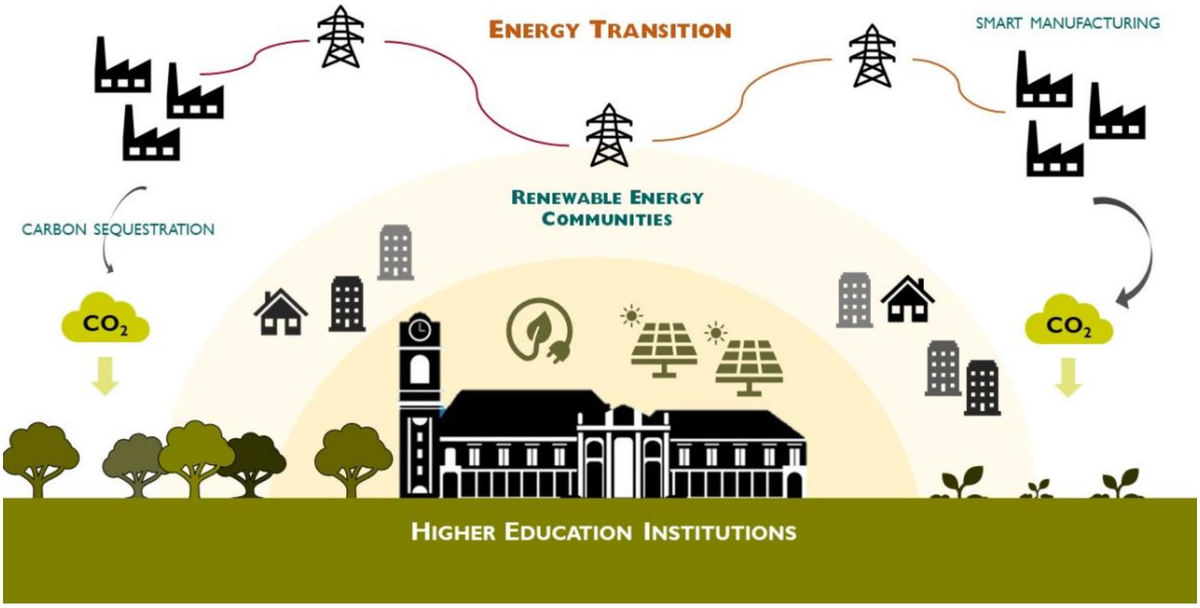

Figure 37. Smart manufacturing in urban areas with carbon sequestration systems - Graphical Abstract

2.8.2 Case Study

2.8.2.1 Abstract

Renewable energy communities (REC) and smart manufacturing are gaining attention for their interconnected ability and potential to contribute to a more sustainable future by lowering the environmental impact of production and consumption while boosting efficiency and reducing costs. Their implementation can be mutually beneficial as surplus energy produced by the REC can be harnessed and used by smart manufacturing facilities, thereby reducing their reliance on traditional fossil fuels, and cutting down carbon emissions. Additional benefits include reduced energy expenses, improved reliability, and decreased vulnerability to energy price fluctuations. In summary, the connection between the two strategies can help improving overall efficiency and sustainability, two fundamental premises of the energy transition process underway.

This case study examines the development of a REC initiative at the University of Coimbra, the oldest higher education institution in Portugal. The analysis includes a characterization of the project and the assessment of its energy, economic and environmental benefits. Furthermore, an empirical evaluation of load diagrams and renewable energy production is performed to illustrate the energy exchange potential of this REC. In the second stage, the study examines how the technologies and tools applied in this case study can be used in a broader interconnected context of smart manufacturing. To this end, it explores the potential impacts and benefits of extending the REC concept to industrial facilities, to promote smart manufacturing through increased performance and sustainability. Carbon emissions and energy costs are focal subjects of this examination. The study concludes with a qualitative theoretical analysis of the implementation of carbon sequestration systems, evaluating their feasibility, potential benefits, and drawbacks.

The results reveal that the REC has the potential to cover approximately 38.8 % of the University's annual electricity consumption, leading to significant reductions in both energy costs and CO_2 emissions and, thereby, advancing the institution's financial and environmental sustainability goals, while progressing towards its carbon neutrality target. Furthermore, these results highlight the project's broader impact, stretching beyond the University's boundaries. Around 40 % of the REC's generated energy can be exploited by nearby industrial consumers, enabling them to reduce energy expenses and CO_2 emissions and enhance energy resilience. It also allows them to foster their financial efficiency and environmental responsibility, while promoting smart manufacturing and decarbonization of industries.

This study highlights the potential of collaboration between higher education institutions and industries in advancing energy transition, decarbonization and smart manufacturing. Beyond financial viability, these joint initiatives offer multifaceted benefits, including energy resilience, competitiveness, and reduced emissions. These outcomes underscore the importance of promoting and replicating this model across similar institutions and companies, thereby accelerating the transition towards a sustainable and low-carbon future.

2.8.2.2 Introduction

The sustainable development of modern societies entails addressing several critical concerns, such as minimizing greenhouse gas emissions, and reducing the environmental, social, and economic costs associated with energy production (Giordano et al., 2019). As part of the European Green Deal (European Commission, 2020), the European Union (EU) set the goal of achieving climate neutrality by 2050, aligning with its commitment to global climate action under the Paris Agreement (European Commission, 2016). Considering that 75% of the EU's greenhouse gas emissions are from energy production and use, the energy transition from fossil fuels to renewable energy sources (RES) is a vital step to decarbonize the EU's energy systems (European Commission, 2022a). In order to increase the penetration of RES in the energy matrix, the Clean Energy for All Europeans package emphasizes the significance of local and decentralized electricity production to accelerate the energy transition by actively engaging citizens in the process through self-consumption or renewable energy communities (REC) (European Commission, 2019).

REC are legal entities that can be composed of citizens, public institutions, cooperatives, municipalities, small and medium enterprises, and other organizations and established in different business models. Currently, the most predominant business models involve generation and supply, collective investments in installations of energy production, and collective self-consumption (European Commission, 2022b). These models can be combined and included variations such as community-owned grids and district heating systems. REC empower their participants to produce, manage, and consume their own energy, providing access to clean and cost-effective energy solutions. This not only contributes significantly to the economy's growth but also helps reduce carbon emissions and fosters public acceptance of renewable technologies (Kubli & Puranik, 2023).

Achieving these benefits is possible by adjusting or reducing energy demand, especially during periods of high energy prices, and by generating income for the community through energy trade, taxes, or the creation of new job opportunities (Brummer, 2018). Furthermore, REC effectively address the mismatch between energy demand and supply, raise awareness about energy consumption issues, and promote an energy-saving behaviour. They also play a crucial role in reaching renewable energy generation targets (Brummer, 2018; Dai et al., 2015; Koch & Girard, 2011).

Although REC offer numerous benefits to society, their implementation faces several barriers. Some of these challenges include complex and burdensome bureaucratic procedures for registration, permitting, grid access, and licensing. Additionally, the high costs of implementation, lack of institutional and political support, general scepticism towards renewable energy, and insufficient financial resources and expertise are obstacles that hinder the widespread adoption of REC (Brummer, 2018).

The implementation of REC in historic buildings, such as the University of Coimbra, presents specific challenges that need to be considered. These buildings hold a crucial place in the architectural heritage of European countries, constituting nearly 40% of the building stock (Cabeza et al., 2018). However, restoring and retrofitting these structures present intricate challenges due to their unique cultural significance and characteristics (Cabeza et al., 2018). Some of these challenges include potential alterations to the building's identity and historical value, the need to obtain permits and approvals for interventions, and technical limitations associated with older architecture and limited space for RES installations (Marrone et al., 2023).

Considering these limitations, integrating heritage buildings with REC can be highly beneficial. This combination can offer environmental sustainability by reducing the carbon footprint of historic buildings. Additionally, it has the potential to create opportunities for educational and community engagement, involving students, researchers, faculty, and nearby residents in the design, development, and exploitation processes of such integration. Therefore, historic buildings can embrace modern energy solutions while preserving their cultural significance and fostering a sense of shared responsibility for sustainable development.

While REC contribute significantly to decreasing carbon emissions, it is crucial to find complementary measures for carbon capture, such as nature-based solutions, to help further reduce carbon emissions from the University's operations. As reported by the IPCC, lowering atmospheric CO_2 levels is imperative to limit the global average temperature increase to well below 2°C above pre-industrial levels (Wennersten et al., 2015). To achieve this objective, carbon dioxide removal (CDR) techniques need to complement the decarbonization of energy-related activities, accomplished by lowering fossil fuel consumption and increasing the penetration of renewable sources (Creutzig et al., 2019; Erbach & Victoria, 2021).

CDR solutions encompass a diverse array of approaches, varying from nature-based methods, which are considered more feasible and cost-effective in the short term, to technological alternatives that may gain relevance in the latter part of the current century (Erbach & Victoria, 2021). Some examples of technological alternatives include Ocean Alkalinization, Enhanced Weathering, Bioenergy with Carbon Capture and Storage (BECCS), and Direct Air with Carbon Capture and Storage (DACCS) (Erbach & Victoria, 2021; University, 2020). Conversely, nature-based methods comprise Forestation, Soil Carbon Sequestration, Biochar, Wetland Restoration, and Agroforestry (Erbach & Victoria, 2021; University, 2020).

The nature-based solution Agroforestry is a highly cost-effective alternative for carbon capture, holding an estimated annual carbon removal potential of 0.1 – 5.7 $GtCO_2$ by 2050, while providing significant returns on investment through the trade of its crops (Erbach & Victoria, 2021). Like soil carbon sequestration, agroforestry can even yield negative costs per ton of CO_2 removed, given the economic advantages resulting from enhanced crop productivity (Kim et al., 2016; Zomer et al., 2016).

The expenses associated with establishing and maintaining agroforestry systems can vary depending on factors such as site preparation, tree species selection, and management practices. However, once established, agroforestry systems tend to be relatively self-sustaining, requiring minimal inputs and management in comparison to other carbon removal technologies. Furthermore, agroforestry provides additional income streams by diversifying agricultural production. This highlights the potential of adopting sustainable and profitable practices that contribute not only to climate change mitigation but also to overall economic prosperity.

With the foregoing in mind, the primary objective of this case study is to evaluate the energy, economic and environmental benefits stemming from the development of a REC at the University of Coimbra. Additionally, this study will identify the potential as well as the barriers that can hinder the progress of this project. Subsequently, we will explore how the technologies and tools applied in this case study can be extrapolated and used in a broader interconnected context of smart manufacturing. Finally, we will simulate the implementation of a carbon sequestration nature-based system to assess its feasibility, potential benefits, and drawbacks.

This case study is structured as follows: the subsequent section provides a comprehensive description of the University of Coimbra's case study. Following that, the proposed solution for this case study is delineated. Afterward, some representative results are showcased and subjected to discussion. Finally, conclusions are drawn, and recommendations are suggested.

2.8.2.3 Description of Case Study

The University of Coimbra, located in the city of Coimbra in central Portugal, stands as one of Europe's oldest universities and holds the prestigious UNESCO World Heritage Site designation. Founded in 1290, the university boasts a rich legacy of academic excellence and cultural significance. Its architectural wonders, spanning the Renaissance, Baroque, and Gothic periods, reflect the history and culture of the city and of the country. While the university's buildings are dispersed throughout the urban centre, they primarily cluster in three main areas or campuses, as depicted in Figure 38. Additional buildings owned by the University of Coimbra, like the Palácio de São Marcos, exist at a greater distance and thus fall beyond the scope of this case study, given they surpass the distance limits stipulated by regulations.

Figure 38. Location of the University Campuses in Coimbra city (Adapted from University of Coimbra)

The University's main campus, Polo I, is located in the upper part of the city centre (Figure 39). This campus includes several historic buildings such as the Joanina Library and the Royal Palace, museums, departments, the Faculties of Law, Arts and Humanities, and the Botanical Garden.

Figure 39. Main campus of the University of Coimbra – Polo I (Source: University of Coimbra)

Polo II is located on the right bank of the Mondego River and houses the Faculty of Science and Technology, which includes all the Engineering departments (Figure 40). Its construction began in 1992, and most departments' inauguration occurred in 2001. Hence, the construction typology of the buildings is very different from Polo I. Since it was built in a peripheral and uninhabited area of the city, it has a larger area available for expansion and implementation of renewable generation systems.

Figure 40. Mechanical Engineering Department at the second campus of the University of Coimbra – Polo II (Source: University of Coimbra)

The most recent campus, Polo III, hosts the Health Sciences faculties and is located close to the University Hospital (Figure 41), and is still undergoing an expansion process. Despite being more recent than the others, the buildings' roofs and the available space represent some obstacles to the installation of RES such as photovoltaic panels.

Figure 41. Campus of the University of Coimbra– Polo III (Source: University of Coimbra)

Determined by the aim of being the first carbon-neutral Portuguese university, recently the University of Coimbra has made significant efforts to reduce its energy consumption and carbon footprint through its Strategic Plan (University of Coimbra, 2019), in line with the Long-term Strategy for Carbon Neutrality of the Portuguese Economy (Ministry of Environment and Energy Transition, 2019). To reach this goal, the university has implemented a range of measures, such as energy-efficient lighting, solar water heating, and building retrofits, to reduce its energy consumption and greenhouse gas emissions. Due to these measures, the University of Coimbra has succeeded in reducing its total annual energy consumption by 17% (Figure 42), and its carbon footprint, the equivalent of 1031 tons of CO_2, between 2019 and 2021 (Figure 43). By the end of 2023, the University of Coimbra intends to reduce its carbon footprint by 20-25% and increase the installed power of renewables by 75-100%, according to the 2019-2023 Strategic Plan of the University of Coimbra[1] (SPUC). Besides the education for sustainability through degree programs and research opportunities in related fields, such as renewable energy, environmental science, and sustainable development, the University of Coimbra has created a sustainability office to promote social and environmental awareness among its students and staff.

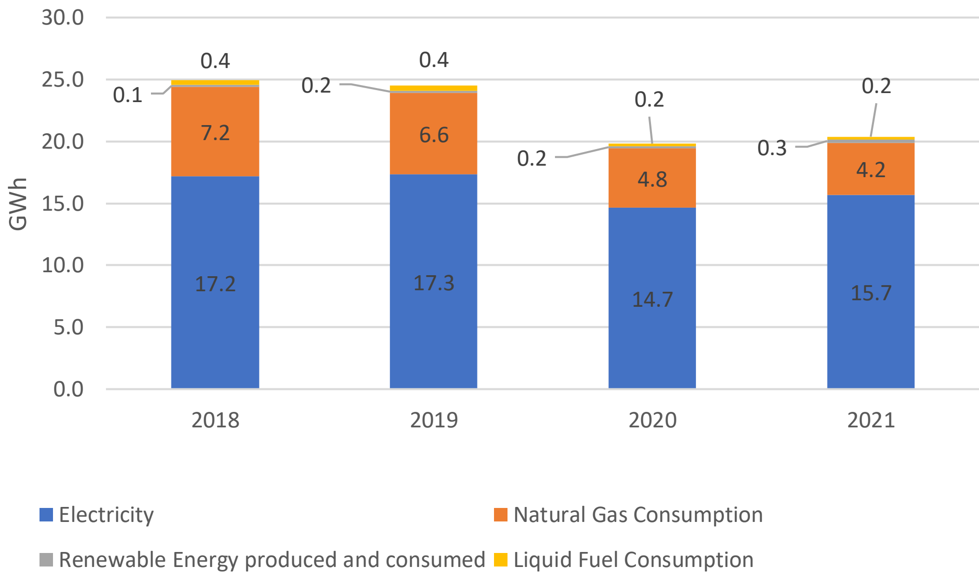

Figure 42. University of Coimbra – Total Energy Consumption (GWh) (Source: University of Coimbra)

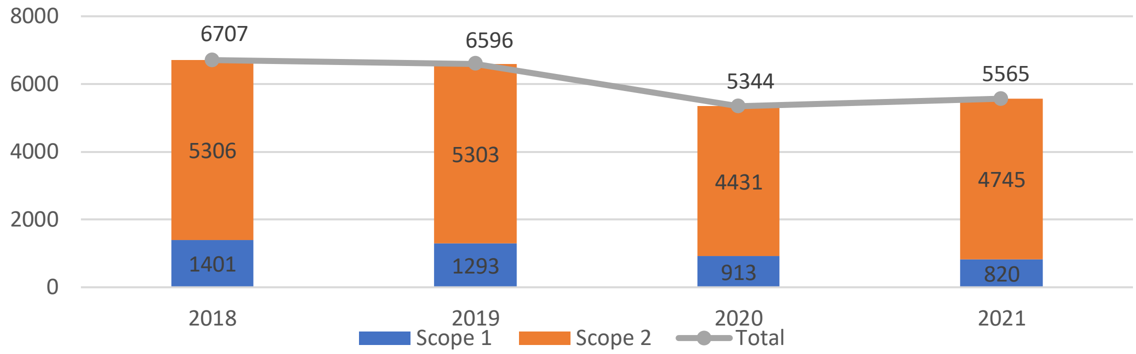

Figure 43. University of Coimbra - Equivalent Carbon Emissions (Sources: University of Coimbra)

To reinforce the commitment to achieving carbon neutrality, this case study focuses on assessing the potential of implementing a REC in the university's facilities with carbon capture strategies. Firstly, by implementing a REC, the institution can increase the contribution of renewable energy sources to meet its demand and increase the energy citizenship of its participants, namely the students. Secondly, carbon capture strategies are critical to balance hard-to-avoid emissions (Directorate-General for Climate Action, 2023), acting as a strong ally for the university to be the first climate-neutral university in Portugal.

REC Regulatory Framework – analysis

Within the European context, the primary directives addressing REC are the Renewable Energy Directive (RED II) and the Internal Electricity Market Directive. Among the member states, the best examples of putting into practice these directives are Denmark, Belgium, Germany, France, Ireland, and Italy (Figure 44). Regarding Portugal, as outlined by Crispim et al. (2023), the country's regulatory framework reflects a commitment to advancing energy transition. This commitment manifests through citizen involvement through both self-consumption and active participation in REC initiatives. Nonetheless, the European Federation of Citizen Energy Cooperatives (Rescoop.EU) identified four specific points where the transposition of the abovementioned directives can be improved (REScoop.EU, 2022):

- The Portuguese regulatory framework needs to address issues such as the autonomy of REC.
- The Portuguese regulatory framework ignores the fundamental concept of REC, ownership, allowing the creation of REC with RES owned by third parties.
- The Portuguese regulatory framework does not clearly distinguish the differences between CER and collective self-consumption.
- The Portuguese regulatory framework considers the geographical proximity of renewable energy production facilities not only as a criterion for choosing the managing entity, but also as a criterion for choosing the members that may participate in the REC, constituting a limitation to citizens' participation in this type of initiative.

According to Decree-Law No. 15/2022, the main regulatory document for REC in Portugal, the key requirements for the establishment of a REC in Portugal are:

- A REC can be formed by natural or legal persons of a public or private nature through voluntary membership.
- A REC should primarily aim to provide environmental, economic, and social benefits, rather than financial gains, to its members and the surrounding community through the production, consumption, storage, and trade of renewable energy between its members and third parties.
- The participating members need to be located in the proximity of the renewable energy project, more specifically with a distance of less than 2 km in the case of low voltage

connections, less than 4 km with medium voltage connections, less than 10 km with high voltage connections and less than 20 km with very high voltage connections.

- An internal regulation is mandatory to define clearly the operation of the specific REC.
- It is necessary to define a management entity of collective self-consumption to manage the community as well as to represent the REC in the most diverse instances.
- For the licensing of the renewable installations, it is necessary to make a prior communication to the General Directorate for Energy and Geology (DGEG).

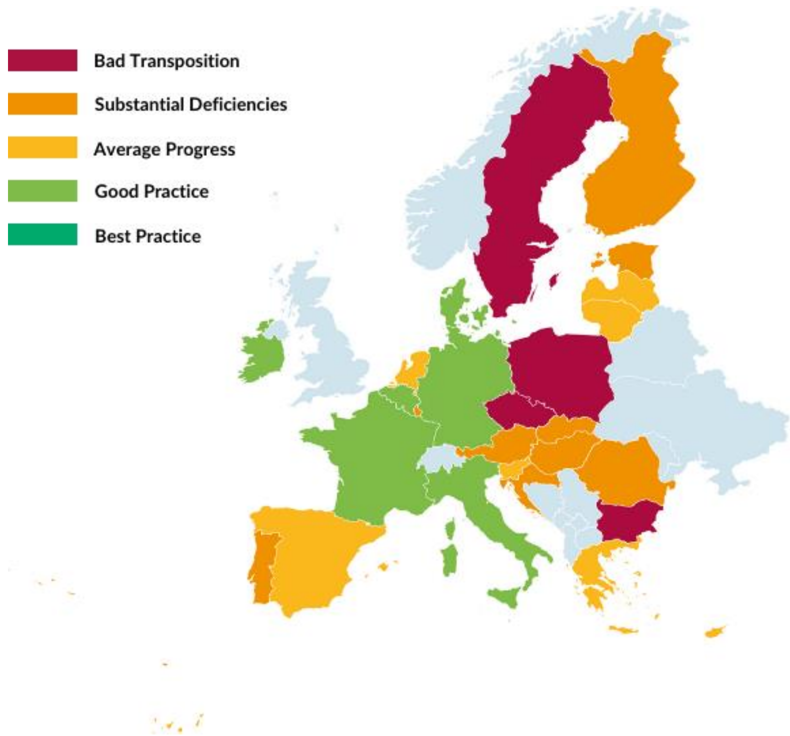

Figure 44. Transposition tracker – REC and CEC definitions (Source: Rescoop.EU)

Besides this diploma, the regulatory framework around REC is also composed by Self-Consumption Regulation (ERSE, 2022) from the Energy Services Regulatory Entity (ERSE) as well as the Directive nº 12/2022 (ERSE, 2022). The purpose of the self-consumption regulation is to regulate the commercial relationship between the agents participating in self-consumption allowing greater effectiveness in the implementation of the REC, as well as to regulate the use of the networks, which tariff calculation is presented in the Tariff Regulation (ERSE, 2020). In the case of Directive nº 12/2022, it presents the general conditions of contracts for the use of networks for self-consumption.

Barriers to the implementation of a REC in the University of Coimbra

As mentioned in the Introduction section, there are several barriers to the implementation of REC. In this case, the main barriers are related to the characteristics of the University of Coimbra buildings, the regulatory framework and the high initial investment required.

The UNESCO World Heritage classification and the historic building structures are subject to strict preservation rules and regulations. In heritage buildings, besides the common building barriers as the limited roof space for solar panels and limited space nearby for wind turbines, the integration of RES is limited by architectural, conservation and cultural barriers (Tsoumanis et al., 2021).

Regarding the regulatory framework, the proximity parameters established in Decree-law nº 15/2022 for the establishment of a REC is a barrier. The University of Coimbra has their buildings spread around the city and considering that the electricity produced by photovoltaic panels will be injected into the grid at medium voltage, it limits the area of the REC of the University of Coimbra to a range of 4 km from the point of injection into the grid. Consequently, certain structures, like the Palácio de São Marcos, are ineligible for inclusion in this initiative, despite their favourable conditions for photovoltaic system installation.

In addition to this regulatory obstacle, and despite not being directly related to the regulatory framework, the licensing period for new renewable projects at the DGEG, including REC, stands as a noteworthy concern. While the REPowerEU Plan aimed to truncate the licensing timeline for renewable projects from 6 to 3 months, these timelines have not been adhered to by member states, Portugal included (European Commission, 2022d; Fox et al., 2022; Lusa, 2023).

Finally, another barrier is the high upfront investment needed to implement a RES in such a large institution. The cost of implementing RES can be high, especially in historic buildings where preservation requirements may increase the cost (Tsoumanis et al., 2021). In addition, the initial investment cost for installing RES can be challenging for universities to justify.

2.8.2.4 Case Study Solution

Given the significant total energy consumption of the facilities comprising the University of Coimbra, and to generate an amount of energy capable of satisfying a non-negligible portion of this consumption, in addition to allowing energy exchange with other consumers, the photovoltaic systems to be installed must inevitably have a considerable size. Thus, an analysis of the available areas in each university campus was first carried out, both in terms of rooftops and land, using the QGIS[2] software.

Following this analysis, and given the characteristics of the university campuses, it became apparent that Polo II is the most suitable location for installing these systems due to various factors. Firstly, Polo II exhibits the highest availability of land, which fulfils the projected requirements. Additionally, unlike Polo I, there are no restrictions concerning historic buildings, eliminating potential obstacles associated with preservation regulations. From this analysis, two plots of land located in Polo II were selected to evaluate the potential installation of the photovoltaic systems, as presented in figure 45.

Energy Analysis

The renewable energy production of the systems was estimated using Helioscope[3] solar design software, which offers features that help streamline several stages of the process, including design, layout, and performance analysis. For this and using the technical data of the selected photovoltaic modules, several simulations were performed with different parameters, such as orientations, inclination angles and numbers of panels. Having as restrictions the energy consumption of the University facilities, the available space, the technical characteristics of the photovoltaic modules and other components, and the costs and viability of the systems, these analyses allowed defining the size of the photovoltaic systems to be installed. The annual production series for the designed photovoltaic plant was extracted from the software and used for the analysis in this study.

[2] QGIS is an open-source Geographic Information System (GIS) software that allows users to view, analyse, and edit geospatial data.

[3] HelioScope is a solar design and simulation software used in the solar energy industry.

After determining the anticipated energy generated by the photovoltaic systems, it is essential to ascertain which portion of this energy will be self-consumed by the institution's facilities and which will be the surplus sold to other consumers, such as industrial ones, as part of this REC.

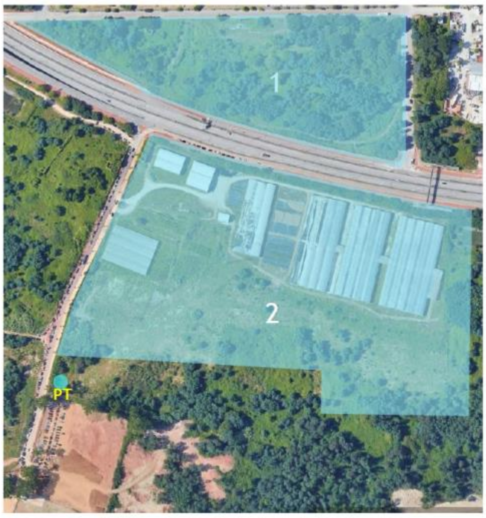

Figure 45. Possible locations for PV installation [Provided by: Cleanwatts, SA]

Given that the primary purpose of establishing this Local Energy Community is to contribute to the University of Coimbra's pursuit of carbon neutrality, prime attention has been devoted to the University's diverse buildings. These buildings are spread across three different campuses as well throughout the city, serving as recipients of the energy produced by the Community, as depicted in Figure 46. In this visual representation, each circle corresponds to the installed power of each building. This group of buildings comprises a total of 80 buildings, 35 of which are supplied at normal low voltage, 28 at special low voltage, and 17 at medium voltage. One building (Palácio de São Marcos) was excluded from this group because it is located at a distance from the other buildings and the production systems greater than the established limit (4 Km), as represented in Figure 46, making its inclusion inviable.

The energy consumption of this group of buildings was obtained in several ways. In the case of facilities supplied at medium voltage or special low voltage, the quarter-hourly data was directly accessed through the platform provided to this type of costumer by the distribution operator. This data is made available through measurement equipment installed by the operator. On the other hand, for buildings supplied at normal low voltage, the data were obtained through measurements and load diagrams from previous energy audits and studies. Additionally, typical consumption patterns, and the analysis of energy bills were taken into consideration.

By comparing the production data of the photovoltaic systems with the energy consumption of the University buildings, it was possible to determine the proportion of energy produced that would be self-consumed by the University and the portion that would be integrated into the Community for exchange with other consumers, particularly industrial users. After determining the percentage of energy self-consumed by the University buildings, it is also possible to calculate the annual reduction of the University's energy acquisition achieved through the photovoltaic systems. These energy-related data lay the foundation for further analyses, including environmental and financial assessments.

Figure 46. Location of the University buildings [Provided by: Cleanwatts, SA].

Environmental Analysis

The environmental analysis consists in determining the amount of avoided CO_2 emissions resulting from the implementation of this REC. To determine the amount of CO_2 emissions avoided ($CO_2\ avoid$) it is necessary to multiply the amount of energy that was avoided from being purchased from the energy supplier (En_{avoid}), being instead produced through this RES, by the emission factor of the Portuguese electroproduction system (FE):

$$CO_2\ avoid\ = \sum En_{avoid} \times\ FE \qquad (20)$$

In the Portuguese case, the value of the emission factor for the electroproduction system was 250 tons of CO_2 per GWh in 2021 (DGEG, 2021). Finally, the total reduction of CO_2 emissions resulting from the implementation of this REC is obtained by adding two parts, namely the emissions avoided by the University of Coimbra and the emissions avoided by the industrial consumers that will be part of this Community.

Financial Analysis

To evaluate the financial feasibility of the proposed REC, two key financial indicators were considered based on the methodology proposed by Umar et al. (2021):

- Net Present Value (NPV)

NPV is used to evaluate the profitability of a project. It calculates the difference between the present value of cash inflows, which includes revenues from electricity sales and electricity savings, and the present value of cash outflows, while considering the time value of money. The cash outflows encompass initial investment, maintenance costs, grid access fees, and other costs, such as the REC's management services and replacement of inverters and other components. A positive NPV indicates the investment's financial attractiveness, while a negative NPV suggests the investment may not be economically viable or profitable.

The annual income revenue from electricity sales for a given year t can be calculated through expression (21), where x_t is the annual amount of electricity sold and C_1 is the stipulated price per kilowatt-hour:

$$Electricity\ Sales\ Revenue = x_t * C_1 \qquad (21)$$

In turn, the annual savings revenue for a given year t can be calculated through expression (22), where y_t is the annual amount of electricity not purchased and C_2 the average price per kilowatt-hour of the University's buildings:

$$Electricity\ Savings\ Revenue = y_t * C_2 \qquad (22)$$

NPV can thus be calculated through expression (4):

$$NPV = -C + \sum_{t=1}^{n} \frac{Q_t}{(1+d)^t} \qquad (23)$$

where C is the initial investment, d is the discount rate, n is the lifetime of the project – in years, t is the specific year for calculation, and Q is the net cash flow. In turn, the net cash flow can be calculated as follows:

$$Q_t = Total\ Cash\ Inflows_t - Total\ Cash\ Outflows_t \qquad (24)$$

For this study, several assumptions will be made: a project lifetime of 25 years (Branker et al., 2011), an discount rate of 5%, an annual degradation of 0.8 % in energy production from the PV systems; and exemption of payment of grid access fees for the first 7 years (Legislative Order 6453/2020, June 19th).

- Adjusted Payback

Adjusted Payback calculates the time it takes for an investment to recover its initial cost, considering the time value of money. Shorter payback periods indicate quicker cost recovery and reduced risk. It can be calculated by the following equation, where $t^*$is the number of years before full recovery:

$$Adjusted\ Payback = t^* + \frac{C - \sum_{t=1}^{t^*} \frac{Q_t}{(1+d)^t}}{\frac{Q_{t^*+1}}{(1+d)^{t^*+1}}} \qquad (25)$$

To find t^* it is necessary to sum the discounted net cash flows (Q) up to the year preceding the year in which the entire investment is recovered.

Carbon capture systems

With the goal of complementing the reduction of CO_2 emissions achieved through the implementation of the REC, as well as replacing food products with high environmental footprints, practicing efficient resource management, and optimizing water consumption, the University of Coimbra plans to test a succession agroforestry system (SAFS) on its campus. Moreover, this agroforestry approach will be enhanced through the incorporation of biochar and soil carbon sequestration techniques. This forward-thinking initiative aligns perfectly with the pillars of its sustainability strategy, demonstrating the University of Coimbra commitment to maintaining its position as one of Europe's most sustainable universities and a prominent institution in Portugal (University of Coimbra, 2019).

2.8.2.5 Results and Discussion

To determine the installed capacity of the photovoltaic systems to be implemented, various restrictions were taken into consideration. The first constraint was the available land area in Polo II, which was identified through analysis using the QGIS software. The second constraint is related to the selection of photovoltaic modules. In this case, the monocrystalline type from JA Solar, model JAM72D30-550/MB, was chosen. It offers a maximum rated power of 550 Wp and an efficiency of 21.2 %. The third constraint is related to the energy consumption profile of the University buildings.

By utilizing the HelioScope software and incorporating the existing constraints, this study assumes the installation of two photovoltaic systems with an approximate installed power of 3.16 MW and 4.33 MW, resulting in a total installed capacity of 7.49 MW. Table 16 depicts detailed information about these systems, such as the occupied area and the number of modules.

Table 16. General data of the production units to be installed.

Site	Area (m²)	Azimuth	Tilt angle	Number of modules	Installed Power (kW)
1	39286	~0º	35º	5740	3157
2	45164	~0º	35º	7868	4327

Based on the results of the final simulation (Figure 47), the systems are anticipated to generate an estimated annual energy production of 10.8 GWh, which corresponds to a total of 1444 equivalent hours of production at the selected coordinates.

Figure 47. Layout of the PV systems to be installed.

Energy balance:

By interconnecting the estimated production series of the PV plants with the consumption points associated with the University buildings, an energy balance was derived. This balance reveals the percentage of generated energy consumed by the University facilities, in addition to the surplus that will be allocated to the other consumers that will be part of the REC (Table 17).

Table 17. REC energy balance.

	Energy (GWh)	Percentage (%)
Consumed by UC	6.45	59.7 %
Consumed by other REC members	4.35	40.3 %
UC consumption supplied by REC	-	38.8 %

This energy balance shows that, based on the consumption profile of the buildings, it is predicted that approximately 60 % of the energy produced by the REC, namely 6.45 GWh, will be internally consumed by the University of Coimbra's buildings, making up approximately 38.8 % of its total energy consumption. These values demonstrate that investing in this initiative can significantly promote the adoption of renewable energy and help reduce the environmental impact resulting from the institution's energy usage, therefore enhancing its overall sustainability. Furthermore, despite the initial high investment, this initiative will yield long-term financial benefits by reducing energy purchases by approximately 39 % of the university's total annual energy consumption. Thus, the project not only contributes to environmental sustainability, but also enhances financial sustainability.

However, the benefits of this project extend beyond the University of Coimbra. The results indicate that around 40 % of the energy generated by the REC, approximately 4.35 GWh, could be consumed by other members that will be part of this Community, namely industrial consumers situated in the vicinity of these projects. By participating in this project, these consumers can also experience reduced energy purchases from typical retailers and CO_2 emissions, thereby improving their financial efficiency and promoting the decarbonization of their operations.

RECs typically involve residential consumers as part of their implementation strategy. This approach serves multiple goals, including addressing energy poverty, particularly among low-income families, and enhancing the social impact and viability of the project. Nevertheless, REC also aim to foster citizen engagement in decarbonization and energy transition. Industrial consumers were prioritized, as one of the main purposes is to reduce the environmental footprint of industrial operations and facilitate the adoption of renewable energy in the industrial sector, contributing to energy resilience, important pillars of smart manufacturing. The inclusion of university residences and low-income residential consumers located in the neighbourhood could be further considered in a next phase of this project, thus also contributing to the energy poverty issue.

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Environmental balance:

Considering the value of the emission factor of the Portuguese electroproduction system of 2021, namely 250 tons of CO_2 per GWh, it is possible to verify that this project, through local generation of renewable energy, allows to avoid 2700 tons of annual CO_2 emissions. Table 19 illustrates the annual CO_2 emissions reduction for both the University of Coimbra and the participating industrial consumers involved in this initiative.

By adopting this sustainable solution, the University of Coimbra not only contributes to the decarbonization and improved sustainability of the Portuguese industrial sector but also achieves a significant reduction in its annual CO_2 emissions from its energy consumption. The reduction is estimated at 29 %, bringing the University closer to its goal of achieving carbon neutrality. This demonstrates the university's commitment to addressing environmental challenges while promoting a cleaner and greener future.

Table 19. CO_2 emissions avoided.

	CO_2 emission avoided (ton)
University of Coimbra	1612
Industrial consumers	1088
Total	2700

Financial balance:

As with other initiatives, the financial component plays a fundamental role, as it can often be one of the main barriers to project initiation and development. Therefore, it is essential to conduct a thorough financial evaluation of this project, bearing in mind that the primary objective is not to generate profits but rather to decrease the energy dependence of the involved institutions and companies, reduce their CO_2 emissions, and enhance the sustainability of their operations. In this regard, two financial metrics were evaluated: net present value and adjusted payback.

To initiate the analysis, the initial investment was estimated at 6,124,342€ (including VAT), using data from the HelioScope software and budgeting by various companies. Then, the remaining components of the project's cash outflow were determined: grid access fees, maintenance costs, and other costs including REC management services, inverters' replacement, insurance, etc. To determine the grid access costs, the legislation defining the values approved by the regulator (ERSE) was consulted, and an average value of 0.025€/kWh was defined. Furthermore, it was considered that, as has been seen in this type of project, there is an exemption of payment of grid access fees for the first 7 years (Legislative Order 6453/2020, June 19th). In turn, to determine the remaining costs (maintenance costs, inverters' replacement, management services, etc.) several companies were consulted. Figure 48 illustrates the variation of the cash outflow's components over the project's lifetime, apart from the initial investment costs.

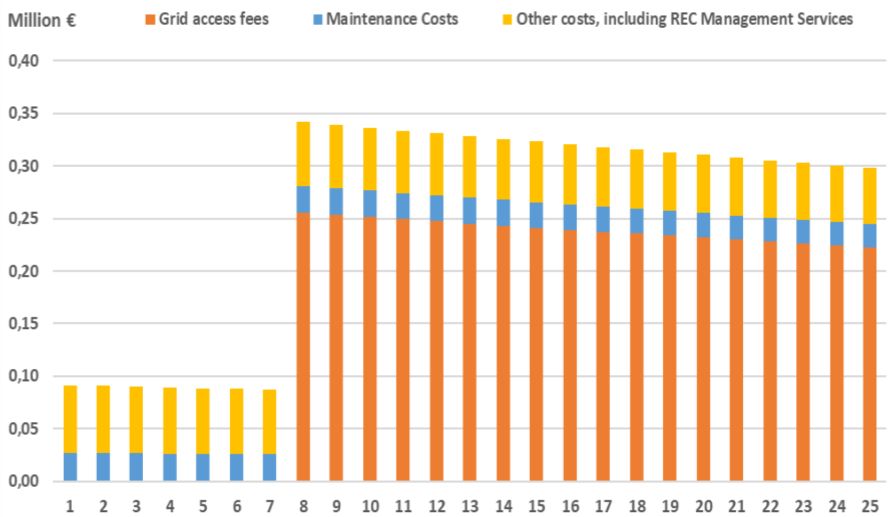

Figure 48. Variations of the cash outflow's components over the project's lifetime (except initial investment).

The subsequent focus was on determining the two components of the cash inflow: estimated electricity savings and estimated electricity sales. The estimated electricity savings stem from the portion of the electricity produced that will be consumed by the University's facilities, thereby avoiding its purchase from the energy supplier. For this calculation, and adopting a conservative stance, the weighted average price per kilowatt-hour (kWh) based on the University buildings' contracts was considered (0.11€). Conversely, the electricity sales are derived from the electricity that will be sold to the industrial consumers, considering an average sale price of 0.06 €/kWh, which is a highly competitive tariff in this segment. Figure 49 illustrates the variations in both cash inflow components over the project's lifetime, accounting for an annual degradation rate of 0.8 % of the electricity production.

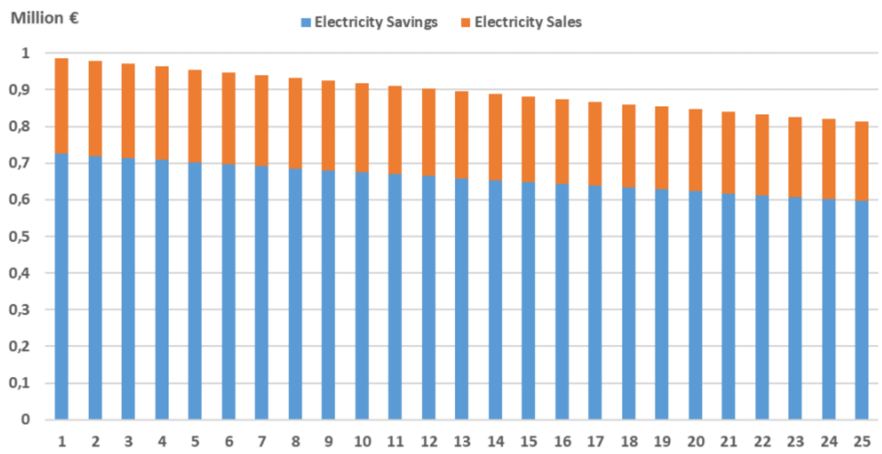

Figure 49. Variations of the two parts of the cash inflow over the project's lifetime.

Based on the previous determined values and considering a discount rate of 5 % and a project lifetime of 25 years as assumptions, the project's financial analysis reveals a positive NPV of 3,576,063 € and an adjusted payback of about 9.8 years. These values demonstrate that the project is financially attractive in the time considered and that the investment can be recovered in an acceptable period, while achieving the main objectives, namely reducing CO_2 emissions and energy dependence of the institutions and companies involved, as well as increasing the sustainability of their operations. To further improve the payback period, complementary strategies like selling electricity to residential consumers at higher tariffs or implementing dynamic tariffs based on time periods could be explored. Figure 50 shows the evolution of project's NPV and other financial indicators over time.

Contribution to Smart Manufacturing:

The implementation of this REC, focused on photovoltaic production, and the consequent inclusion of industrial consumers, plays a key role in advancing smart manufacturing practices. By establishing a local and sustainable energy supply, industries gain access to an environmentally friendly energy supply, resulting in higher energy resilience and stability and reducing concerns over energy availability and energy cost fluctuations. Furthermore, it also leads to reduced overall operating and production costs over time through the resulting energy cost savings, thereby making manufacturing industries more economically viable by enhancing their competitiveness and productivity in the global market. In addition, the resulting cost savings also enable greater capacity to invest in technologies and further enhance the development of smart manufacturing.

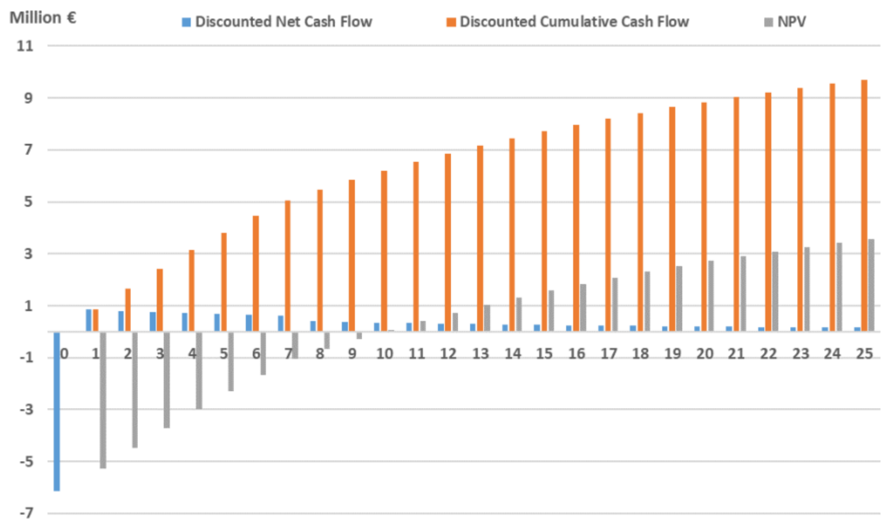

Figure 50. Evolution of NPV, discounted net cash flow, and discounted cumulative cash flow over time.

From an environmental point of view and given the current environmental problems and consumption of natural resources, this project makes an important contribution to enhancing the environmental sustainability of the involved industrial consumers. By reducing dependence on fossil fuels and fostering the adoption of cleaner energy alternatives, this project helps industrial consumers to significantly lower their carbon emissions and move closer to the overall goal of decarbonizing their production processes, another of the main objectives of smart manufacturing.

Agroforestry for Carbon Capture

Agroforestry, as a nature-based solution for carbon capture, proves to be highly cost-effective and a promising approach to combat climate change (Erbach & Victoria, 2021). This approach generates significant returns on investment and economic benefits, driven by enhanced crop productivity (Kim et al., 2016; Zomer et al., 2016). Furthermore, once established, this system is relatively self-sustaining, requiring minimal inputs and management in contrast to other carbon removal technologies. Farmers can benefit from both marketable timber or non-timber forest products, in addition to crops or livestock raised within the system.

Given the increasing recognition of agroforestry, with special emphasis on succession agroforestry systems (SAFS), the University of Coimbra intends to apply this type of system on its campus. SAFS mimic the natural succession processes of ecosystems and integrate them into agricultural practices (Dufty et al., 2000; Goetsch, 1992; Montagnini & Ashton, 1999; PENEIREIRO, 1999; B. Schulz et al., 1994; J. Schulz, 2011; Vaz, 2000; Vieira et al., 2009) . In SAFS, each plant species is provided with optimal conditions for growth, occupying their natural positions in both space (stratification) and time (succession). To accomplish these objectives, SAFS focuses on creating species combinations that exhibit functional behaviors similar to important natural successional stages (Goetsch, 1992; PENEIREIRO, 1999; J. Schulz, 2011; Vaz, 2000; Vieira et al., 2009) .

With the aforementioned in mind, the University of Coimbra will adopt an alley-cropping design for its SAFS, inspired by successful practices observed in many Portuguese agroforestry farms (Leitão, 2022). The SAFS design involves planting trees and/or shrubs to establish alleys where agricultural or horticultural crops can thrive. Therefore, its stratification will entail spaced rows of fruit orchards, like citrus, olives or others, intermixed with forestry trees, such as poplar or eucalyptus, used for multipurpose functions and occupying the upper layer of the SAFS. These trees will provide physical protection to crops and contribute to biomass production (pruning), possibly for biochar. Vegetables like tomatoes, peppers, lettuce, green beans, cabbage, among others, will grow in two or three beds within the alleys, filling the lowest strata and the early phases of succession, mimicking forest succession processes and supporting valuable tree growth, particularly fruit trees. Placing specific tree specifies closely maximizes photosynthesis.

The University of Coimbra's planned SAFS aims to sequester CO_2 emissions from campus activities through photosynthesis. Simultaneously, these systems will yield diverse fruits and vegetables, suitable for the campus canteen, following the example set by Paladin at the Mendes Gonçalves S.A. farm, or potential sale, using a business model like what is observed at Quinta da Manguela or Planta Floresta farms (Leitão, 2022). Beyond these practical applications, the SAFS will also serve as an educational and research field, mimicking the role played by farms such as Quinta do Monte or Herdade do Freixo do Meio (Leitão, 2022).

Finally, to complement CO_2 sequestration and enrich soil quality, water retention capacity, and nutrient availability, biochar will be incorporated into the soil as part of the cultivation preparation process. This can be achieved through soil carbon sequestration techniques like low or no-tillage, which mitigate carbon release from the land to the atmosphere (Lal, 2004; Li & Pang, 2010).

2.8.2.6 Conclusion and Recommendations

This case study aims to demonstrate how the commitment to energy transition, through the installation of photovoltaic plants and the creation of a REC, will enhance the clean energy production and reduce not only the carbon footprint of the University of Coimbra, but also increase energy autonomy and reduce the institution's energy costs. According to the results, implementing this REC would provide about 38.8 % of the University's annual electricity consumption, a total of 6.45 GWh. This local generation of renewable energy would allow a substantial annual reduction in energy costs and CO_2 emissions, contributing significantly to the financial and environmental sustainability of the institution, and bringing the University of Coimbra closer to the established carbon neutrality objective.

The case study also highlights that the project's benefits extend beyond the University, demonstrating its significance in driving energy transition and smart manufacturing. According to the results, approximately 40% of the energy generated by the REC, equivalent to around 4.35 GWh, could be utilized by industrial consumers in the project's vicinity. By participating in the REC, industrial consumers can benefit from reduced energy purchases and CO_2 emissions, leading to improved financial efficiency and enhanced energy resilience, while promoting the decarbonization and environmental sustainability of their industrial activities. The resulting energy cost savings further contribute to reduced operating and production costs, boosting the competitiveness of manufacturing industries in the global market. Moreover, these savings increase the capacity to invest in technologies and further enhance the development of smart manufacturing.

The project's financial analysis indicates a net present value of 3,576,063 € and an adjusted payback of approximately 9.8 years. These results affirm the project's financial attractiveness within the considered timeframe, ensuring a reasonable period for the investment to be recovered. Moreover, the project successfully aligns with its main objectives, which encompass reducing CO_2 emissions and energy dependence of the institutions and companies involved, as well as increasing the sustainability of their operations. Overall, the financial viability, coupled with environmental advantages, underscores the project's potential success. Moreover, in later stages of the project, complementary strategies like selling electricity to residential consumers at higher tariffs or implementing dynamic tariffs based on time periods could be explored to further improve the payback period, as well as including low-income residential consumers to tackle energy poverty.

Simultaneously, the results allow to increase the general population's knowledge regarding this subject, serving as potential awareness material and as an example to mobilize citizens, companies, and institutions to follow this example and enhance the implementation of RECs that are not limited to the residential and service sectors, but also integrate the industrial sector.

The University of Coimbra's SAFS aligns seamlessly with its sustainability strategy, acting as a pivotal reinforcement to the University's REC in significantly curtailing CO_2 emissions arising from campus activities. The integration of biochar and soil carbon sequestration techniques will amplify the SAFS' effectiveness. In comparison to other carbon dioxide removal options, the University of Coimbra's SAFS exhibits remarkable cost-effectiveness. Notably, considering the revenues generated from product sales, the costs of carbon sequestration might even be negative.

In summary, this case study demonstrates that collaboration and symbiosis between higher education institutions, currently committed to the energy transition and decarbonization of society, and industrial companies, typically characterized by their intensive consumption of energy and resources, in the development of renewable energy production projects and the creation of REC can be an interesting solution to promote energy transition and smart manufacturing. The results illustrate that, despite the initial costs, this type of projects is financially viable and brings additional benefits beyond financial ones, including increased energy resilience, enhanced competitiveness, and reduced CO_2 emissions from operations and activities. In addition, the environmental benefits for education institutions and for companies can be further enhanced through complementary implementation of carbon capture solutions. As such, this type of initiative should be promoted and replicated by other institutions and companies.

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2.9 Halmstad University – Sustainable Bioenergy and Side bio-products Production on coastal urban areas

2.9.1 Executive Summary

This case study investigates industrial symbiosis in the biogas context in a coastal urban area of the Swedish west coast. The aim is to involve various stakeholders to develop the full potential of the biogas market and identify suitable forms of collaboration, figure 51. In conclusion, to ensure the success of the biogas system, it is crucial to create a regional strategy involving key stakeholders and emulate successful examples from other areas while generating market demand through infrastructure and facilitation programs.

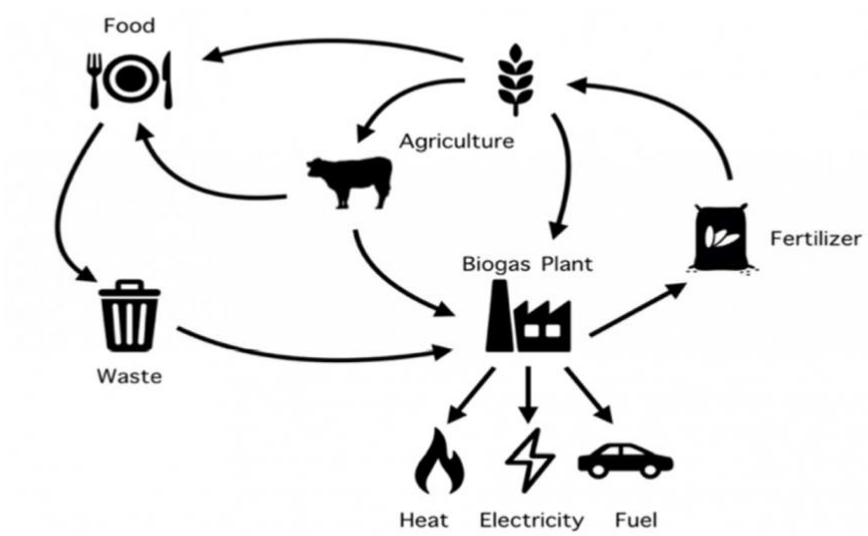

Figure 51. Sustainable Bioenergy and Side bio-products Production on coastal urban areas - Graphical Abstract

2.9.2 Case Study

2.9.2.1 Abstract

Biogas production and utilization is a circular system that can contribute to bioenergy supply and climate transition. The biogas system however needs to involve industrial actors and other organizations in order to develop the full potential of the biogas market.

This case study will use the coastal urban area of the Swedish west coast to investigate drivers and barriers to industrial symbiosis in a biogas context, and to identify suitable forms for stakeholder collaboration. The aim is to identify the actors, their roles and current and potential interactions within the system of industrial symbiosis. While doing so, business partners will be involved from different parts of the value chain that has an interest in developing the biogas market, sustainable business models, and industrial symbiosis. Side bio-products production using for instance the digestate as fertilizer or as basis for other products will be explored. Outcome of these activities in collaboration will be more circular solutions in society and more biogas substituting natural gas.

2.9.2.2 Introduction

The circular economy aligns with the overarching idea of sustainable development that meets the needs of the present generation without compromising the needs of future generations (Korhonen et al., 2018). Main areas and activities of the circular economy include the 5 R's: reuse, repair, refurbishment, remanufacturing, and recycling to address the overarching aim of creating a closed-loop system that minimizes the use of resource inputs and the creation of waste (Maranesi & De Giovanni, 2020). According to Vanhamäki et al. (2020), a systematic change where local and regional actors play a central role is required to enable a transition to a circular economy. More specifically, broad cooperation among stakeholders such as municipalities, authorities, companies, and academia could facilitate sustainability-oriented investments and create business opportunities that originate from the perspective of circularity and resource efficiency. Biogas is a renewable and regionally produced fuel based on anerobic digestion of biomass. Biogas systems have the potential to reduce methane emissions from waste like manure and food residues and at the same time the biogas produced can substitute for fossil fuels. Biogas can be utilized for heat, electricity, vehicle fuel production or as raw material in industry. Biogas plants constitute promising future energy supply systems in which demand-driven electricity can be provided to compensate for mismatches between energy demand and supply from unpredictable sources such as wind and solar power (Mauky et al., 2017). Moreover, biogas technology has a small carbon footprint and has a low lifecycle greenhouse gas emission compared to other biofuels (Uusitalo et al., 2014).

Biogas closes loops and contributes to an economy where waste and residuals become valuable resources, such as climate friendly biogas, biomethane and biofertilizer (Swedish Gas Association, 2021). In Europe the demand for biogas has recently increased due to the possibility to substitute natural gas with biogas. Moreover, it has been shown that biogas solutions can contribute to all the 17 UN Sustainable Development Goals which indicates that biogas solutions need to be studied and understood in a broad, cross-sectoral system perspective (Hagman & Eklund, 2016).

Sweden has increased biogas use dramatically since 2015 but the increase is mostly due to import of biogas from Denmark. An increase of Swedish biogas production up to 10 TWh until 2030 has been suggested (Biogasmarknadsutredningen, 2019) and new policy instruments have been introduced. Of the biogas produced in Sweden most (64 %) is upgraded and used for road transport due to favourable financial support systems. The market for biomethane as transportation fuel is now rather developed in Sweden but is highly dependent on increased policy incentives and long-term support systems to take the next step (Klackenberg, 2023). Biogas is also in demand by industry as a fuel and raw material for a range of industrial purposes such as plastic, paint and lubricants (International gas union, 2015). Biogas production is considered to contribute to a green, local economy that provides job opportunities and secures nutrient cycling. Although many benefits can be gained from biogas production Swedish actors have been struggling with low profitability and the development has reached a stagnation. There are however still many actors that want to develop their activities and existing business models by developing new business concepts aimed at future biogas expansion and thus contributing to the climate transition. A way forward for these actors could be more long-term subsidies and subsidies linked to regional biogas development objectives (Niskanen & Magnusson, 2021) but also more cooperation between different local businesses in industrial symbiosis. In a collaboration model, stakeholders are independent and interdependent in their interactions. They create norms, rules, and structures for how to act and how to achieve collaborations based on mutually beneficial interactions. Collaboration models expect to bring through achievements that otherwise may not have been obtained (Knudsen, 2007) and enabling organizations to collectively manage risks and take advantage of potentials, e.g., facilitate market launch, gain access to new markets and to offer mechanisms to avoid potential market failures (Laperche & Liu, 2013). For example, customers may contribute with new ideas and solutions, improve design, provide information on market trends, and identification of market opportunities (Nieto & Santamaría, 2007).

Suppliers may for instance identify new methods, technical or design problems and contribute to successful launch of new efficient solutions (Jean et al., 2014). Thus, the aim of collaboration models also includes establishing of a culture where citizens become active parts in the development.

The overarching aim of this case study is to develop a framework that can support establishment of industrial symbiosis based on biogas production where supply and demand of biogas and its bioproducts can be increased and matched.

2.9.2.3 Description of Case Study

The case study has been structured into three parts that build on each other in order to meet the aim. These are all part of a process that will initially create a benchmark for the possibilities of increased biogas production and utilization in symbiosis with other actors in the value chain, develop a conceptual roadmaps of how such industrial symbiosis could be arranged, and provide further understanding of how the industrial symbiosis based on biogas production could be established and managed through collaboration models and a knowledge base for a prototype. Such a prototype will ease the dissemination, communication, and application of the case study results.

After this work has finished the prototype can serve as inspiration and encourage actors to start collaborating and building industrial symbiosis networks.

2.9.2.4 Case Study Solution

The main idea of industrial symbiosis (IS) is to create synergies; one business's waste become another business's feedstock in order to improve resource efficiency. From the district energy industry in Sweden there are many examples of industrial symbioses where partners need to understand each other's processes and value drivers (Thollander et al., 2010; Walsh & Thornley, 2012). The case study will investigate motivations, dynamics, interactions and governance, which are important aspects for facilitating and maintaining the synergies (Martin, 2020). Industrial symbiosis can contribute to a secured energy supply as well as lead to more robust businesses contributing additional job opportunities within the green sector giving a positive and sustainable impact on the communities that the symbiosis acts within. However, knowledge on practical industrial symbiosis cases which will contribute to a renewable, robust, and flexible energy system is treating and refining biological streams (e.g., the biogas process) remains underexplored, and a more in-depth understanding of opportunities and challenges presented by industrial symbiosis is needed to advance its applicability (Vanhamäki et al., 2020).

The methodology of the case study will be first a literature study to increase the knowledge of the concept of industrial symbiosis and to establish a benchmark for understanding needs and challenges in connection to industrial symbiosis in general and also in the biogas context.

Interviews will be performed with different stakeholders that could be involved in an industrial symbiosis.

There is also a need for a deeper understanding of how current and potential stakeholders, critical for the establishment of biogas industrial symbiosis, can be involved in the development process. Research have shown that biogas producers and users need to innovate not just the biogas product and attached services but also collaboration and business models, and that successful dissemination and adoption of biogas typically requires transformation of processes, business activities and organizations (Karlsson et al., 2019). Collaboration models (in which businesses cooperate with each other and/or stakeholders to jointly explore e.g., knowledge transfer and new business opportunities) may be specifically critical in cases as the biogas market with many small, separated stakeholders, with limited resources and with difficulties to have capacity and channels for commercialization. Currently, we identify a lack of a unified conceptualization of collaboration models (K. Blomqvist & Levy, 2006). We need to know more about challenges in the development of collaboration models in the context of biogas production and how to overcome such challenges. Moreover, It is also relevant to explore the collaboration models, their fundamental cornerstones and orchestration of them, particularly in the context of biogas industrial symbiosis and viable business models. The field of collaboration models have so far been neglected in the biogas area and studies like this is needed for bringing forth collaboration for early-stage innovative products and services in the biogas market in order to develop viable offerings to the multiple key stakeholders. In this, stakeholder's ability and willingness to take part of the exchange and to commit to the collaboration are in previous studies identified as critical (Knudsen, 2007). One key example is collaboration with regards to sustainable business model transformation.

To accelerate commercialization and adoption of biogas and for the potential industrial symbiosis to be developed the case study will create roadmaps based on collaborative processes actively involving practitioners as key stakeholders to incorporate different skills, resources, market aspects and societal needs. Identification of a biogas-business-industrial symbiosis-fit will be an iterative process were the research team and the partners co-create and align their views and understanding of both possibilities and limitations but also how to overcome hurdles.

The results will be made available and useful for many different actors and develop recommendations for measures that can promote the development of industrial symbioses with a biogas context. In the long run, this should lead to more biogas plants being established and more actors being involved. The results have a direct impact on several important target groups:

- actors who intend to build new biogas plants
- actors who can use the biogas or biofertilizer in production or processes
- actors who can otherwise be linked to the industrial symbiosis
- government officials
- the public interested in biogas

These target groups are directly involved in the project and develop increased knowledge and new perspectives through participation in interviews. In the closing workshop, other target groups also have opportunities to directly influence the recommendations that are highlighted as results. Target groups here are the entire biogas industry, and also county administrations and municipalities.

2.9.2.5 Results and Discussion

The practice of utilising by-products and residual energy from industrial and urban processes is not a new practice. However, it appears that many opportunities still exist to be exploited but have not been developed for various reasons. One of the key reasons is due to lack of a facilitation programme that increases awareness and knowledge flows, as well as a lack of specific policy incentives.

The generic Roadmap for IS in Sweden (Harris et al., 2018) was developed to highlight key components and actions needed to enable the identification, development and realisation of industrial symbiosis exchanges between partners. The Roadmap is focussed around five critical elements and actions:

1. Create a systematic facilitation programme - Regional Centres supported by a National Centre.
2. Establish support mechanisms – including Task Forces that provide supporting knowledge in key areas, (e.g. recovery technology) and drive forward key issues; as well as research in key areas.

3. Generate market demand – e.g. through awareness activities, as well as local and national government procurement.
4. Develop policy drivers - for industrial symbiosis whilst improving the overall policy environment by removing barriers.
5. Align IS across different sectors and approaches – this refers primarily fostering IS across the key pillars of society urban areas, industrial and agriculture and forestry; as well as aligning sectorial policies to ensure IS can flourish

In the bigas context a report was developed with 2 different scenarios discussing how biogas production can be increased through industrial symbiosis (Symbiosis Center Denmark, 2019). The cases from Denmark could show that there are possibilities but also barriers in terms of technical or legal barriers but also the need for investments can be an essential barrier to the establishment of green industrial symbiosis with utilisation of biogas. The uncertain prospects for the framework conditions for production, sales and use of biogas reduce the willingness to invest in both biogas plants and biogas processing plants (Symbiosis Center Denmark, 2019).

In the coastal urban area of the Swedish west coast there are several cases of industrial symbiosis recently started or already developed with biogas as a key component.

- In Vessige Biogas there are about 30 members in a cooperative with several big animal farms producing manure and other kinds of substrates for the biogas production but also working with other, upgrading to biomethane, using the biofertlizer and running a gas station. The biogas is used for heating, electricity, input on the gas grid and as fuel for cars, tractors, and heavy vehicles. The municipality in which the cooperative is situated, Falkenberg municipality is important in permit processes and have an interest in the development of Vessige biogas since the municipality vehicles can use the biomethane and since it creates business opportunities, facilitate the fulfillment of climate goals and contribute to rural development in the municipality. The University researchers have investigated what motivations and obstacles there are for developing industrial symbiosis and what policy evolution and behavioral change could possibly drive a positive development of biogas production in the agricultural sector. In order to be able to make these investments Vessige biogas cooperative have received governmental support (Klimatklivet) distributed via the Swedish environmental protection agency and through that been able to start the development of an industrial symbiosis.
- Sotenäs Symbiocenter currently has an industrial symbiosis network where several actors collaborate with the sea as a starting point. The symbiosis network started its development in 2011 and today it operates a privately owned biogas plant (Renahav) as a connecting hub for resource exchanges between sea and land. With more companies in the blue industry being established in Sotenäs, the network will be further developed and opportunities for new synergic effects created. At the same time, several companies in the network want to review side streams for better resource utilization. Through collaboration between academia, authorities, public and private sector, the industrial symbiosis will contribute to higher knowledge and competence for the use of resources and energy from the food industry, agriculture and aquaculture, e.g. through product processing and biogas production.

2.9.2.6 Conclusion and Recommendations

In order to establish an industrial symbiosis in the biogas context there has to be networks of different stakeholders that are interested in collaboration and increasing the biogas production and use of biogas, biomethane and biofertilizer.

Recommendations for further development of industrial symbiosis in the biogas sector is to:

- Create a regional strategy for the development of the biogas system together with key stakeholders and local politicians
- Create meeting points and communicate IS among companies, farmers, consultants, municipalities and academia
- Mimic the good examples from other areas
- Start facilitation programs to support initiatives from the beginning
- Generate market demand through infrastructure and procurements

There must also be continuous learning and activities such as workshops, study visits and sharing of knowledge. With this a successful development of industrial symbiosis in the biogas context can be realized.

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2.10 WiTEC – Gender inclusion in work processes with renewable energy projects in cities

2.10.1 Executive Summary

This study analyses two organizational change initiatives, one successful and one unsuccessful, to understand the factors influencing resistance and success on gender inclusion, figure 52. The purpose is to identify key elements for increasing the likelihood of success in similar projects. Success factors include internal initiation, voluntary participation, theory-practice integration, expertise, adequate time for research and change, bridging status gaps, forming alliances, adopting an evolutionary approach, addressing resistance, and emphasizing fairness and justice.

Why change initiatives fail	Ways to lower resistance in change initiatives:
• Resistance to change is argued to be a main reason for failures in change initiatives	• Internal initiation • Voluntary participation • Integration of theory and practice • Adequate expertise • Time for research and change • Bridging status gaps • Forming alliances with committed collaborators • Evolutionary approach • Addressing resistance • Emphasizing fairness and justice

Figure 52. Gender inclusion in work processes with renewable energy projects in cities - Graphical Abstract

2.10.2 Case Study

2.10.2.1 Abstract

This study compares two different case studies on organisational change initiatives, one of which was deemed successful and the other one deemed unsuccessful; this study examines the reasons for the varying levels of resistance within these two projects with the purpose is to identify factors that can increase changes of success in similar initiatives. Success factors identified in this case study for change initiatives include internal initiation, voluntary participation, integration of theory and practice, adequate expertise, allowing sufficient time for research and change, bridging status gaps, forming alliances with committed collaborators, adopting an evolutionary approach, addressing resistance, and emphasizing fairness and justice. These factors serve as guidelines for implementing effective change initiatives in organisations and are applied on the project RES4CITY in a shorter analysis.

2.10.2.2 Introduction

Within the area of organisational change, the term resistance to change is well-documented. Resistance to change is argued to be a main reason for failures in change initiatives, as it tends to introduce unanticipated delays to the process, aiming to keep the current situation (Pardo del Val & Martínez Fuentes, 2003). Current research on resistance to change understands it as a systemic concept, as opposed to older sources – such as managerial literature – which oftentimes viewed the phenomenon as caused by individual psychological factors; another difference between older and newer perspectives on resistance is the view on whether it should be seen as a resource or as a threat – trying to fight it has grown outdated, as understanding it as a form of feedback instead becomes more popular (Blomqvist & Frennberg, 2012).

There might as well be problems with accepting the classical view of resistance. For instance, it might portray the change agent as an inferior player against strong, irrational forces – creating situations where the change agent might either reduce their own liability, such as by assuming that the resistance exists independent of them and therefore turn a blind eye to their own role and involvement. It might also create resistance where there initially was not any: when a change agent expects resistance, they may actively look for it and find it – for example by framing mildly critical voices as resistant thus building discord within the group, creating self-fulfilling prophecies (Blomqvist & Frennberg, 2012).

It is suggested that gender equality action programs that challenge gender order is bound to be met by resistance, judging by literature in the field. This case study is based on an article examining the differences between two different feminist action research projects: (i) the successful FGF project which was not met by resistance and (ii) the not very successful BAF project, which was met by resistance (Blomqvist & Frennberg, 2012; Meyerson & Kolb, 2009). The objective of this work is to extract the relevant lessons from these examples, in order to create better understanding and conditions for making relevant action initiatives work within the context of the RES4CITY project.

2.10.2.3 Description of Case Study

In this section, two different feminist action research projects will be presented; all descriptions of the FGF project are from Blomqvist and Frennberg's report (2012), and all descriptions of the BAF project are from either Blomqvist and Frennberg's or Meyerson and Kolb's report (2009).

In this case study, it is advised to reflect on the reasons why two similar projects might either fail or succeed. It is recommended to think about reasons for and forms of initiatives within the two projects, structural conditions within their organisations, as well as general factors that might benefit or disadvantage gender equality interventions. The findings are presented in the case study solution, along with more detailed accounts of the differences that led to the varying end results. Worth considering is how this case study may have parallels to the RES4CITY project; consider different ways of viewing the structures of the project: (1) RES4CITY as an entity consisting of its internal bodies, (2) RES4CITY as the entity with external partners and collaborators, and (3) RES4CITY with partners and people involved in the project's interventions (for example students involved with micro credentials).

The FGF project

VINNOVA (the Swedish Governmental Agency for Innovation Systems) funded the FGF (Change and gender in FOCUS) project in 2008, which aimed to enhance organisational competitiveness and sustainable growth within an organisation, following the logic that these goals would be achieved as gender equality increases – the program therefore focused on the gender aspect, for instance by increasing awareness and knowledge of gender-related mindsets as well as creativity restricting actions within organisations. Expected outcomes included enhanced organisational competence, integration of new gender perspectives, attracting more female researchers, and developing new application areas and research projects in the civilian sector.

The Information Systems Division of the organisation initiated and organised the planning and launch of the FGF project. Following the decision to apply for funding, a gender researcher and a consultant were added to the project team. The project was set up with a group of core employees who were selected based on their interest and commitment; these, so called, co-researchers came from different parts of the organisation and had varying levels of experience. During selection of co-researchers, the project aimed to include people who could facilitate dialogue and internal communication, including management staff, department managers, business managers, and those working with the official gender equality plan; gender ratio of co-researchers was approximately equal. The co-researchers received training on the theoretical aspects of gender in an organisational context and were involved in defining and implementing project tasks.

The work plan of the project was divided into three main areas: organisational culture, internal processes, and dissemination; these areas were studied to examine gender and equalityrelated processes and practices within the organisation and to take actions for change.

The organisational culture area was studied through seminars, suggested literature and discussions conducted by the project team and the gender researcher from Uppsala University. The co-researchers observed their environment and discussed their observations within the project team, which helped increase knowledge on gender issues and gender theory among the team and other managers and employees. Later, this knowledge was used to work on creating a more creative research environment and improving career opportunities by scrutinising factors that influence career prospects and making career paths more transparent. Metrics were collected to visualise the ratios of female and male employees in different areas, and these were used to discuss the present state, underlying causes, and suggestions to change the situation. Metrics played a significant role in internal processes, but the focus was on increasing knowledge and adapting procedures to facilitate change. The Information Systems division launched an extensive recruitment campaign early in the project, and the project team discussed how to attract female researchers through advertisement formulations. These discussions were then communicated to the department managers in the project team who presented them to the division management group during discussions. Changes were made in advertising and interviewing practices to prevent gender bias in recruitment. As a result, the percentage of female employees increased from 11% to 13.5% over the course of the project.

The project identified project management as an important platform, as project managers have high visibility and are appreciated within the organisation and by customers. However, metrics showed that female researchers were underrepresented, especially among project managers leading large projects. To address this, it was made mandatory for all larger projects to have an assistant project manager, which would allow more employees to develop the skills needed for project management. Additionally, the wage structure was surveyed, and the project team gave input to the gender equality plan, making the plan more comprehensive and explicitly outlining its goals. The project team also emphasized the importance of allowing the knowledge and results acquired during the project to influence the equality plan for a long-term implementation of the results.

Internal and external communication is an essential aspect of any research project; the project team regularly disseminated their results in seminars for management and all employees, and the co-researchers presented the project at department meetings on a regular basis.

The BAF project

The FGF project will be compared to a similar but relatively unsuccessful action research project, referred to as the BAF (Beyond Armchair Feminism) project, in which feminist researchers aimed to create a gender-equal workplace at a large global retail and manufacturing company.

The theory behind the BAF project centered around the idea that gender inequities in organisations stem from ingrained assumptions, values, and practices that grant power and privilege to specific groups of men at the expense of women and other men – from this perspective, the researchers aimed to establish transformative change that fundamentally alter these mentioned power relations. In the project's grant proposal, a "gender lens" was outlined, consisting of four sets of questions to probe the underlying assumptions and practices that sustain gender inequities: (1) questions exploring the deeply entrenched assumptions and values that support hierarchical, competitive, and controlling organisational structures, (2) questions regarding the valuation and devaluation of different work styles and activities, particularly in relation to gender, (3) questions exploring the relationship between the public sphere of work and the private sphere of home and family, and (4) questions delving into the ideology of individualism and competition within organisations.

The BAF project begun as one of the feminist researchers had connections to the founder and CEO of the company, and they both shared a vision of creating a gender-equal workplace; therefore, the project had a clear top-down initiation. During the feminist researchers' initial visits to the organisation, they faced challenges in translating their theoretical framework into practical implementation as people struggled to grasp the broader understanding of gender beyond its association with women. The proposed process seemed ambiguous and lacked specific outcomes and timelines, leading to requests for concrete deliverables. The researchers relied on examples from other projects, but their applicability was not always clear to the BAF project.

To initiate the project, the authors needed to explain how applying a gender lens could be beneficial to the organisations; they emphasized a dual-agenda approach, highlighting how employing a gender lens to identify areas for intervention could benefit both the business and promote gender equity. They shared success stories from other projects where interventions designed to enhance gender equity had led to significant business-related improvements. This resulted in people primarily perceiving the researchers as problem-solvers for business related challenges; many executives volunteered to collaborate on projects that they believed would address pressing business issues within their own departments, and it remained unclear to what extent the group understood or prioritised the gender equity aspect of the researchers' agenda. The partners from the organisation chose one of their manufacturing plants as the starting point for the researchers' project; the plant operated in an outdated manner, with job and level segregation based on gender – women held lower-level positions while men occupied supervisory and management roles, however morale was low among both genders with little hope for advancement. The plant's physical and cultural isolation within the company made it an attractive choice, as it was rarely visited by headquarters and seen as a separate entity. Looking back, the researchers concluded they were directed to this plant because their impact there would be limited, reducing the potential for harm.

2.10.2.4 Case Study Solution

In this section, the cases will be compared to each other in order to extract the meaningful differences setting the two projects apart and leading to differing outcomes. According to Blomqvist and Frennberg (2012), the different outcomes had to do with the lack of resistance to the FGF project, outlined in the following themes; reflections by Meyerson and Kolb (2009) are used to complete the analysis of the outcomes:

1. **Initiation**

The BAF project was started by external feminist researchers who entered the organisation and were friends with the CEO of the company, while the FGF project was initiated from within by the

Information Systems Division with the involvement of a consultant and gender researcher. This form of internal initiation in the FGF project is crucial for legitimacy within a change project – which in the case study was observed to indeed be the case, by an external observer confirming the FGF project enjoyed a high degree of legitimacy at the workplace.

2. **Voluntariness**

The BAF project had internal collaborators assigned by the CEO while the FGF project had a group of voluntary co-researchers, hand-picked based on their expected interest in the project. The FGF co-researchers were a diverse group of middle managers, researchers, project managers, and administrators with a high educational level and as a group they were deemed stable; the stability of the group was due to their voluntary participation and commitment to the project's outcomes as they were interested in the issue. In contrast, the BAF project's collaboration was not entirely voluntary, as the collaborators were assigned by their superiors. Also, it might be argued that the BAF project's failure to communicate its theoretical frameworks in intelligible ways of practical implementation, might have led to less enthusiasm for the project within the organisation.

3. **Epistemological conditions**

The BAF project faced difficulties in applying gender theory to practice, while the FGF project had an easier time due to the gender researcher providing talks and discussions on gender theory early on (Blomqvist & Frennberg, 2012). The BAF project had to consult a group of their armchair and practitioner feminist colleagues to develop a framework and pedagogy for the organisation members to learn the basics about feminist theory for them to learn how to work with a gender lens as a basis for critique; from where they started, most organisation members had troubles understanding the meaning behind words such as gender (Meyerson & Kolb, 2009).

Most of the co-researchers in the FGF project were researchers themselves and were used to academic and scientific processes – such as reading scientific texts – which made it possible to integrate gender research articles into the project. The shared critical and problematising approach of both the natural sciences and gender research disciplines allowed for careful mapping of the organisation and the identification of points calling for change. Co-researchers functioned as gender researchers, making observations on gender practices and masculinity performances in their workplace and identifying relevant points and processes for gendering the work organisation. (Blomqvist & Frennberg, 2012)

4. **Time for research**

In the BAF project, internal collaborators kept asking for concrete outcomes and deliverables, but the researchers couldn't provide them. In contrast, the co-researchers in the FGF project, who were researchers themselves, understood the time-consuming nature of research and the lack of quick fixes. They took responsibility for identifying ongoing goals and targets for change and gave the change process the necessary time.

5. **Equality**

Action research typically involves bridging the gap between the action researcher and the participants to achieve equality in their relationship. This often requires raising the status of participating employees. However, in the FGF project, the gender researcher did not have to bridge any significant status gap; if there was a status gap, it did not favour the gender researcher – in this organisational setting, as in many other societal contexts, natural and technological sciences have a higher status compared to gender research.

In the BAF project, the researchers' goal from the outset was to identify a small group of collaborators who would share their commitment to making changes – they therefore sought to establish an alliance with a willing part of the organisation, with which to collaborate. This approach differs from how it was done in the FGF project. However, it is important to have in mind that the organisations in the two projects were quite different, and thus may have provided different conditions for equal encounters between researchers and participants. In the BAF project, the researchers worked on a manufacturing plant with old-fashioned operational structures characterized by sex-segregated hierarchies disadvantaging female workers – therefore the female researchers' involvement might have been met with resistance from the beginning, given the oppressive structures within the context. (Meyerson & Kolb, 2009)

6. **Powering the core group**

Equal opportunity work is typically managed by employees who do not hold positions of power within an organisation. However, this was not the case in the FGF project. The core group consisted of two out of five department managers, one out of three business managers, and the divisional director was part of the project reference group. This means that the project had the support of individuals in powerful positions, which had an impact on the group's organisational skills, insights and impact. Many of the change agents knew how to manage change and, importantly, what not to do in order to avoid any obstacles.

In the BAF project, the researchers felt that the internal collaborators that had been chosen were not ready to fully collaborate – they were reluctant to enter the proposed processes and had troubles understanding the project's approach enough to responsibly sign on; however, they felt compelled to move forward with the researchers due to the commitment from the senior team, particularly the Chief Executive – in this way the BAF project had support from the top levels of the organisation, yet in practice this was lost due to the assigned collaborators not being ready to collaborate. (Meyerson & Kolb, 2009)

7. Not revolutionary

Change that challenges the status quo can be difficult to implement, especially if it involves gender relations. The changes proposed by the FGF project were not revolutionary, but rather evolutionary in nature. The project did not propose quotas, which could have been met with resistance in an organisation that valued meritocracy. However, the changes made were still significant, as they integrated a gender perspective into the policies, procedures, and practices of the organisation. The project targeted the entire organisation, and the perspective was long-term and continuous.

8. **Not being too sensitive**

When change agents are implementing changes, they may interpret employee reactions as resistance. Looking back at the FGF project, the change agents realised that there were events that could have been classified as resistance had they been more sensitive or anxious about employee responses. For example, there were delays in receiving salary data and in signing the gender equality plan, and employees raised questions about the link between gender equality and productivity during a seminar. However, the change agents did not view these incidents as resistance at the time and were glad they didn't, as the salary data was eventually delivered, and the equal opportunity plan was signed after thoughtful consideration. The questions raised at the seminar prompted the change agents to review studies on the link between gender equality and productivity, and they found that the evidence for a causal correlation is weak. This led the change agents to stress the ethical aspects of equality more strongly in communicating the project, which was appreciated by employees. The BAF project from the start both expected to see and noted resistance from the organisation.

9. The ethical dimension

The FGF project aimed to improve both organisational goals and gender equality; in Sweden, it is deemed politically incorrect to oppose gender equality, which means people may try to hide or redirect their objections to change in such initiatives – for instance by disguising or redirecting resistance into other forms of opposition. To address this issue, change agents should try to uncover and make visible any resistance to gender equality initiatives.

Fair treatment and organisational justice can create a positive attitude towards change and fairness can also be seen as a competitive advantage; a sense of fair play and solidarity are positive qualities that can facilitate efforts to change gender relations. Change efforts aiming at gender equality may be more easily accepted in workplaces where employees have strong feelings of justice. To overcome resistance to change in gender relations, it may be useful to stress the aspects of fair play in the proposed change without silencing opposition.

2.10.2.5 Results and Discussion

Here, in the Results and Discussion section, the lessons learnt from the presented case studies of FGF and BAF will be compared to the RES4CITY project and its gender diversity work. It is however important to keep in mind the different natures of WiTEC's involvement in RES4CITY, compared to the action research projects FGF and BAF – therefore, analogies are at risk of being misleading if too directly applied. Instead, as advised in the Introduction, it was worth considering RES4CITY as a large system consisting of many groups intersecting in either the development or utilisation of the project's interventions. In the following discussion, we will therefore analyze the system at these different levels.

As we learned from studying the FGF and BAF projects, the initiation of a project plays a significant role in its potential for success. Whether the project is started by external researchers or initiated internally within the organisation, the way it is initiated can have a profound impact on its legitimacy and acceptance. In the case of RES4CITY, gender diversity is already included on the agenda; in this internal initiation there is a greater chance of success as the objectives are more likely to be seen as aligned with the organisation's goals, values, and culture.

Voluntariness plays a crucial role in the success in the adoption of perspectives and frameworks, and it can take different forms. In the RES4CITY project, a gender diversity aspect was stipulated to be a part of the project from the beginning – from this perspective, it can be argued that this inclusion was not necessarily voluntarily driven but rather a mandatory requirement; from another perspective, the rate of voluntariness would rather be made visible in whether the interest in and practical applications of gender diversity measures, for instance as proposed in the Gender Equality Plan (GEP). In the practical interventions of the RES4CITY project, such as the educational frameworks and industry-academia partnerships, the issue of voluntariness is once again relevant; here, it is key to consider how gender diversity aspects might be perceived by external collaborators in partnerships, and eventually students and participants – to engage the collaborators in a transparent discourse might be a way to avoid triggering resistance.

As documented in the FGF project, RES4CITY has similar epistemological conditions given the project's ties to academic and educational subjects; as we learned in the comparative case study, this means better conditions for familiarisation with theoretical concepts and knowledge about gender diversity perspectives – and eventually also better implementations of the GEP in RES4CITY's different steps of the project.

Regarding the topic of equality, we consider the co-operating internal bodies within the RES4CITY project to be at similar. On the other hand, it is important to be aware of interactions with external partners during the project – by assuring that the potential status gaps are bridged, a more transparent exchange of ideas and feedback can be attained, which for instance could be key in obtaining information about how specific targeted interventions may have affected the targeted group. On a similar note, the question of powering the core group is here important; core groups can for instance be thought of as being female and marginalised student groups – whose conditions are in focus in the work of WiTEC – and academic and industry partners with special experience and knowledge of these student group's patterns in their local society. Conclusion and Recommendation

2.10.2.6 Conclusion and Recommendations

To conclude the findings in this case study, some success factors in change initiatives have been found:

1) Internal initiation – change projects initiated from within the organisation, involving employees and key stakeholders, tend to have higher legitimacy and acceptance.

2) Voluntary participation – involving individuals who have a genuine interest in the project and are willing to contribute voluntarily increases commitment and enthusiasm.

3) Integration of theory and practice – providing clear and intelligible explanations of theoretical frameworks and linking them to practical implementation helps in garnering support and understanding within the organisation.

4) Adequate expertise and knowledge – having individuals with the necessary expertise and knowledge, such as researchers or professionals familiar with the subject matter, helps in integrating relevant research and effectively addressing the identified issues.

5) Time for research and change process – recognising that research and change take time and avoiding the expectation of quick fixes enables a more thorough and comprehensive approach to achieving the desired outcomes.

6) Bridging status gaps – ensuring equality and raising the status of participating employees can foster better collaboration and engagement in the change process.

7) Alliance with committed collaborators – establishing alliances with individuals or groups who share the commitment to change increases the likelihood of successful collaboration and implementation.

8) Evolutionary approach – implementing changes that are seen as evolutionary rather than revolutionary can help mitigate resistance, especially when challenging the status quo or addressing ingrained gender relations.

9) Addressing resistance – being sensitive to employee reactions and interpreting them as potential areas of resistance helps in understanding concerns and addressing them effectively.

10) Fairness and justice – emphasizing fairness and organisational justice in the change process creates a positive attitude towards change and can be seen as a competitive advantage.

These points therefore lay as foundation for the recommendations of this case study and may be used as a guideline for change initiatives within an organisation.

2.10.2.7 References

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3. Conclusion

The RES4CITY project carried out ten lighthouse case studies as part of Task T2.2 to address specific energy-related urban challenges. These studies demonstrate the economic viability of such interventions and their positive contributions to the energy transition. Additionally, they yield several supplementary advantages, including reduced environmental impact, improved quality of life, and increased competitiveness.

The primary purpose of these case studies is to promote and accelerate the adoption of renewable energy systems in urban contexts. They will serve two key functions. First, they will serve as learning tools within the RES4CITY learning and upskilling programs, offering in-depth and practical examples of topics to be taught. Furthermore, these case studies will act as multipliers for replication, aligning with the objective outlined in WP6 *Dissemination, Communication, Exploitation and Replication*.

By analyzing each of the **ten lighthouse case studies** in detail, it is possible to draw relevant findings that could play an important role in the desired energy transition:

Showcasing the implementation and success of Ireland's first community-owned wind farm as an example, the lighthouse case study developed by the **Tipperary Energy Agency** demonstrates how the adoption of innovative renewable energy projects emerging from local community initiative can contribute to the energy transition and the revitalization of dwindling rural communities. It highlights how, despite the challenges of securing funding and obtaining planning permissions, this type of project can be developed by the community, without recourse to financial and business conglomerates, in a profitable way, generating business opportunities and channeling future revenues into further community initiatives, from renewable energy projects to social interventions. Finally, the lighthouse case study emphasizes how community involvement and ownership are crucial factors in increasing the acceptability and success of this type of project.

The **University of Genoa**'s lighthouse case study evaluates the application of cold ironing technology to supply energy to cruise ships during the hotelling phase, to understand how it can be a viable alternative to the use of auxiliary or main engines powered by fuel oil to aid energy transition, while reducing the environmental impact of this sector. By analyzing energy consumption, pollutant emissions and externality costs for both on-board energy production and cold ironing, this case study assesses the energy, environmental and economic impact of applying cold ironing to a cruise ship during its hotelling phase in an Italian port. This comparison demonstrates that cold ironing technology significantly reduces fossil fuel consumption and greenhouse gas and air pollutant emissions, while ensuring economic viability. Finally, this lighthouse case study highlights the importance of considering the energy mix and externality costs when making decisions about this technology.

Using the Benicalap district of Valencia, the lighthouse case study developed by the **Polytechnic University of Valencia** tackles the intricate challenge of achieving fair carbon neutrality while dealing with a vulnerable population in an expanding tertiary economy, estimating the decarbonization potential at the neighborhood level and creating a roadmap for achieving carbon neutrality. It quantifies greenhouse gas emissions across various sectors and evaluates the proposed measures within distinct lines of action from technical, economic, and environmental standpoints to determine their effectiveness in mitigating emissions. Based on the mitigation roadmap created, the results highlight the significance of self-generation through photovoltaic systems and the implementation of a more sustainable transportation model for reducing emissions. Finally, this lighthouse case study underscores the scalability and replicability of such initiatives while emphasizing the importance of addressing technical and non-technical factors in urban sustainability projects.

The lighthouse case study developed by the **University of Grenoble Alpes** focuses on the transition of Grenoble's district heating network to renewable energies, which is the second largest heating network in France with 178 kilometers and serving 100000 housing equivalents. With a goal of achieving 100 % renewable and recovered energy by 2033, the study examines scenarios like constructing new plants, refurbishing existing ones to use renewable sources instead of fossil fuels, and the incorporation of new biomass sources. It explores the technological aspects of the heating network, the economic considerations for optimal resource control and the involvement of various stakeholders. Finally, this lighthouse case study highlights challenges, including data collection difficulties for decarbonization calculations, and recommends densifying the existing network, exploring partnerships to import combustion materials, and developing a local economic and energy system to achieve sustainability.

The lighthouse case study developed by the **National University of Ireland Maynooth** examines the growth potential of used electric vehicles in the UK market, focusing on industry trends, factors influencing second-life electric vehicle battery expansion, and opportunities and challenges in the reconditioned electric vehicle market. Results highlight the crucial roles of charging infrastructure growth and battery repurposing/recycling facilities in driving the second-life electric vehicles market expansion. Furthermore, technological advancements in battery innovation and recycling methods significantly contribute to the viability and appeal of second-hand electric vehicles. Recommendations emerging from this study include collaboration with leading manufacturers, strategic planning for popular car models, continuous market trend analysis, and battery recycling and health assessment practices to exploit the potential of the growing used electric vehicles market.

Focusing on an abandoned industrial complex in advanced state of decay, located in the urban area of Sassari in Sardinia, Italy, the **University of Sassari**'s lighthouse case study assesses the construction sector's potential to curtail raw material demand through reclamation, recycling, and reuse practices, especially of abandoned materials. In view of Europe's multitude of abandoned and renovation-demanding buildings, this study explores various methodologies and strategies for recycling and reusing raw materials in the construction sector, assessing the embodied energy and carbon and costs of existing material and of new material components, and determining the potential benefits of these practices. The study's outcomes suggest substantial benefits, including reduced extraction, processing, and transportation of raw materials, energy savings, diminished carbon emissions, landfill waste reduction, and urban area improvement.

In alignment with Denmark's objective of achieving full decarbonization in the heating sector by 2035, the lighthouse case study developed by the **Technical University of Denmark** examines the current state of Lyngby municipality's heating network. Additionally, it investigates, from a social sciences and humanities perspective, the ambitious goal of expanding this network to cover 98 % of the urban area and the implementation of decarbonization measures to decrease reliance on natural gas. It not only maps stakeholders' needs but also leverages existing practices, literature, and stakeholder dialogues to provide valuable solutions towards achieving these objectives. The lighthouse case study underscores the critical role of stakeholder engagement and social acceptance, proposing solutions like enhanced communication, collaboration with neighboring municipalities, diversified and decarbonized heat sources, and ensuring certainty in heat supply. Importantly, it highlights that the insights gained from this development can be deployed in other cities and communities.

The **University of Coimbra**'s lighthouse case study explores the potential for collaboration between higher education institutions, deeply committed in the energy transition and decarbonization of society, and industries, recognized for their high energy and resource consumption, in advancing energy transition, decarbonization and smart manufacturing through the implementation of renewable energy projects and the creation of renewable energy communities. By analyzing the development of a renewable energy community at the University of Coimbra and the subsequent integration of industrial consumers, the results show that, notwithstanding the initial costs, this type of projects provide a wide range of advantages beyond mere financial viability, including increased energy resilience, enhanced competitiveness, and reduced carbon emissions and energy expenses. In addition, the environmental benefits can be further enhanced through complementary implementation of carbon capture solutions. Given the potential benefits, this case study underscores the importance of promoting and replicating this model across similar institutions and companies to accelerate the transition towards a sustainable and low-carbon future.

Focusing on the costal urban area of the Swedish west coast, the lighthouse case study developed by **Halmstad University** evaluates the potential of biogas production and utilization as a circular system for bioenergy supply and climate transition. Through the involvement of target groups, this study investigates drivers and barriers to industrial symbiosis within the biogas context, with the aim of identifying suitable forms of stakeholder collaboration and prospecting secondary bioproduct exploration. It underscores the critical role of engaging industrial players to unlock the biogas market's potential and introduces a framework for establishing biogas-based industrial symbiosis, increasing supply and demand. Finally, the study recommends regional strategies, stakeholder communication, and learning from successful cases to promote industrial symbiosis in the biogas sector.

The **WITEC**'s lighthouse case study discusses the concept of resistance to change within organizational change initiatives by comparing two projects with distinct outcomes, one successful, which encountered minimal resistance, and other unsuccessful, which faced several challenges. By thoroughly examining the reasons for varying levels of resistance in these two projects, this study identifies factors that significantly impact the outcomes and can increase the chances of success in similar initiatives. The study recommends considering several key factors, including internal initiation, voluntary participation, adequate expertise, alliances with committed collaborators, and sufficient time allocation for research and change, as guidelines for implementing successful energy transition-related change initiatives within an organization.

These case studies have been prepared to showcase impactful initiatives and outcomes that can help boost the energy transition. They should be actively employed as effective tools for raising awareness and inspiring citizens, companies, and decision-makers. The dissemination of these case studies can play a key role in increasing awareness and tackling some of the common barriers that frequently forestall such projects. It's important to emphasize that these challenges extend beyond economic barriers, such as a lack of capital or high initial investments.

Furthermore, it is of paramount importance that these lighthouse case studies are replicated across a board spectrum of geographical areas to maximize their potential impact. In pursuit of this goal, they should be employed as examples and practical guidelines to facilitate widespread replication. Nevertheless, it is fundamental to acknowledge that replication may not always be straightforward. In such cases, these case studies should serve as foundational resources for specialized and qualified entities in those regions, allowing them to review and adapt the strategies to suit their specific circumstances.