Assessment of the Transition Towards a Future 100% Renewable Energy System in Mallorca

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Synopsis:

The aim of this project is to make an assessment of the future energy system needed by the island of Mallorca in order to fulfill its goal to be 100% renewable energy based in 2050. The research question of this project is ***"How can the energy system in Mallorca be modelled to comply with the objectives established by the Climate Change and Energy Transition Law?"***. Moreover, an analysis of the institutional context is carried out.

Nomenclature

Abbreviations

CAES	Compressed Air Energy Storage
CCL	Climate Change and Energy Transition Law
CEEP	Critical Excess Electricity Production
CO_2	Carbon Dioxide
CSP	Concentrated Solar Power
EU	European Union
EV	Electric Vehicle
HP	Heat Pumps
MLP	Multi-Level Perspective
NG	Natural Gas
PP	Power Plant
PV	Photovoltaic
RES	Renewable Energy Sources
TSO	Transmission System Operator
V2G	Vehicle to Grid

Contents

1 Introduction

Climate change is one of the main issues that have to be dealt with due to its negative impact on the environment and natural ecosystems and consequently, on the economy and health of humanity. This problem has a direct correlation with the greenhouse gas emissions coming from the usage of fossil fuels. The island systems are among the most vulnerable to climate change [Veron, 2019], as the temperature increase have a deeper impact in the normally endemic ecosystems of the islands, the rise of sea level will also provoke the reduction of the territory and the possible intrusion of saline water.

According to the Spanish Meteorological Agency, the increase of the average temperature due to the climate change in the island of Mallorca will be higher than the global average, moreover, a study [Lavola, 2018] supported by the regional government of the Balearic Islands and the Ministry of Environment of Spain analyzing the vulnerability of the region alongside with Catalonia stated that in Mallorca, in addition to the increase of the average temperature, the main factors that will affect the island will be the reduction of the average precipitations and the escalation of extreme events such as heat waves or floods caused by concentrated heavy rains.

Furthermore to the climate change threat, Mallorca has other issues related to its energy system that are problematic. It has a high energy dependency from outside the island and a low ratio of integration of renewable energy sources, the main power plants of the island are still being fuelled by fossil fuels, as well as the majority of the transportation sector. The island bases its economy in the tourism sector, limiting the presence of qualified industrial jobs that could lead the transition to new and more environmental-friendly technologies. Moreover, the human pressure during the touristic peak season, specially in the coastal zones, united with the lack of an effective public transportation system that could help to diminish the usage of cars, increase the levels of greenhouse emissions, surpassing at some points the levels recommended by the Health World Organization. Moreover, the climate change effects would deeply affect the touristic attractiveness of the island, as well as the primary's sector functioning, leading the island to not only an environmental crisis, but also to an economical and social crisis.

In order to fight this impact of climate change in the island of Mallorca and to face the rest of the aforementioned issues, a transformation of the energy system including the transportation sector is mandatory, and therefore, the government of the Balearic Islands issued in 2019 the Climate Change and Energy Transition Law [GOIB, 2019] which sets the objectives for the province in terms of greenhouse gas emissions reduction and renewable energy sources inclusion in the energy generation system and provides the legislative framework in order to make these objectives achievable.

In this project, this law is studied through an institutional analysis, in order to determine how it helps the transition of the energy system and the transportation sector towards a more sustainable future, while at the same time there is an energy system analysis carried out with the energy assessment tool EnergyPLAN in order to study the technical possibilities of this transition by the examination of possible scenarios and assessing them. The theories and methods in which these analysis are based are also explained and the results are discussed upon. To sum it up, there is a conclusion in which the obtained answer to the research question and sub question posed in the report are answered.

2 Problem Analysis and Formulation

This project is centered on the energy system transition of the island of Mallorca. The following problem analysis compares some of the main objectives of the Climate Change Law of the Balearic Islands to the actual state of the island's energy system and the technologies that could be used for the solution of the problem.

2.1 Problem Analysis

As explained in the Introduction, climate change is a major challenge for the world, and also for Mallorca, therefore, the Government of the Balearic Islands issued in 2019 the Climate Change and Energy Transition Law, from now on referred as the CCL, in order to comply with the international commitments of the Paris Agreement and guide the transition of the Balearic energy system to one based on a decarbonized, efficient and renewable energy model [GOIB, 2019]. Even though the law is addressed to all the Balearic Islands, in this project the focus is set on the island of Mallorca, the biggest one of the four in terms of population and energy consumption and generation. Therefore, from now on in this report the other islands are omitted and the spotlight is set on Mallorca only.

The goals for the energy transition are aimed to comply with the European directions to decarbonize the energy system and increase the share of RES in it, as well as reducing the energy dependency of the island. However, when comparing between the situation as of 2018 in Mallorca and the objectives of the CCL, it is seen how the island is far away from these objectives. In this subsection, the current energy system situation of the island is described comparing it to the main goals of the CCL.

In the CCL it can be found the Energetic Transition and Climate Change Plan, which ordinates the objectives and policies that aim to accomplish the purposes of the CCL. This plan establishes the reference indicators of the quotas to be achieved in some key parameters related to the transition to a renewable and sustainable energy system. In broad terms, as the CCL will be analysed further in the Chapter 4, this law aims for three main energy objectives that can be highlighted above the rest of the act. [GOIB, 2019]

- 100% of the energy produced from renewable sources by 2050.
- A 100% emissions reduction by 2050.
- Prohibition of all petrol and diesel vehicles to enter the island from 2035.

In Figure 2.1, it is seen the primary energy sources of the Balearic Islands in 2016. When adding the production of solar and wind energy sources and considering the energy produced using biomass as renewable, not even the 1% of the primary energy demand was covered by RES. Currently, the Balearic Islands only produce 2% of the energy using renewable sources, according to the Balearic government [CAIB, 2018c], therefore, the objective of a full renewable production of energy is far off and with a strong need of both private and public impulse.

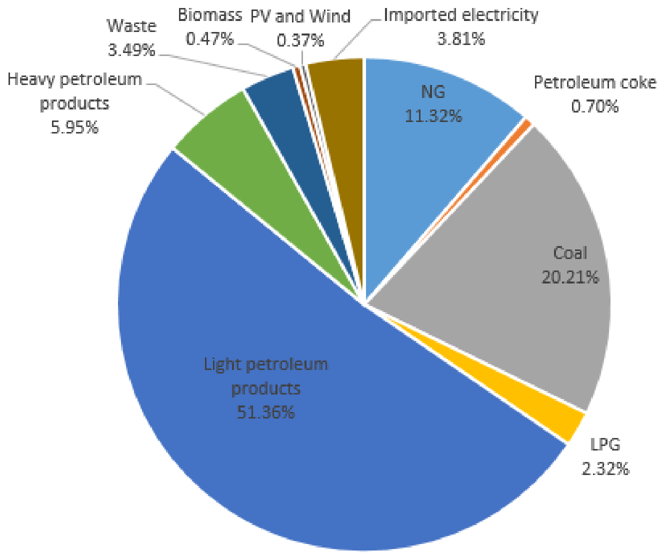

Figure 2.1: Primary energy sources in the Balearic Islands 2016. Based on data from [GOIB, Direcció General Energia i Canvi Climàtic, 2017]

In terms of emissions, during 2018 in the Balearic Islands there was a total of around 9,400 kilotons of CO2 equivalent in greenhouse gases emissions, of which 8,600 kilotons correspond to CO_2 gas itself [CAIB, 2018b]. This can also be deduced by looking at Figure 2.1, even though the data is from 2016, the current energy system has not changed significantly and is still based on fossil fuels which are highly polluting. The central power plant of "Es Murterar" alone, which uses coal as a fuel, is responsible for the 25% of the emission in the Balearic Islands, while the 35 % of the emissions are due to road traffic [CAIB, 2018c].

In regards of mobility, the overcrowding due to tourism and the lack of a proper public transportation network, pushes the majority of the residents in the island to use cars for individual transportation, and the tourists to rent an auto when arriving to Mallorca. Due to this, the Balearic Islands is the community with the highest cars per person ratio of the whole Spanish country, moreover, only 0.18% of the cars registered in Mallorca are not using fossil fuels. Furthermore, the official statistics of the number of vehicles don't take into account the vehicles brought by the incoming tourists by boat when the summer comes, or the total number of the rental cars that circulate through the island in summer, as some car rental companies register the cars in other places with a more favourable tax system in order to save money, and when the summer arrives these cars registered somewhere else arrive to Mallorca contributing to the overall emissions. It could be said that there is a long road ahead in order to promote public transport and the switch from conventional fossil-fueled vehicles to other less-polluting options.

Moreover, the arrival during peak touristic season of planes and cruisers is a major issue due to the high pollution provoked by this two transportation methods. However, the increase of the number of vehicles during the summer season is not the only problem caused by the excessive tourism on the island. More than 10 million people visit Mallorca every year [Balearic Islands Tourism Board ATB, 2017], increasing the Human Pressure Index to maximum values rounding 1.46 millions [IBESTAT, 2020b], this being the estimation of the actual demographic load per day on the island during the peak season. Therefore, during the touristic season, which usually goes from April to October with its peak on the months of July and August, this massive influx of people leads to an increase in the energy demand and transportation and therefore, in the greenhouse gas emissions. Furthermore, this arrival of people creates a demand for hotels or other accommodation facilities, as well as leisure options for these tourists, for example restaurants and bars. Due to the high numbers of tourists, this demand makes a significant impact on the job offers available on the island, which are mostly related to this touristic sector, with a high rate of temporary jobs, and making Mallorca's economy to be mainly based on tourism. There is not an industrial or technological sector that could provide qualified jobs, with the additional problem of the high dependency in only one economic sector, leaving Mallorca with an urgent need of a restructuring not only the energy system and transportation sector, but also the whole socioeconomic structure that should be diversified in order not to depend only on the touristic sector.

2.2 Problem Formulation

As seen in the Problem Analysis, Mallorca has a long road ahead to accomplish the objectives set by the CCL, needing a transformation of its energy system with the support from the authorities in order to make this transition while favouring the creation of new technological sectors that could boost the economy and society of the island, improving its self-sufficiency. This leads to the following Research Question.

How can the energy system in Mallorca transition to comply with the objectives established by the Climate Change and Energy Transition Law?

And the following sub-question:

How does the Climate Change and Energy Transition Law help to this transition?

In this project, the technical assessment of the transition to the target energy system is studied, focusing on the electricity and transportation sector, through the analysis using an energy assessment tool in which the technical scenarios are modelled. Moreover, the institutional context analysis of the energy system helps to understand how this CCL affects the transition, the role of the authorities and its importance in managing the energy system transition for it to be done in a beneficial way for the socio-economic fabric of the island.

2.2.1 Scope and Delimitations

The scope of the project is the assessment of the ongoing transition of the island of Mallorca towards a renewable energy system. In this context, the focus is set on the paper of the CCL in this transition, and the analysis of the changes in the electricity, heat and land transportation sectors. There are some aspects that could be looked upon further in future projects and that are not included in this report because of the time and man-power limitations. The land transportation sector is looked upon but the marine and aerial vehicles are not investigated in depth, although the fuel consumption of the latter is considered in the energy system scenarios due to the high percentage of the fossil fuels destined to it. Moreover, the aspects of energy efficiency or demand side management posed on the CCL are just assumed to have an impact on the electricity consumption of future scenarios but are not comprehensively examined. For the same limitations, the impact of other energy systems surrounding the island on Mallorca's transition, and in reverse, the impact of the island's energy system change on the surrounding energy systems is not taken into account. Finally, the costs and economic aspect of the energy system transition is also not thoroughly explored, as this project is more centered on the institutional and the technical assessment of such transition.

Methodological Framework 3

After defining the logical path and the problems to be resolved that led to the Research Question and the sub question, this chapter explains the theories and methodology used in order to carry out the different analysis done to answer those questions.

3.1 Institutional Analysis Theories and Methods

In order to provide the institutional context to the study of the transition towards a more sustainable energy system on Mallorca dealt with in this project, the Multi-level perspective (MLP) has to be introduced. The MLP was originally developed by Rip and Kemp in 1998 and identifies the socio-technical systems whose interactions produce the technological transitions [Whitmarsh, 2012]. Socio-technical systems are groups of aligned elements necessaries to fulfill society's needs [Kern, 2011]. For example, in Figure 3.1, it is seen the cluster of different elements that conform the socio-technical system of land-based transportation.

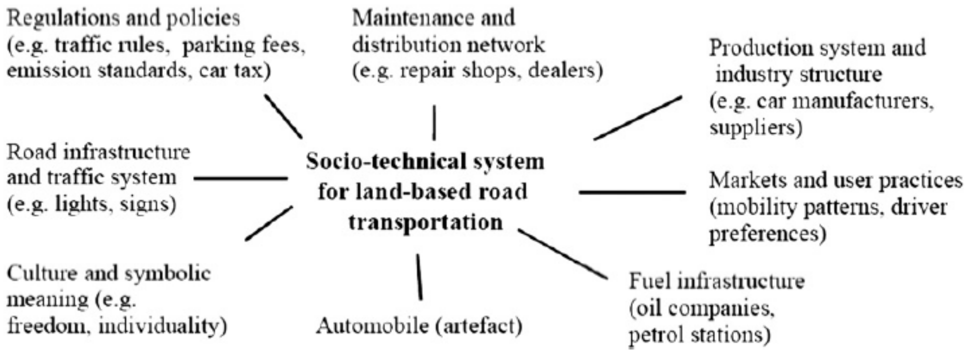

Figure 3.1: Example of a socio-technical system. Source: [Kern, 2011]

According to Frank W. Geels [Kern, 2007], the MLP considers transitions as non-linear processes that result from the interaction between evolution at three analytical levels. These three analytical levels of socio-technical systems are the landscape, the regime and the niches. The landscape is defined as the outer context in which the regime and the niches are embedded in, influencing its interactions and representing the slow-changing developments that cannot be influenced by the actors in the regime or the niche systems in the short run [Geels, 2011].

The regime forms the backbone of the predominant socio-technical systems. It is the conjunction of rules that dictate how the different actors and elements of the social groups conforming the socio-technical structure are arranged. Examples of these rules could be the current institutional agreements and policies, or the lifestyles and cognitive routines of the people that make up society. The regimes are stable, making it difficult for transitions to happen, considering transitions as a transformation from one regime to a new regime [Geels, 2011].

The niches are the alternative spaces in which its actors develop and encourage innovations that differ with the current regime, with the aim of integrating these innovative ideas or technologies into the regime, being important for the transitions as these innovations bring the change to the predominant socio-technical structure [Geels, 2011]. There are three main processes in the niches development:

- Creation of expectations that aim to attract the implication of important actors. As expectations become more accurate and accepted, the niches gain momentum.
- Expanding the assets of the niche by constructing a wider social network.
- Learning processes on various dimensions, for example technical design or policy instruments.

In Figure 3.2 it is seen the structure of the MLP on transitions.

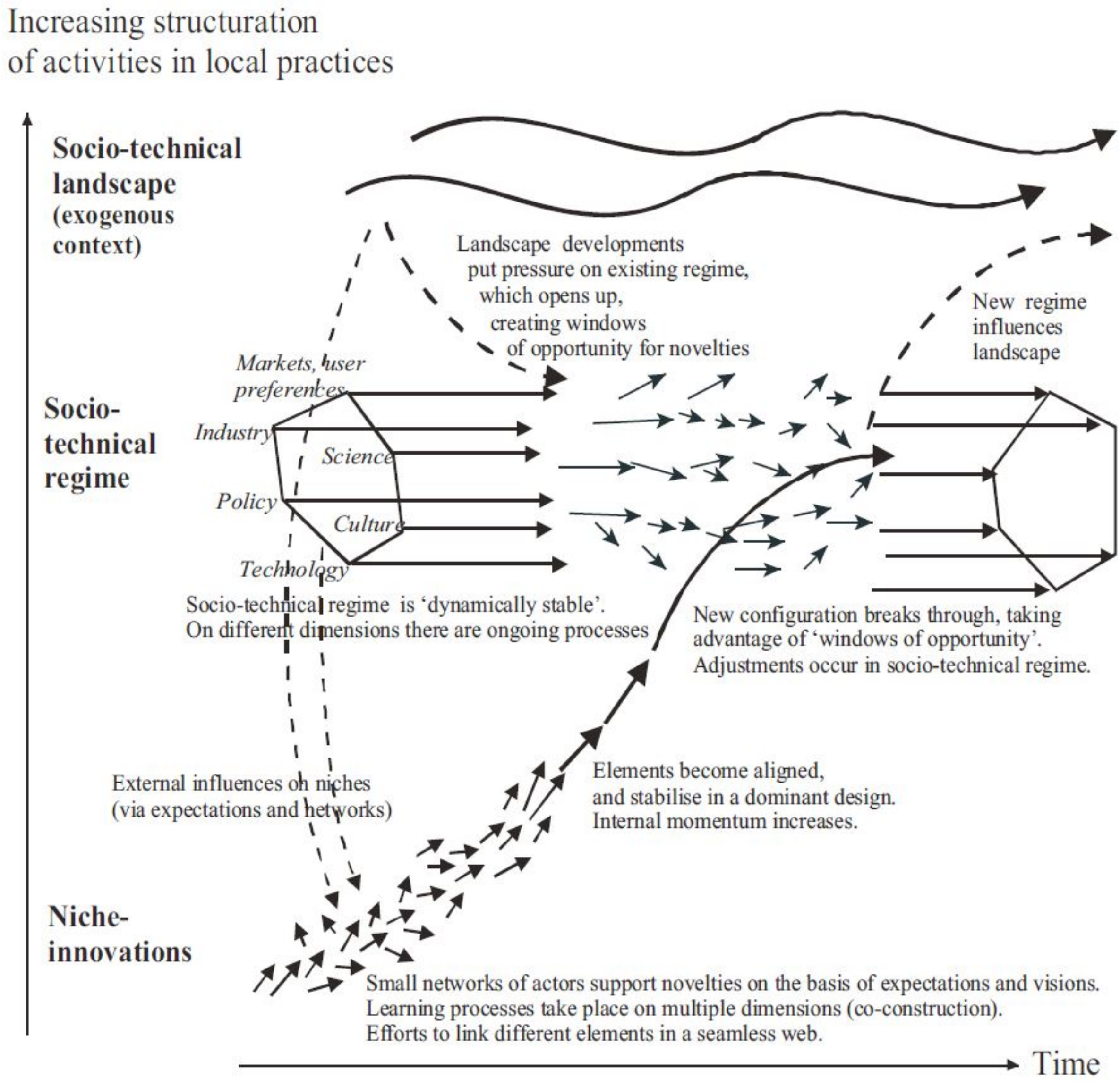

Figure 3.2: The Multi-level perspective on transitions. Source: [Geels, 2011]

Therefore, as seen in Figure 3.2, as the landscape slowly changes, the regime has to adapt to this changes and while doing so the niches that have enough support and acceptation get the chance to enter into the regime using these "windows of opportunity" created by the destabilisation of the regime, adjusting it to the necessities. There is also the possibility that the regime cannot cope with the deep structural reforms needed in order to adapt to the new landscape, thus there is the possibility of a transition to a new regime, which would evolve from the niches that have the tools and support needed to be functional within the new landscape. These transitions are not driven by just one cause or motive, but by a conjunction of processes happening in different levels that interconnect and add up reinforcing each other to advance [Geels, 2011].

Moreover, the institutional analysis includes the study of the three pillars of the institutions of the island in accordance to [Scott, 2001]. The transition processes can also be analysed in terms of evolution in rules, technologies and social structures, which in broad terms form the three pillars of the institutions that are described below:

- **Normative pillar:** Includes behavioural norms, values and role relationships and is described as *"how actors should behave"*.
- **Cognitive pillar:** Includes the belief systems and heuristics that dictate *"how actors usually behave"*.
- **Regulative pillar:** The regulative pillar includes laws, rules and legal obligations which can be supported by sanctions, and is described as *"how actors must behave"*.

In this project, the MLP gives the overview of the socio-technical systems in which the transition towards a more sustainable energy system is taking place, and taking into account the study of the three pillars of the institutions, with special attention to the regulative pillar as the focus is on determining the influence of a law, the institutional analysis of this case is useful for the analysis of the CCL and how it affects the transition in Mallorca, not only from the energy system point of view, but including a broader perspective.

3.2 Technical Analysis Methods

In this section, the methodology followed in order to carry out the energy system analysis of this project is explained. Firstly, the energy assessment tool choice is explained, followed by a guidance on the data collection and the reasons behind the scenarios set up used in the report.

3.2.1 Energy System Simulation Tool

This project includes an analysis of the energy system through the study of different technical scenarios modelled with an energy assessment tool. In order for this analysis to be as accurate and coherent as possible, the energy simulation tool has to be the correct one. According to [Connolly et al., 2009], there are many computer tools that could be used for modelling energy systems, however, the aspects that need to be assessed in this project narrow those options down.

First of all, the program or computer tool used needs to be able to model the energy system in a large, regional-level scale at least, as the island of Mallorca has a considerable energy system. Moreover, the software has to have the ability to model different sectors and their interactions, as the focus of this project is both the electricity and land transportation sector. The idea of the analysis, as said before, is to model different scenarios for its technical assessment, therefore the program chosen has to have that capacity of modelling different scenarios while comparing the same parameters. These parameters are another aspect to take into account, as the program must be able to give an output of, for example, the CO_2 emissions of the energy system and other key parameters for the project that will be further explained. In addition, as the interconnector between Mallorca and the Spanish Peninsula is so important for the island's energy system, the program has to be able to model that interconnection and integrate it to the scenarios.

According to these needs the EnergyPLAN software tool is chosen, being a program with a user-friendly interface being able to create energy system scenarios based on the inputs introduced by the user and resulting as an output reports with the data of the simulated system. As explained in [Connolly et al., 2009], EnergyPLAN is a program that works on a national or regional level, with a scenario time frame of 1 year with an hourly time step simulation. Moreover, EnergyPLAN can model the electricity, heat and transport sectors at the same time and simulate the sector coupling between the different sectors, being able also to simulate 100% renewable energy systems, and this is exactly what is needed for this project. In addition, the output reports are detailed in information regarding a lot of parameters on the aforementioned sectors as well as in the economy and environmental part of the energy systems. The option of including the interconnectors in the energy system is also available in EnergyPLAN, although the input of the capacity for the interconnectors can only be introduced as the combined capacity between all the different interconnectors, affecting the operation for example in this case that there is more than one interconnector connecting the island with the Peninsula and the neighbouring islands.

There are two simulation strategies that can be carried out in EnergyPLAN, the market simulation and the technical simulation. The one chosen has a significant impact on the output, as both have a different way of simulating the operation of the energy system model. As explained in *Finding and Inputting Data into EnergyPLAN* [Connolly, 2015], the technical simulation strategy focuses more on the minimisation of the fossil fuels consumption and the market simulation tries to minimise the operation costs of the energy system against an electricity market described by hourly spot market prices. Therefore, knowing that this project aims to assess the transition from a fossil fuel-based energy system to a RES-based one, the technical simulation is chosen, as it prioritises the introduction of such RES into the energy system. Moreover, the market simulation strategy is centered around cost-efficiency and the economic part of the system, which is not the focus of this project. The technical simulation prioritises the functioning of the units that are less polluting, as well as utilising flexibility across sectors while having a focus on reducing the CEEP, therefore applying sector coupling strategies that are further explained in Section 5.2.

For the input of some of the data EnergyPLAN requires the creation, or the use of the already existent, hourly distributions. These distributions have to be introduced as a text file in the Distributions folder of the program. There have to be 8784 entries of data in each text file corresponding to the number of hours of a leap year, therefore, being 2018 not one of the leap years, the data of a fictional 29th of February is introduced in the created distributions for this project. These data entries are usually between one and zero, as EnergyPLAN takes it as the percentage of the generation or demand. However, if a distribution is entered with real values the program will automatically index the distribution therefore real hourly data from the correspondent sources can be introduced without having to manually index it [Connolly, 2015].

3.2.2 Scenarios in EnergyPLAN

For the technical assessment of this project, three main scenarios are modelled and simulated in EnergyPLAN. The scenarios take place in different years, with the objective to assess the process of the transition towards a sustainable energy system on the island as defined by the CCL. The important years in the development of the transition are 2018, 2035 and 2050, therefore those are the years in which the scenarios in EnergyPLAN take place. The reason why these are the years chosen for the scenarios are explained below.

The 2018 Scenario assesses the situation of the Mallorca's energy system prior to the entry into force of the CCL. This scenario is mainly descriptive and is used as the base scenario upon which the changes on the energy system in the following scenarios are carried out. In this scenario it is shown the model of the fossil fuel-based energy system as it was functioning during the 2018, this is, with the coal power plant being one of the main electricity producers of the island and a sparse RES share, among other things.

The 2035 is chosen as an important year in the transition, and therefore a year worth modelling and simulating in an scenario, because it is the year in the middle of a transition that goes from 2020 to 2050. Moreover, this is the year in which the circulation of all land vehicles using fossil fuels will be banned on the island. Therefore, after the simulation of the 2035 Scenario it can be assessed the situation of the transition while it is still in process, and what are the issues to be solved in order to be able to get to the wanted renewable island in 2050.

The final year of the transition is aimed to be 2050, that is why it is chosen to be one of the important years to be modelled in EnergyPLAN. This is the year in which the transition should be completed and therefore, according to the CCL, the year in which Mallorca is a 100% renewable island. This is the most important scenario, as it is the one assessing if the measures taken by the government and included in the CCL are enough for completing the desired transition and reach the objectives posed by the CCL itself.

Of these scenarios, there are some important parameters of the EnergyPLAN output sheet that are worth highlighting and to be assessed:

- **CO_2 Emissions:** As the main objective is the decarbonization of the island's energy system in order to stop the effects of climate change, the CO_2 emissions of each of the scenarios is a key parameter to be highlighted.
- **RES share of electricity production:** The electricity will be the main energy vector in the future energy system where the fossil fuels are phased out. Therefore, to know how much of that electricity is generated via RES is an important parameter to show how sustainable Mallorca's energy system is in the scenarios based on the future years.
- **RES share of primary energy:** As stated in the CCL, one of the main objectives in the future energy system is the self-sufficiency of Mallorca, therefore, the share of generation of primary energy based on RES which are installed on the island is an important indicator on the status of such self-sufficiency.
- **Fossil fuels consumption:** One of the most important intentions of the future energy system is the phase out of the fossil fuels due to their high pollution and the fact that they are not produced on the island and therefore increase its dependency from external parties.

Moreover, the **Critical Excess Electricity Production (CEEP)** is an important parameter to be taken into account, as its appearance indicates an unbalance between supply and demand that has to be contained. The intention is to keep the CEEP in 0 TWh/year in the scenarios. The CEEP is explained further in the Section 5.2.

3.3 Data Collection Methods

For the institutional and the energy system analysis, a series of sources are used for the documentation and study of the necessary theories and data. In order to have a critical approach when choosing the sources, some important parameters are taken into account, such as the validity of the source or the year of publication. The reliability of a source comes from the author, if it is an official institution or a researcher from a university the source is considered reliable. For the year of publication, the closer in time, the better, as some theories or data may have been changed or improved since the year of publication if it is from more than some years ago, specially in the field of renewable energies, in which the development and evolution of the technologies is advancing fast.

The sources for the institutional analysis are mainly material and lectures from the Sustainable Energy Planning and Management master at the Aalborg University, as well as peer-reviewed articles for the study of the theories and methods upon which the analysis is based. Then, in order to conduct the analysis, the current CCL law and other legislative acts issued by governments or public institutions are used. As the CCL is the main focus of the analysis, it is the most used source of the chapter.

For the transition strategy, the main source used is the *Renewable energies and energy efficiency on the Balearic Islands: Strategy and action lines.* [GOIB, 2015] document issued y the government in which the different technologies and their availability in Mallorca are studied in order to accomplish the transition to a RES-based island. However, other sources are also consulted for that chapter in order to fact-check and to contrast some of the data and to expand some sections.

In the energy system analysis, different sources are used in order to acquire the data and necessary knowledge of the EnergyPLAN program. For the latter, sources from the EnergyPLAN web page and its support material are used that explain the functioning and how to input data into the EnergyPLAN. For the data needed in order to set up the scenarios, official statistics from the government and peer-reviewed scientific articles are used. The creation of an exact model scenario for the whole energy system of the island of Mallorca with the time and man-power resources available for this project can't be 100% accurate, however the data and assumptions used in each one for the scenarios is further explained in Chapter 6. For example, the creation of the 2018 Scenario takes some of the data from the scenario in EnergyPLAN created for the Heat Roadmap Europe project, specifically from the 2015 scenario for Spain [Paardekooper, 2018], as well as from the 2018 Energy Balance of Mallorca provided by the Balearic Government [CAIB, 2018a] and the data of hourly electricity generation and demand from the Spanish TSO [REE, 2020b], [REE, 2020a]. All these sources are considered to be reliable having awareness of the source criticism.

4 Institutional Analysis

In this chapter, the institutional context of the current energy system in Mallorca and its relationship with the CCL is included. It starts with the Multi-level perspective in order to get the overview of the socio-technical systems in which the transition is occurring. This, combined with the analysis of the three pillars of the institutions in relation with the CCL illustrates how this law affects the island's transition towards sustainability and the role of the government in making this transition favorable for the social networks of Mallorca.

4.1 MLP

The MLP can be used for the analysis of policies, as it allows to assess them when it comes to their paper in stimulating socio-technical transitions [Kern, 2011]. In order for these transitions towards sustainability to happen, the interactions between the technologies, institutions and markets are necessary [Kern, 2011], therefore, the role of the institutions is major when it comes not only to promoting via incentives the niches necessary for the transitions to happen, but also in regards of market regulation, sanctions, encouragement of public ownership and democratization, for example. To get to know these institutions and their role in the transition, first, it is necessary to understand the levels in which the socio-technical systems are embedded in. The three levels of socio-technical systems according to the MLP in Mallorca as of 2018 are explained below.

Landscape
The landscape in which the transition of this project is taking place is the current situation world-wide of fighting climate change by reducing the human contribution to it in order to try to minimize the harmful effects not only for the people, but for the whole environment. As explained in the Introduction, these effects of climate change for the island of Mallorca could even be more adverse and ruinous than for non-island environments. From the point of view of Mallorca, the current Kyoto protocols, Paris agreement and EU legislation in regards to climate change could also be assumed to be part of the landscape as it has a big influence on the actions taken y the island's society and are mostly beyond its control. This landscape forces changes in the current regime of Mallorca as the latter is currently not able to keep up with the necessary non-polluting socio-technical structure, creating windows of opportunities for niches to enter the regime.

Regime
The regime of the island of Mallorca in which this project focuses, is a fossil fuel-based energy and transportation sector, with an economy based mainly on tourism. As seen in the Problem Analysis, the situation as of 2018 is an energy sector in which RES are marginal and that, as well as the transportation sector, rely on fossil fuels for its functioning with its corresponding contribution, via CO_2 emissions for example, to climate change. Therefore this regime needs a transition in order to comply with the necessities posed by the landscape of fighting climate change. Moreover, another one of the socio-technical systems supported by the current regime

in the island is the dependence from tourism at an economic level. Both the fossil fuels and tourism reliance show the dependence from the exterior of the island.

This means that the rules or norms that define how the different actors and elements of society are arranged are favouring the socio-technical systems of the fossil-fuel based energy and transport sectors. The way in which this regime does this and how is settled in Mallorca's society is explained further in the analysis of the three pillars of institutions in Section 4.2.

Niches

The main niches relevant for this project are the RES and a decarbonized transportation sector. The implementation of such technologies would require of a transition from this 2018 regime to a future one in which the fossil fuels are marginal. Moreover, the introduction of these niches into the socio-technical structure of the island could open the possibility of a diversification on the economy of Mallorca, making it less dependent on tourism and offering a new range of more technical jobs that could improve the life standards of the population. Furthermore, by reducing the dependency from external actors, both in terms of fossil fuels and tourism, Mallorca would gain autonomy.

These niches' technologies are well tested and technically designed by the scientific and engineering community around the world, making them a viable option. However, in order to gain the necessary momentum for their implementation, these technologies need a stronger support from the institutions and a wider social network in the island of Mallorca. The described levels of socio technical-systems in Mallorca are illustrated upon the structure of the MLP on transitions in Figure 4.1:

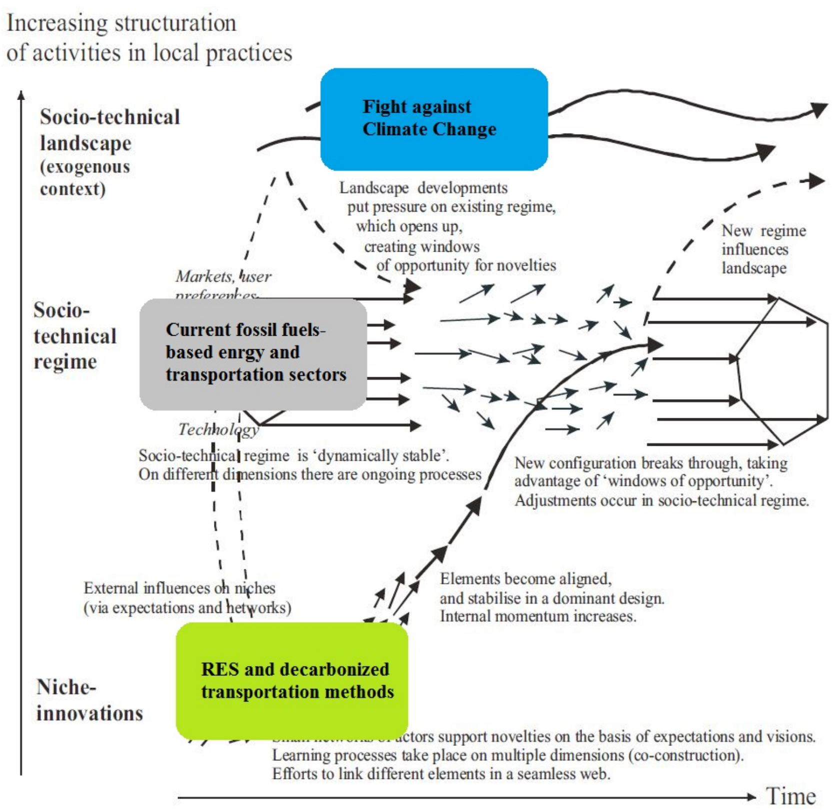

Figure 4.1: Assumed socio-technical systems in Mallorca as of 2018. Based on picture from: [Geels, 2011]

4.2 Pillars of Institutions Analysis

As said in Section 4.1, the 2018 regime is based on the so-called three pillars of the institutions: normative, cognitive and regulative. In this Section the analysis of the aforementioned pillars is conducted. These pillars are interconnected and influence each other deeply, however, the focus of this project is set on the regulative pillar, as it is the one regarding the legislation and laws, as the CCL.

Normative pillar
This pillar includes the behavioral norms and values that shape the way in which the actors interact between them and with the environment. As of 2018, the main actors on the energy and transportation sectors are already aware of the perils of climate change, however, the shift to a decarbonized structure would suppose a great investment and most of the companies are not fond of doing it. However, the EU regulations and international agreements on climate change started to adjust this view, while it is still needed a more specific plan for Mallorca in order to set things clear.

Cognitive pillar
The cognitive pillar, as explained in Section 3.1, dictates how the society and its actors usually behave. The energy sector in Mallorca have always been reliant on fossil fuels and managed by large private companies regulated by the government's laws, although the high lobbyist power of these companies might have influenced the administration's law-making. Moreover, people in Mallorca have internalized the usage of car as a personal mobility method, as said in Section 2.1. In addition to that, the influx of tourists renting cars and the fact of the insularity that limits the options to arrive to the island down to boat or plane, adds up to a fossil fuel dependency rooted into society. This tendency is acquired after years of using these types of technologies, therefore, their use and operation is already well known and is one of the reasons, as well as the investment needed, why the actors controlling these sectors are reluctant to change.

Regulative pillar
In regards to regulation and legislation, the pressure for the regime is already high, as it has been mentioned, the EU regulations and international agreements should make Spain to move towards a sustainability plan for its energy system. However, currently as of 2020 there is still not a unified law in regards to the transition towards a greener energy and transportation sector for the whole country, being the CCL the pioneer in regards of this matter. Therefore, the situation as of 2018 is a set of different norms and laws that plead for the transition towards the decarbonization but without a unified norm that sets specific objectives and impose sanctions to those who don't comply with them, thus the actors of the fossil fuel-based regime do not have neither motivation nor specific examples from the administration to change the technologies' functioning towards a more sustainable one.

As seen in this Sections 4.1 and 4.2, the situation in Mallorca as of 2018 favours the current regime of a fossil fuel-based energy and transportation sector, with insufficient efforts from the regulative side of the island's government in order to make effective the needed transition towards sustainability that is demanded not only by the EU regulations and international agreements, but by the common sense of not wanting to suffer the effects of a climate change that is proven will happen if measures are not taken. In this context, the Climate Change and Energy Transition Law came into force in 2019 and changes the scene. In next Section 4.3, a deeper look into this law and its institutional consequences can be found.

4.3 Climate Change and Energy Transition Law

The Climate Change and Energy Transition Law is approved on the 22nd of February of 2019 by the Parliament of the Balearic Islands. This law is a major step taken in the transition towards sustainability and in this Section, an analysis of this law from the institutional perspective can help to discern why.

First of all, this law aims not only for a transition of the energy system alone, but for the decarbonization of the whole island, by wanting to eliminate the CO_2 emissions of the transportation sector as well. Moreover, the unified guidelines and specific objectives of this law hep to the better understanding of the route to follow for the transition, while at the same time it appeals to a responsible transition, this is, not focusing only on the technological part but helping the society also. Specifically, this law pursues the following purposes [GOIB, 2019]:

- Decrease in the energy demand, prioritizing energy savings and energy efficiency.
- Reduction of the energy dependency of the island, advancing towards self-sufficiency while guaranteeing the maintenance of the security of energy supply.
- Decarbonization and implantation of renewable energy sources into the economy.
- Promotion the democratization of the energy system.
- Intelligent management of the energy demand in order to optimize its utilization.
- Planning and promotion of the resilience and adaptation of the society and productive sectors to the climate change effects.
- Advance to the new energy system with a fair transition that takes into account the interests of the citizens' and sectors affected by it.
- Promotion the increase of the public initiative in the energy commercialization.
- Promotion of occupation in the new economic sectors resulting from the energy transition promoted by this law.

As it is seen from the purposes stated in the law, and for the different range of them, this law manages the transition from different perspectives, unifying the previous set of different regulations under one document that guides the decarbonization of the island while promoting the importance of the citizens' role in the new energy system. Another important feature of this law is the specification in the energy objectives, and enforcing this implementation by imposing sanctions to the actors that don't comply with said objectives. These objectives are the following.

Firstly, it sets the five-year emission reduction targets with reference to 1990 emissions. The distribution of the reduction among the different sectors will be defined by the carbon budgets. The objectives are:

- 40% by 2030
- 100% by 2050

However, as the data corresponding to the 1990's emissions in Mallorca can be inaccurate or missing, according to the Pact of the Majors for the Climate and Energy in Mallorca [Consell de Mallorca, 2018], the reference year for the calculations is set to be 2005.

It establishes also five-year targets for energy saving and efficiency (based on the primary energy consumption registered in 2005). Objectives:

- 26% by 2030
- 40% by 2050

Moreover, it institutes five-year renewable energy (RE) penetration quotas, as a proportion of the final energy consumption. Objectives:

- 35% by 2030
- 100% by 2050

It also states that the transition plan should foresee measures for the self-sufficiency of the territory, so that there is the capacity to generate in Mallorca 70% of the final energy consumed in the island in 2050. This last objective as written in the law is a bit confusing, as it is stated that in 2050 there is the objective of having a 70% RES penetration share on the final energy consumption and at the same time a 100% RES share on the same parameter. In this project, this is assumed to be a mistake in the law, and, looking at the blueprint of the Spanish CCL that the country's government is preparing [MITECO, 2020], it is assumed that the intention of the Balearic CCL is to reach by 2030 a 70% RES share of the electricity production.

In order to boost the share of RES in the system, apart from stating in the document that in all the buildings and installations the usage of RES will be progressively incorporated, the CCL contemplates this series of specific measures:

- Administrative authorization will not be required for RE installations with a rated power < 100kW
- New parking lots on urban land with a surface area $> 1000\text{m}^2$ will be covered with photovoltaic solar panels (PV).
- Existing facilities with surface parking on urban land occupying $> 1{,}500\text{m}^2$ and contracted power superior to 50kW will have to incorporate PV panels.
- New buildings or object of comprehensive reform / change of use with built area $> 5000\text{m}^2$ or floor area $> 1000\text{m}^2$ (except fiber cement roof) will be covered with PV panels.
- New buildings or buildings that go through a change of use (agricultural use not included) on land catalogued by the government as rural must cover all of their consumption through RES as long as there is no prior connection to the electricity grid.

The CCL also regulates a series of government agencies that aim to help from the administration to the organization of the energy transition. The Interdepartmental Commission on Climate Change, the Balearic Climate Council, the Committee of Experts for Energy Transition and Climate Change and the Balearic Energy Institute are created. Moreover, the position of the energy manager will be implemented in each public administration and audits will be carried out in the buildings occupied or owned by said administration. [GOIB, 2019]

In addition, the climate perspective will be incorporated, as well as action plans in laws, budgets and sectoral, municipal and island master plans, including an analysis of emissions and vulnerability to climate change, as well as measures to reduce both and an assessment of energy needs together with measures to meet those needs with RE sources. Moreover, large and medium-sized companies must calculate and accredit their emissions and the Carbon Footprint Registry is created for this purpose. It will also include emission reduction plans and carbon dioxide absorption projects. Furthermore, aid and subsidies are to be granted with the aim of increasing the energy efficiency of buildings and reducing their environmental impact. The efficiency certificate is necessary for first occupancy license to new buildings or completion certificate. [GOIB, 2019]

Every building with facilities of nominal thermal Power > 70kW or contracted electrical Power $>$ 100kW must have energy management plans, this means qualification of the building and thermal facilities, energy savings, Energy Efficiency and RE inclusion measures, annual monitoring of energy consumption and compliance of Thermal Installations Regulation. [GOIB, 2019]

Furthermore, the implementation of the RE installations will be favored to be in the Priority Development Zones, that will be defined by the authorities taking into account not only the availability of the energy source, but also territorial and environmental aspects such as the low productivity or low primary sector interest in the zone, preservation of protected areas, as well as the energetic necessities and available energy infrastructure of the nearby municipalities. Moreover, local ownership of the RES is promoted as well as using RE as a source for new thermal power plants, however, if the usage of fossil fuels was strictly necessary and justified, Natural Gas (NG) would be prioritized over the other fossil fuels. [GOIB, 2019]

The CCL also promotes the use of public transportation and pleads for the rationalization of the individual transportation use, and advocates for this individual transportation to transition into bicycles or vehicles using non-polluting fuels. It also states that the vehicle rental companies, or companies that annually replace$>$ 30% of their vehicles, when renewing the fleet, they must include minimum percentages of vehicles with zero emissions, going from 2% in 2020 to 100% in 2035 , and must communicate to the administrations the necessary information and will identify all the units they have and if they are emissions free. In both private and public parking sites, spots are to be reserved for the emissions-free vehicles. Finally, the most restrictive measures in regards of the transportation sector in this law is the prohibition of entering the island to any diesel vehicle starting from 2025, while from 2035 this prohibition will be extended to all petrol vehicles as well.

Seeing these measures, it can be said that this law is making changes in all three pillars of the current institutional regime. First, the improvement for the transition that means having a unified guide with specific objectives backed up with sanctions, in comparison with the previous regulative pillar in which there was a set of different laws, focusing on different parts of the energy system or the decarbonization and not made on purpose by the government of the island, but by the EU or the Spanish state.

While the approval of this law by itself has already changed the regulative pillar, it could be said that the objectives of this law are to shift the cognitive and normative pillars. It is too early to determine whether the cognitive pillar of society will change, although the actions taken and approved with the CCL certainly plead for it. The measures regarding the creation of the government agencies and forcing the public administration buildings to be the ones setting the example on implementing the energy efficiency actions raises awareness among society. Furthermore, the promotion of local ownership points towards a future in which the main actors of the energy system are not big companies owners of large centralized power plants, but cooperatives or individuals owning smaller and distributed RE plants, while the promotion of public transportation aims to break the current cognitive rule of people using private cars for the mobility on the island.

Moreover, this law reflects on the normative pillar, as it gives a better example to the actors of how they should act specifically in order to comply with the EU directives and international agreements on climate change. However, not all the actors agree with the model of how they should behave posed by the CCL, as this law received criticism from the Spanish Car and Trucks Manufacturers' Association [Balears, 2019], thus showing that not all the actors share the same interest in this transition, although they will have to comply with the objectives or face the transition, making evident the importance of the regulative pillar.

4.4 Conclusion

As seen in this chapter, the CCL gives momentum and legitimacy to the niche of the RES and decarbonization of the transport sector in order to already enter the regime and produce the necessary transition in order to deal with the current landscape characterised by the menace of the climate change, as one of the most powerful actors in Mallorca's society, its government, is giving legitimacy to these innovations and setting a unified regulatory framework that not only centers on the energy system development, but also in concepts of public ownership and innovative democracy, so the transition advances in a way in which the people that conform the society of the island can also get the benefits of this new energy system and the opportunities that come with it.

Transition Strategy 5

In order to achieve the renewable and emission-free energy system in Mallorca, a strategy and a line of action has to be followed. As explained before, the focus of this project is the decarbonisation of the electricity production and the land transportation sector, however, this transition can't be done by just decommissioning the fossil fuel power plants and vehicles and installing RES without studying the possibilities and availability first. In this subsection the renewable technologies available on the island and the possibilities of its implementation are explained.

The Balearic Government issued a report on the strategy to follow towards a sustainable energy system, focusing on the renewable energies availability on the Balearic Islands, named *Renewable energies and energy efficiency on the Balearic Islands: Strategy and action lines.* [GOIB, 2015] that is mainly used as the base for this section. In said document a detailed view of the possibilities of the implementation of renewable on the islands, and therefore also in Mallorca, can be found. The approach is to substitute the existing central fossil-fueled power plants with distributed generation based on renewable energy sources. These potential RES and their readiness in Mallorca is explained below.

5.1 RES

In this section, the proposed RES to be considered for implementation in Mallorca are explained, along with an assessment of the possible availability of such RES on the island.

5.1.1 PV

Photovoltaic panels directly convert solar irradiation to electricity. It is a proven and mature technology used around the world with good results. The performance of the common commercial models is around 16% [GOIB, 2015], with a growing tendency due to the improvement of the developing technologies and methods used for the manufacturing of these panels. Moreover, the price of the PV panels is projected to diminish as time passes, being cheaper in the future.

The potential for implementation in Mallorca of this type of technology is huge. Taking the most conservative data from different sources, the average total annual irradiation, the sum of both incident and diffuse, on the horizontal surface in the Balearic Islands is 1,569 kWh/m^2 [GOIB, 2015], with negligible differences between municipalities. In order to determine the potential use of that radiation, the amount of surface available for the installation of the PV panels has to be quantified.

There is a differentiation between rural and urban ground available for the installations, being the urban ground mainly roofs and parking lots this is, installing the PV panels on already constructed surfaces. rural is the legal term that describes the non constructed terrain for agricultural use or areas without construction, infrastructure or natural interest, the PV plants situated on rural ground are installations on the soil with a different legal regime and that would be occupying space that could be used for the primary sector, thus the differentiation with the urban ground.

For the calculations of the potential, the following technical parameters are assumed [GOIB, 2015]:

- Inclination of the PV panels of 30°with respect to the horizontal plane.
- No solar trackers installed.
- Performance of the PV panels of 13.5%.
- Installations efficiency of 80%.

The potential areas of installation for the PV panels on rural ground is shown in Figure 5.1, where the green zones on the island represent the areas in which PV panels could be installed. The red and white zones are protected or urban areas where it is not legal to install the panels, or areas in which the slope and/or orientation make it not suitable for the proper functioning of the installations.

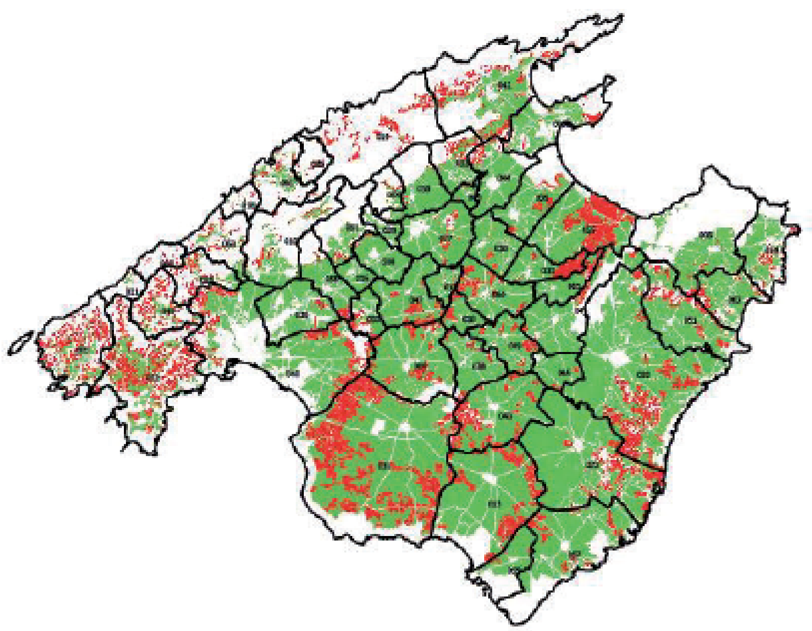

Figure 5.1: PV potential on rural ground. Source: [GOIB, 2015]

These potential areas are categorized based on the orientation and slope in order to quantify the percentage of suitable land use and the incident energy in kWh/m^2. With that, the potential power to be installed per square meter is calculated and with the combination of these data and the available square meters, the overall potential PV capacity on rural ground is obtained. This capacity in Mallorca equals to 60 GW, that would produce 92 TWh of energy per year, and that occupying 40% of the territory, although the intention is not to cover as much as 40% of the island with PV panels [GOIB, 2015]. The calculated potential is based on conservative assumptions, therefore in reality the installed power could be higher. Moreover, seeing the results of these calculations, the projected PV production is enough to cover the total electricity demand in 2018 of the island 20 times, and could cover the aforementioned demand using less than 2% of the territory.

For the urban potential, the calculation of the available roof and parking surfaces is divided into four different categories depending on the use of the urban surface, this is, intensive residential, extensive residential, touristic or industrial. The slope of the surfaces is also taken into account. The resulting calculations give a potential installed capacity on urban surfaces of 1.75 GW, with a projected annual energy production of 2.5 TWh [GOIB, 2015]. This is assumed to be the PV panels that will be installed first in a future energy system, as it is preferable to use roof surface on urban ground that is already constructed than using rural ground and taking that area from the primary sector or natural and non-constructed zones. With the projected electricity production of the PV panels installed on urban surfaces, around 50% of the electricity demand in 2018 could be covered.

5.1.2 CSP

Like the PV panels, the concentrated solar power technology also uses the solar radiation as the source of energy, however, it does not convert it directly into electricity, but into thermal energy. This thermal energy can also be converted into electricity through a thermodynamic cycle. The irradiation needed by this technology is direct irradiation, different than the irradiation needed for the PV that can be direct or indirect. In order for a plant to be feasible, the direct irradiation in the selected location has to be of at least 1,600 kWh/m^2. Moreover, these plants have a huge need of water, requiring between 3.5 and 4 m^3 per produced MWh [GOIB, 2015].

According to the calculation made in [GOIB, 2015], the electricity production of a solar thermal plant in Mallorca equals to 75.56 kWh/m^2. Taking into account the available zones and needed slope and orientation for a feasible installation, the total capacity that could be installed in Mallorca, occupying 738 km^2, amounts to 24,600 MW, with an annual output of electricity production of 56,600 GWh.

Mallorca has the potential for the installation of solar thermal plants, however, these plants would require the same areas as the PV panels and when choosing between these two technologies, in this project the choice is for PV looking into the short and mid-term scenarios, due to its flexibility of installation because there is no a minimum dimension for the plants, the fact that there is less direct irradiation than there is diffuse and the higher maturity of the PV technology. However, for the long term scenario, the possibility of a solar concentrated thermal power plant could be considered, as the storage capacity of these plants could be helpful for the management and integration of this technology in the energy system.

5.1.3 Onshore Wind

Wind turbines use this meteorological condition by converting the wind's kinetic energy through a rotor, a gear box and a generator into electricity. These different elements stand on top of a tower. The downside of this technology is the social acceptance that it might have by the locals of the zone in which the wind turbine is located, due to its high visual impact and the possibility of noise pollution. However, over the years, social acceptance of this technology is growing, associating the image of wind turbines with green energy, and as the technology advances, the turbines are quieter.

For the proper functioning of the wind turbines, the rotor should be placed in windy and elevated places. The potential of such RES in Mallorca depends in a great manner on the availability of areas in which it is permitted to build the turbines and that have enough height and wind velocity in order to make the installations viable. After the study conducted in [GOIB, 2015], the areas available for the installation of wind turbines that have a minimum of 1,800 hours equivalent of wind at a 80 metres height, are shown in red in Figure 5.2.

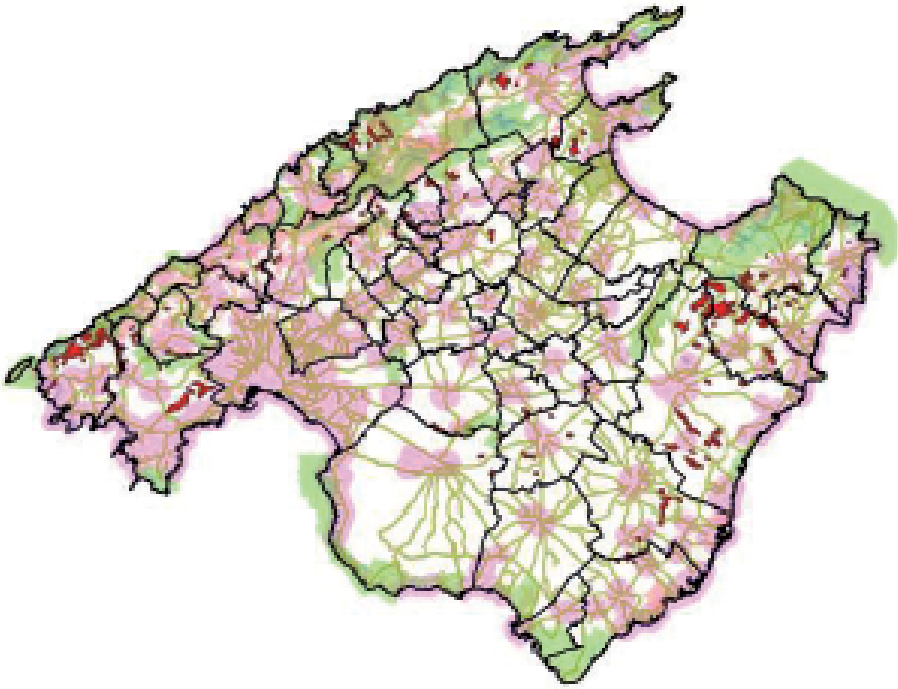

Figure 5.2: Potential locations, in red, for the installation of wind turbines. Source: [GOIB, 2015]

In the Figure 5.2 it is highlighted that the availability of areas for the installation of wind turbines is rather reduced on the island compared to the areas of potential PV panels. After locating these potential zones with wind resource, the calculations of the potential capacity are done. Assuming wind turbines with a rated power of 2 MW, a tower height of 80 meters and taking into account the distance between turbines, the number of wind turbines that could be installed is 1,605, with a combined capacity of 3,210 MW and producing 7,308 GWh per year of electricity [GOIB, 2015]. As happens with the PV potential, the data assumed is conservative, and with the development of the technologies in the near future, the capacity and electricity generated could be even higher than the calculated numbers.

5.1.4 Offshore Wind

Offshore wind turbines have the base of the tower in the sea, making it more difficult for the installation, as there is no current electricity infrastructure in the sea near the islands, and the environmental conditions are tougher than on land, making these wind turbines more expensive to set up and to maintain. This technology, if the aforementioned problems are overcome, has its advantages, as there is a bigger wind resource in the sea and the land problems of social acceptance, noise pollution and visual impact wouldn't affect these installations.

The problem is that the Mediterranean is too deep and there are few available areas for the set up of wind turbines. In Figure5.3, the zones with the necessary conditions for the installation of offshore wind turbines are shown. These areas are selected based on this criteria: A minimum of

2,500 hours of enough wind resource in order to have a feasible functioning, a maximum depth of 50 meters and being more than 1 km away from touristic or protected zones [GOIB, 2015].

Figure 5.3: Potential locations for the installation of offshore wind turbines. Source: [GOIB, 2015]

Even though the potential of installed power is big, it is more cost-effective the installation of onshore wind turbines, and due to the fact that the potential capacity of those in Mallorca is already enough for the demand needs, the installation of offshore wind turbines won't be considered for the future scenarios of this project.

5.1.5 Biomass

The biomass has an organic origin, usually from the primary sector's waste, energy crops or from the forest. The usage given to this biomass as an energy source is to fuel thermal or electricity production installations, being more efficient in the first case (around 80% efficiency) than in the second one (around 30% efficiency) [GOIB, 2015]. Therefore, the biomass potential for the electricity generation per square kilometer is rather low compared to other technologies, as is seen in Figure 5.4.

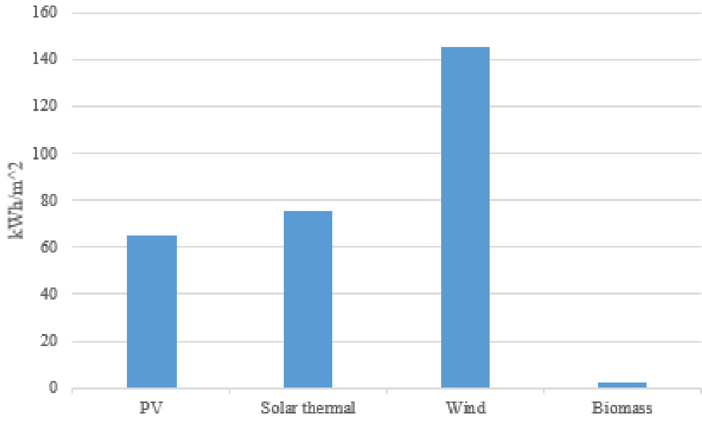

Figure 5.4: Comparison of the performance in electricity production per m^2 of different RES. Source: [GOIB, 2015]

As seen in Figure 5.4, the use of biomass for electricity production is not efficient, and could only have a significant impact on the electricity production when using massive amounts of land for energy crops which would not be viable in the island of Mallorca. This is why in this project biomass is not taken into account as one of the main solutions for the transition towards a renewable energy system, but rather as a support fuel source for the individual heating to take advantage of the natural waste of forests and primary sector.

The biogas also comes from biodegradable substrates that are transformed into biomethane after microbiological decomposing of the organic matter. It can be used as a thermal source, as a biofuel, or injected into the NG grid as it has similar properties to NG and is able to replace it in most of its functions.

5.1.6 Chosen RES

There are other technologies that are not developed enough to be implemented in a large scale, like wave power, or that are not available on the island, like hydro power or tidal power, because of the absence of rivers or tides in Mallorca. Therefore, these technologies are not considered to be implemented in the scenarios of this project. Wave power could be thought of a technology that could get to be implemented, but it still has a long way in order to be mature enough for its installation and the wave potential in Mallorca, and the majority of the Mediterranean coasts, is rather low.

Therefore the main technologies to be used in this project are PV and onshore wind power generation, with the possibility of adding solar thermal in the 2050 Scenario, due to their availability on the island and the maturity of such technologies. This type of distributed renewable generation has its downsides too. The fact that these technologies are based on meteorological conditions, means that the production of electricity is fluctuating not based on the demands, but on external and non-controllable circumstances. Therefore, fluctuating RES can lead to decoupling between the demand and supply of electricity, if the demand is high when there is not enough wind or irradiation, or if there is too much electricity production that exceeds the electricity demands. These situations can lead to shortages of supply and/or critical excess electricity production (CEEP), that cause trouble to the energy system, thus stressing the need for the energy system simulations. The problem with the fluctuating energy sources and CEEP is explained further in the Section 5.2 below.

5.2 CEEP

With a small amount of RES integrated into an energy system based on centralized and controllable power plants, the decoupling between supply and demand of electricity is not a problem. However, as the share of RES electricity production increases, the fact that the most important part of these RES produce the electricity based on meteorological conditions instead of having a supply regulated to fit the demands as it happened in the centralized power plants energy system, can lead to the decoupling between the electricity demand and supply. This decoupling between supply and demand can be a limiting factor for the integration of RES into the energy system, as it can get to situations where there is an excess of electricity production. If this excess electricity production cannot be exported or stored, then it is critical excess electricity production, or CEEP.

In Mallorca, this situation is more limiting for the wind turbines technology, as it is more likely to have a peak of supply during valley hours of electricity consumption on some windy autumn nights for example, while the PV production usually matches better the demand as its peak supply hours are during the central hours of the day, specially in summer, when the demand is the highest [GOIB, 2015]. In a real scenario of an energy system, the possible solution to handle CEEP would be the operator-induced curtailment techniques in which the production of the RES is stopped. This poses the issue of the loss of potential renewable-produced electricity due to lack of planning and it reduces the efficiency and profitability of the RES installations. This is why it is important to simulate the future scenarios in order to minimize the appearance of the CEEP, as it is not the optimum utilization of the RES.

In order to minimize the possibilities of CEEP or supply shortages, there are different strategies to deal with the challenge of an energy system based on fluctuating renewable energies: sector coupling, electricity storage and interconnections. These different strategies and their availability in Mallorca are explained further in the Subsections below.

5.2.1 Interconnectors

Interconnectors are cable infrastructures that allow the exchange of electricity between networks of different regions or countries. In the transition towards a RES-based energy system, interconnectors can help face the challenge of CEEP by transporting the electricity from the markets in which there is excess generation to other regions where that electricity is needed to fulfil the demand, and therefore making it possible to integrate a larger amount of RES. Moreover, interconnectors also help to improve the possible supply shortages in a RES based region when there is no wind or enough irradiation for the PV and wind turbines to supply the electricity demand needs, or in the case of a failure of one of the main power plants, thus improving the energy security of the region [The European Commission, n.d].

In the case of Mallorca, there are currently (as of June 2020) three interconnectors available, a cable connecting Mallorca and the Spanish Peninsula, and two interconnectors linking Mallorca with the two neighbouring islands, Eivissa and Menorca. The main interconnector, or the one with the biggest capacity, is the one connecting Mallorca and the Peninsula. The intention of the Balearic Government is to double the total capacity of interconnectors in the near future in order to help the integration of RES on the island and to move on with the transition [GOIB, 2015].

5.2.2 Electricity Storage

The most mature and contrasted form of electricity storage nowadays is the pumped hydro energy storage. However, in Mallorca the combination of height and water nearby is mainly located in coastal zones, as the island has no rivers, an therefore the construction of this type of technology in these usually protected zones would not be allowed and this type of strategy could only be implemented in a small scale, not enough to provide the necessary storage for a RES-based energy system. Another interesting storage technology is Compressed Air Energy Storage or CAES, where excess power is used to compress air and store it in a cave underground for its potential use later in time. The problem with this technology is that the already operating systems have efficiencies of around 50% and in order to be suitable for large scale operations, it relies on the existence of natural geologically suited caves, as the manufactured ones have technical size limitations [Benedikt Dollinger, Kristin Dietrich, 2013]. These natural caves capable of holding a CAES are not available on the island, thus this technology is discarded as well.

Electrochemical batteries are a well-known and proven way of storing electricity, however, these type of batteries are better used in decentralized and small scale applications, such as the EVs and RES microgrids. Batteries to be used in a large scale are still too expensive for short or mid-term scenarios but could be considered for long term future scenarios if the technology advances enough to be viable in a large scale. It is also worth considering the fact that in the future this electricity storage technology could be declared by the Spanish Government as public utility installations, and this way granting these resources with public aid and incentives [GOIB, 2015].

There are other types of storage, as the power-to-gas, that belong to the sector coupling strategies and are explained in the subsection below. Moreover, as mentioned before, the solar thermal power plants have the possibility of installing thermal storage thus helping the flexibility of this plants.

5.2.3 Sector coupling

As the name suggests, sector coupling is based on the use of the excess electricity to power other sectors and make a more distributed use of the excess electricity production. In Figure 5.5, the principle of sector coupling is illustrated. The three main sectors considered in this project are the electricity, transport and heat sectors.

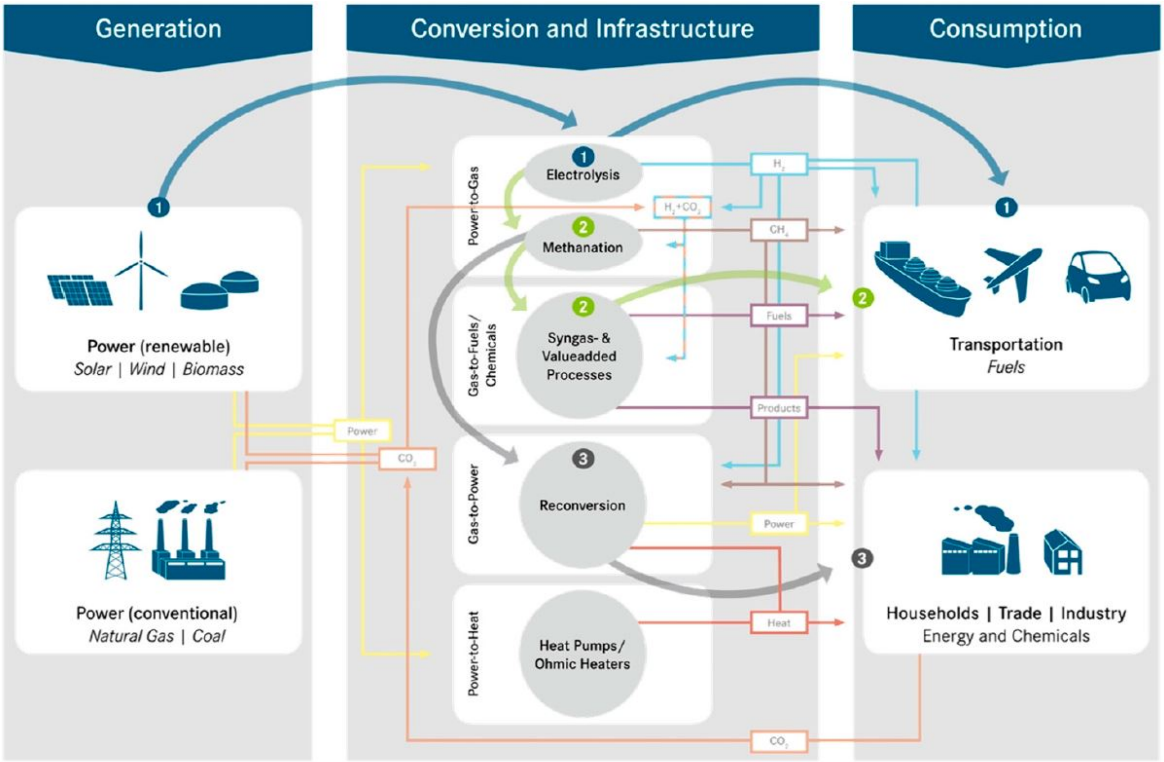

Figure 5.5: The principle of sector coupling [Robinius et al., 2017]

In the traditional fossil fuels-based energy system the three main sectors are separated from each other and don't interact. The centralized power plants produce the electricity supply, the transportation sector is fuelled by petroleum products as well as the heat sector. In a future RES-based energy system the electrification of the transport and heating sector in order to reduce the demand of fossil fuels can lead to sector coupling, as the flexibility derived from it can help reduce both the CO_2 emissions and the CEEP.

The heating sector in Mallorca is not too significant as the heat demand is rather low and concentrated on the winter months, moreover, there is no existing district heating network. However the electrification of the individual heat demand and the substitution of the NG and oil fueled boilers for HPs is a power-to-heat technique that is worth its application in the future scenarios in Mallorca.

Power-to-gas techniques can be applied in the electrolysis process for the production of hydrogen, where electricity and water are converted into the gas. This hydrogen can later be injected into the NG grid after a process of methanation and be used by the industry. Moreover, the hydrogen can later be converted into electricity by the use of a fuel cell which can be useful in the transportation sector, and thus also applying gas-to-power strategies. The storage of the hydrogen as a a gas is easier than the storage of electricity and therefore these power-to-gas and gas-to-power are an efficient way of increasing the flexibility of the energy system.

In a future electrified transport sector, the battery capacity of the EVs can be used effectively as a sector coupling strategy in order to reduce the CEEP by storing the peak production from the RES. Moreover, this stored capacity can also be injected into the grid on times of low RES production to counter the necessity of import or the electricity production using fossil fuelled power plants. Due to the geographical singularity and the short distances of the island of Mallorca, the generalization of the EV is suitable for the private transportation.

The implementation of these sector coupling strategies can allow the transition towards a renewable energy system to happen more efficiently than by using RES curtailment, while still adding flexibility to the system and reducing both the appearance of CEEP and the CO_2 emissions caused by the fossil fuel consumption.

5.3 Conclusion

To sum up the ideas posed in this chapter, in order to carry out the transition towards a renewable energy system in the island of Mallorca, first the decommission of fossil fueled power plants have to be done, starting from the most polluting one that is the coal fuelled power plant of Es Murterar, however, not all the traditional power plants can be decommissioned as there is the need by law to count with these power plants, although this could change in the future. To cover the electricity demand of the island, the future energy system is set to rely on RES such as PV and wind turbines, with the possibility of the inclusion of solar thermal power plants. The implementation of these fluctuating RES in a large scale can lead to CEEP, which would be a problem for the energy system. In order to handle the CEEP, the solution is to increase the island's interconnector capacity as well as implementing sector coupling strategies, such as the use of the EV batteries, hydrogen production or electrification of individual heat pumps for the balancing of the energy system. With these strategies, not only the CEEP can be handled but moreover, the decarbonization of the Mallorca's transport and heat sectors advances for the objective of a emission-free island.

6 Energy System Analysis

In this chapter, the energy system of Mallorca will be analyzed from a technical point of view, by using EnergyPLAN for the modeling of the scenarios.

6.1 2018 Situation

In this section, the situation as of 2018 of the energy system in Mallorca that will be taken as the foundation for the creation of the base scenario in EnergyPLAN is described. Firstly, the electricity generated in Mallorca comes mainly from three thermal and fossil fuels-based power plants, therefore, the electricity production is neither renewable nor emission-free. The biggest plant in terms of power is the "Son Reus" complex, with a rated power of 611 MW consisting of two units of combined cycle fueled by NG. The other NG fueled power plant is the "Cas Tresorer" one, with a rated power of 477 MW and also with two combined cycle groups. Finally, the third major thermal power plant is the "Es Murterar" power plant, which is coal based with a rated power of 585 MW divided in six groups. This power plant is set to be decommissioned starting from 2020, as it is the most polluting one of the thermal power plants of the Balearic Islands, responsible for the 25% of the greenhouse gases emissions of the community. The decommission started on the 1st of January 2020 by partially shutting down two of the six groups, the oldest ones, which will be working a maximum of 500 hours per year, compared to the 1,500 hours that they were operating in the past.

Since 2012, Mallorca and the Spanish peninsula are interconnected with a submarine cable for the exchange of electricity, helping with the supply and stabilization of the island's energy system. This interconnector is known as the Romulo project and has an overall transmission capacity of 400 MW. This interconnector transports the electricity as direct current, and then gets transformed into alternating current in the transforming stations situated in both ends of the cable. In 2018, the electricity exchange using this interconnector was 1.22 TWh. Moreover, the island of Mallorca is interconnected with Ibiza with a cable of 200 MW capacity.

The generation of electricity using RES in Mallorca is mainly based on PV panels and the waste incineration plant located in the Son Reus compound. In Figure 6.1, the installed power capacity in the Balearic Islands in 2018 is shown. As noticeable by looking at the figure, the implementation of RES is far from the one aimed at by the CCL or the European Union.

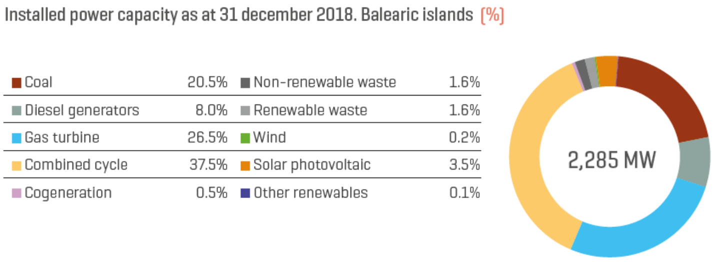

Figure 6.1: Distribution of the installed power capacity in the Balearic Islands in 2018. Source: [REE, 2019b]

In Figure 6.2, the graph of the electricity produced in Mallorca in 2018 sorted out by its source is shown, expressed in GWh.

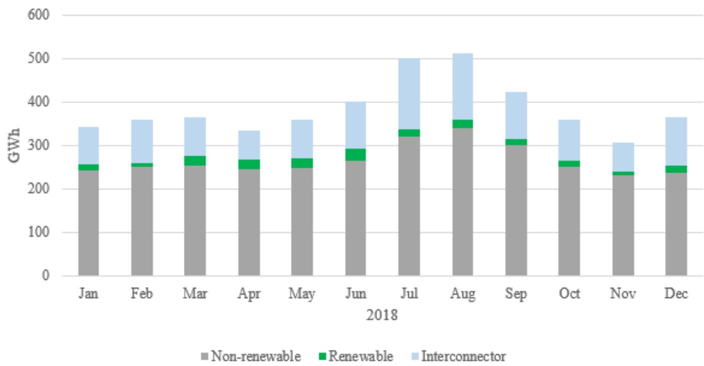

Figure 6.2: Distribution of the Demand Coverage in the Balearic Islands in 2018. Based on data from [IBESTAT, 2020a]

The demand of electricity during 2018 for the Balearic Islands is depicted in Figure 6.3. Around 76% of this demand corresponds to the island of Mallorca alone, with a similar distribution of the coverage.

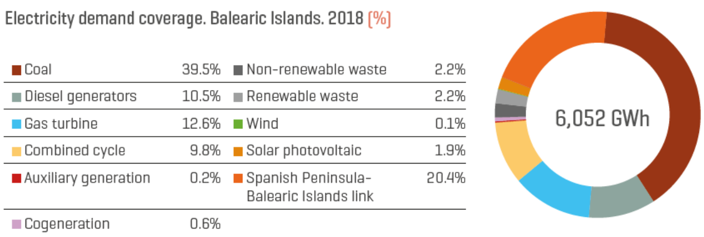

Figure 6.3: Distribution of the Demand Coverage in the Balearic Islands in 2018. Based on data from [REE, 2019b]

As the weather in Mallorca is the typical Mediterranean warm climate, the need for heating is low and centered around the coldest winter months, while the major consumption of energy happens in summer, due to the increase in temperatures which lead to the need of air conditioning, and the massive influx of tourists that make Mallorca one of the world's most visited destination.

The transportation sector in the island mainly relies in individual fossil-fueled cars for individual use. In Mallorca it is seen how adding the vans and the cars, there are more than one car or van per person, specifically 1.28 cars per person in the island of Mallorca.

In Table 6.1, it is shown the number of vehicles registered in Mallorca in 2018, sorted by type of vehicle and fuel used.

Table 6.1: Number of vehicles by type of vehicle and fuel needed in 2018. Based on data from [IBESTAT, 2020c]

	Petrol	Diesel	Other	Total
Cars	351,926	218,008	1,015	570,949
Motorcycles	99,074	31	382	99,487
Buses	13	1,963	14	1,990
Vans and trucks	13,869	88,033	374	102,276
Tractors	0	1,704	0	1,704
Trailers and semi-trailers	0	0	5,704	5,704
Others	1,173	4,982	241	6,396

6.2 Scenario 2018

The situation of the energy and transportation sector described in Section 6.1 is used as the foundation for the creation of the 2018 scenario which will be serving as base for the future scenarios. First, an explanation on how the scenario is set up in EnergyPLAN is necessary, and after that the display and analysis of the results of the simulation is given in this section.

Set Up of the 2018 Scenario

In this subsection, the process of forming the scenario in EnergyPLAN is explained. On the demands side, first the hour distribution of the electricity demand is introduced. To do it, the data provided by Red Eléctrica de España [REE, 2020a] is used. This database provides the MW of electricity consumed each day in Mallorca in a ten minutes time step for 2018. After the process of filtering this ten minute time step data, the hourly consumption is obtained, moreover, as EnergyPLAN requires 8784 hours and 2018 wasn't a leap year, the data for the 29th of February is added by copying the consumption of the 28th of February. The total electricity consumption in TWh/year is the sum of the hourly consumption converted into the aforementioned units. In this electricity demand is already included the electric cooling and heating. Moreover, almost 25% of the electricity demand was covered by the import of electricity from the Peninsula via the Romulo interconnector. The distribution of the import/exports between Mallorca, Ibiza and the Peninsula is obtained from the TSO as well, and filtered in the same way as the electricity demand. The total fixed import/export in TWh/year is the sum of the hourly exchanges. The input of the electricity demand into the program is shown in Table 6.2.

Table 6.2: Input of the electricity demand data into the 2018 Scenario in EnergyPLAN

	TWh/year
Electricity demand	4.63
Fixed import/export	-1.15
Total electricity demand	3.48

As mentioned in Section 6.1, the heating demand in Mallorca is not such an important consumption as it could be in colder countries and it is not the focus of this project, however, in order to be as accurate as possible, the individual heating fueled by fossil fuels or biomass is introduced. The thermal efficiency of the boilers is taken from the Heat Roadmap Europe project, from the 2015 scenario of the Spanish energy system [Paardekooper, 2018]. For the fuel input, the oil type used for the boilers can be found in the disclosure of the petroleum products purchased in Mallorca in [CAIB, 2018a]. There are no coal boilers in use in Mallorca, as the 100% of the imported coal for the island is used in the coal-fueled power plant. For the fuel input of the NG and biomass boilers, it has been assumed that the proportion is the same in Mallorca as in the whole Spanish country, and so the country's input in [Paardekooper, 2018] has been adjusted to the population of the island. The cooling demand is mainly covered with the electricity, therefore it will be assumed that, as mentioned before, is already included in the electricity demand. The input of the individual heat demand into the program is shown in Table 6.3.

Table 6.3: Input of the individual heat demand data into the 2018 Scenario in EnergyPLAN

Fuel input	TWh/year	Thermal Efficiency	Heat Demand
Oil boiler	0.6147	0.8	0.49
NG boiler	1.038	0.8	0.83
Biomass boiler	0.4634	0.75	0.35
Total demand			**1.67**

The industry fuels consumption is extracted from the statistics provided by the Balearic Government [CAIB, 2018a]. The consumption of the industry and the primary sector are taken as one, as the primary sector in Mallorca accounts for around 4% of the energy consumption on the island, which is the same percentage as the industry sector, and it doesn't have a dedicated input tab in the EnergyPLAN. The oil-derivative products, namely light and heavy petroleum products, LPG and petroleum coke are grouped under the Oil consumption in the inputs. The input of the industry's fuel consumption into the program is shown in Table 6.4.

Table 6.4: Input of the industry fuel demand data into the 2018 Scenario in EnergyPLAN

Fuel input	TWh/year
Oil	1.4518
NG	0.028
Biomass	0.027

The transport sector is the main final energy consumer in Mallorca, accounting for the 62.5% of it. As explained previously, the data of the registered vehicles is not entirely useful, as there is a number of rental or tourist's vehicles that are not actually registered in the island. Moreover, land vehicles are only a part of the fuel consumption on the island, with the jet fuel needed for the aviation being a large part of the consumption, therefore the data used for the consumption of the transport sector in Mallorca is extracted from the data regarding the purchases of petroleum products on the island, that can be found in [CAIB, 2018a]. These data are broken down depending on the type of petroleum derivative, and is adjusted to the three types of petroleum inputs for the transport sector in EnergyPLAN. The data is then converted to TWh/year and introduced in the program as the transport demand. The same process is followed for obtaining the LPG used in transportation. The input of the transport demand into the program is shown in Table 6.5.

Table 6.5: Input of the transport sector fuel demand data into the 2018 Scenario in EnergyPLAN

Fossil fuels input	TWh/year
JP (Jet Fuel)	6.0636
Diesel	4.7233
Petrol	2.2001
LPG	0.0168

For the supply of the island's energy system, the first input is the electric capacity of the power plants. As said in Section 6.1, the overall installed capacity of the three power plants of Mallorca is 1,673 MW, of which 585 correspond to the coal power plant of Es Murterar and the rest to the two NG-fueled power plants of Son Reus and Cas Tresorer. In EnergyPLAN is possible to divide the power plants in two categories, if the efficiency between the power plants has a high contrast. In order to determine whether the power plants in the energy system of Mallorca have such contrast in their efficiencies, it has been calculated using the definition of efficiency, in which the efficiency of the power plant is determined as the ratio between the fuel input and the electricity generated, following the example displayed in [Connolly, 2015].

$$\eta = \frac{Electricity\, Output}{Fuel\, Input} \tag{6.1}$$

Both the yearly electricity output and fuel consumption in TWh/year are known for the two types of power plants, extracted from the TSO data of electricity generation in Mallorca [REE, 2020b] and the island's energy balance provided by the Government of the Balearic Islands [CAIB, 2018a], respectively. After doing the calculation of the efficiency for both power plants, the results obtained were very similar, with an approximate efficiency of 35% for both power plant types. Therefore, the input of the power plants capacity is the total capacity of 1,673 MW with an efficiency of 0.36, as shown in Table 6.6.

Table 6.6: Input of the power plants and interconnector capacity data into the 2018 Scenario in EnergyPLAN

	MW-e
Electric Capacity PP1	1,673
Electric Efficiency PP1	0.36
Interconnector capacity	600

The renewable production in Mallorca in 2018 is rather low. The data entered in this EnergyPLAN model comes also from the hourly electricity generation found in [REE, 2020b]. There is no wind electricity production on the island, the only RES are the PV panels and a small amount of other varied RES. The generation peak of the PV panels is 53 MW, while for the other renewables is 1.2 MW. The hourly distribution is introduced in the program, with an assumed installed capacity of 60 MW of PV in order to cover both the real generation of the PV and the other renewables. The input of the RES electricity supply into the program is shown in Table 6.7.

Table 6.7: Input of the RES data into the 2018 Scenario in EnergyPLAN

RES	PV
Capacity (MW)	60
Estimated production (TWh/year)	0.10
Estimated capacity factor	0.18

The fuel distribution used by the power plants for the electricity generation are extracted from the Mallorca energy balance [CAIB, 2018a] and converted to TWh/year, to be entered as an input in the Fuel Distribution tab in EnergyPLAN. The waste is also a part of the electricity generation structure, and therefore is included in the waste tab of the program. To do so, the distribution of the electricity produced by waste is extracted from the TSO [REE, 2020b] and entered, as well as the overall electricity production in TWh/year. As the amount of waste inputted into the plant is not known, the electricity production from waste is taken assuming an efficiency of one and therefore equals the waste input. These inputs are depicted in Table 6.8.

Table 6.8: Input of the fuel distribution for the power plants and waste data into the 2018 Scenario in EnergyPLAN

Distribution of fuel (TWh/year)	PP1	Waste plant
Coal	6.7509	0
NG	1.9	0
Waste	0	0.27

The CO_2 content in the fuels and the investment and operation and maintenance costs are extracted from the EnergyPLAN Cost Database version 4.0 [Team, 2018], except for the fuel costs, that are adjusted to 2018 from the fuel costs available on the 2015 Spain Scenario of the Heat Roadmap Europe project [Paardekooper, 2018]. The values of the CO_2 content in fuels entered in EnergyPLAN is seen in Table 6.9.

Table 6.9: Input of the CO_2 content in fuels data into the 2018 Scenario in EnergyPLAN

Fuel	CO_2 content (kg/GJ)
Coal	98.5
FuelOil Diesel Petrol/JP	72.9
NG	56.9
LPG	59.64
Waste	32.5

Validation

The results of this 2018 Scenario are relevant when compared to the results of the next scenarios, as this one is used as the base scenario upon which the changes on the energy system are introduced in the future scenarios. However, it is important to see whether the output of the EnergyPLAN is similar to the real data. The complete output sheets of the Scenario 2018 is found in the Appendix A, with a more in-depth and detailed depiction of all the inputs and outputs of this scenario. As the inputs are taken directly from the real data, the simulation could differ in the outputs of the fuel consumption of the power plants, however as seen in Table 6.10 the results of the EnergyPLAN simulation of the 2018 Scenario are similar to the real ones according to the 2018 energy balance data provided by the Government of the Balearic Islands [CAIB, 2018a]

Table 6.10: Comparison between the fuel consumption data from the GOIB's Energy Balance 2018 and the output of the Scenario 2018.

	Energy Balance 2018 (TWh/year)	**Scenario 2018 (TWh/year)**
Coal	6.75	6.74
Oil	14.84	15.05
NG	2.78	2.98
Biomass	0.07	0.49
Waste	0.27	0.27

As seen in Table 6.10, the biomass consumption is higher in the modelled scenario than in the real 2018 fuel balance, this is due to the input of the iomass boilers for the individual heating which as explained before, is not based on the real input of Mallorca's biomass use for individual heating that couldn't be found, but on an estimation assuming same distribution as the one in Spain. The main parameters that serve as the reference for the next scenarios are shown in Table 6.11

Table 6.11: Main parameters of the Scenario 2018.

	Scenario 2018
CO_2 Emissions (Mt)	6.98
RES Share of Primary Energy (%)	3.4
RES Share of Electricity (%)	8
Fossil Fuels Consumption (TWh/year)	24.77

As shown in Table 6.11, the CO_2 emissions also correspond to the emissions of the island of Mallorca, taking into account that the 81% of the emissions of CO_2 in the Balearic Islands correspond to Mallorca according to [GOIB, 2009]. Therefore, the difference between the 6.974 Mt of CO_2 emissions corresponding to Mallorca in 2018 according to the Balearic Government and the 6.98 Mt obtained after the simulation of this 2018 Scenario is negligible.

6.3 Scenario 2035

In this Section, the set up and analysis of the results of the 2035 Scenario are explained, in order to have an assessment on the status of the future transition in the middle of the process, as explained in Section 3.2.2. The assumptions needed for the set up of the scenario follow the line actions explained in Section 5.

6.3.1 Set Up of the 2035 Scenario

According to *Hourly-resolution analysis of electricity decarbonization in Spain (2017–2030)* [Marta Victoria, 2019] the electricity demand in Spain is assumed to grow 0.5% per year. This annual demand increment is assumed to be this low because of the implementation of demand side management and energy efficiency measures. Making the calculations for the projected 2035 electricity demand in Mallorca assuming the aforementioned percentage of growth, the result amounts to 5.04 TWh/year of electricity demand. However, when substituting the land vehicles for EVs and the individual boilers for HP in EnergyPLAN, the overall demand of the island in this model exceeds the calculated demand. Therefore, in this scenario it is assumed that the input of the electricity demand will continue to be 4.63 TWh/year as in the 2018 Scenario, and the rest of the electricity demand is added after the decarbonisation of the transport and individual heating sectors. The distribution of the hourly electricity demand remains the same as the one in Scenario 2018. These inputs of data into the program is seen in Table 6.12. Moreover, the fixed import/export of the 2018 scenario is removed, as the exchange of electricity with the Peninsula and the neighbouring islands depends on the new energy system functioning, this will be further explained in this Section.

Table 6.12: Input of the electricity demand data into the 2035 Scenario in EnergyPLAN.

	TWh/year
Electricity demand	4.63
Elec. for transportation	3.04
Electricity for ind. HP	0.54
Total electricity demand	8.21

The heating demand is also assumed to grow a 0.5% per year, resulting in a demand for 2035 of 1.82 TWh/year. To cover that demand in this scenario, the oil and NG boilers are substituted by HP, in order to introduce power-to-heat sector coupling in a scenario with a large presence of fluctuating RES. The assumed COP of the HP is the one used in the 2050 Spain Scenario of the Heat Roadmap Europe project [Paardekooper, 2018], with a value of 2.711. The biomass boilers used in the 2018 Scenario are left untouched, as they are not fossil fuel based. Also the individual heat demand distribution is the same as in the 2018 Scenario. The data introduced in the EnergyPLAN scenario is seen in Table 6.13.

Table 6.13: Input of the heat demand data into the 2035 Scenario in EnergyPLAN.

	Input (TWh/year)	**Efficiency/COP**	**Heat demand (TWh/year)**
Biomass boilers	0.4634	0.75	0.35
HP	0.54	2.711	1.47
Total heat demand			1.82

The industry and fuel tab has some changes with respect to the 2018 Scenario. A hydrogen plant that will be placed on a decommissioned cement production plant is projected to start functioning on 2021 [ENTSOG, 2015]. This hydrogen plant will be powered by a 10 MW PV installation and is planned to supply with hydrogen the NG-fuelled industries of Mallorca, as well as the possibility of using it in the future for the transportation sector. In this 2035 Scenario however, the hydrogen is only used to cover the industry's demand of NG of the former 2018 Scenario. Moreover, the decommissioned cement plant is the only petcoke consumer of the island, therefore, the 1.24 TWh/year of the industry's oil that was due to the cement plant are eliminated from the input of the industry fuel consumption. The rest of the oil consumption is left as in the 2018 Scenario because it is assumed that in order to convert the industry and primary sector fossil fueled machinery to renewable-based machinery will need more time.

Table 6.14: Input of the industry fuel demand data into the 2035 Scenario in EnergyPLAN.

	Fuel Input (TWh/year)
Oil	1.2115
NG	0
Biomass	0.0271
Hydrogen	0.028

The decarbonization of the land vehicles is a big change in this 2035 Scenario, as the CCL bans the circulation of any fossil fueled vehicle on the island from 2035. Assuming an efficiency of 30% for petrol/LPG and diesel vehicles and 85% for EVs [AAU Plan, 2018], it is calculated that the fossil fuel consumption of the land vehicles in the 2018 Scenario can be replaced by 2.45 TWh of EVs functioning on Smart Charge. The difference between dump and smart charge is that the dump one charges the EVs according to the driver's habits, while the smart charges the EVs when there is an electricity surplus due to fluctuating production from the RES with the objective of minimizing the overcharging and improving the grid's stability. In the future energy system the regulation of the battery charging of the EVs can bring a necessary improvement for the adaptability of the electricity system, allowing the set of batteries to act as a large-scale storage system and thus helping to stabilize and couple the electricity demand and the fluctuating supply from the RES.

The transportation sector demand is assumed to grow, as it has been doing through the years. The increase in population and the uncertainty in the success of the public transportation measures in an island that, as explained in Section 4.2, has internalized the use of individual transportation as the way of mobility, advocate for a conservative assumption of keeping the tendency of vehicles growth in Mallorca. With the data available from the government's statistics [CAIB, 2020], the tendency of growth in vehicles on the island is calculated. In Figure6.4, this tendency is depicted as a graph.

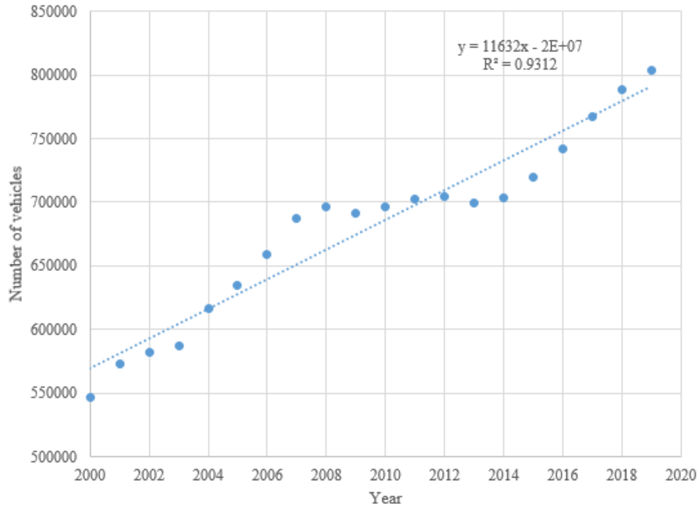

Figure 6.4: Graph showing the growing tendency of number of vehicles in Mallorca. Based on data from: [CAIB, 2020]

With this assumed growth rate, the number of vehicles projected for the 2035 Scenario is 976,702. Taking this also into consideration, the adjusted electricity demand for the EVs in Mallorca is 3.035 TWh/year. The transport demand distribution is extracted from the HRE 2050 Spain scenario [Paardekooper, 2018]. To calculate the capacity of the batteries of the transport sector for the smart charge, an average of the battery capacities and power of the EV for sale in Spain is done, based on the data from *Electric vehicles in Spain: An overview of charging systems* [Juan Martínez-Lao, 2017]. This averaged battery capacity in kWh and power in kW is multiplied by the number of vehicles to get the overall battery storage capacity in GWh and the capacity of grid to battery connection in MW.

Table 6.15: Input of the transport demand data into the 2035 Scenario in EnergyPLAN.

	Input
JP (Jet Fuel) (TWh/year)	6.064
Electricity demand for EVs (TWh/year)	3.035
Number of vehicles	976,702
Capacity of grid to battery connection (MW)	58,602
Battery storage capacity (GWh)	21.5

For the energy supply side, the coal power plant of Es Murterar will be fully decommissioned by 2035, therefore, the power plants' overall capacity in this Scenario is 1,088 MW, resulting from the combination of the two NG-fueled power plants. Regarding transmission lines, in 2020 the interconnector between Mallorca and Menorca started functioning with a capacity of approximately 100 MW [REE, 2019a]. Moreover, the overall interconnector capacity of the island is expected to be higher in the near future by doubling the existing interconnectors [GOIB, 2015]. Assuming that these plans take place and are implemented before 2035, the new interconnector capacity of the 2035 Scenario amounts to 1400 MW.

Table 6.16: Input of the power plants and interconnector capacity data into the 2035 Scenario in EnergyPLAN

	MW-e
Electric Capacity PP1	1,088
Electric Efficiency PP1	0.36
Interconnector capacity	1400

The fuel distribution among the power plants is not fixed anymore but a variable input of NG that is used only when needed. Moreover, the capacity of 10 MW is introduced in the Hydrogen tab of the EnergyPLAN. The waste electricity production and the CO2 emissions per fuel are assumed to be the same ones used in the 2018 Scenario.

The introduction of the RES in the system is the main difference in this Scenario. In 2035, in the middle of the transition, the installation of the RES is assumed to be already growing fast. The new distributions for wind and solar production are extracted from the web Renewables Ninja, and are based on the real production of a PV panel or a wind turbine according to the real meteorological conditions of the island.

In order to assess the amount of RES to be introduced in the energy system for this scenario, a sensitivity analysis is carried out by studying the output performance of the model when introducing a higher amount of RES. As explained in Section 5, the main technology to be used is PV panels, with a minor implementation of onshore wind turbines. This is why the steps on increasing the installed capacity of PV are of 500 MW and the ones of wind introduction are of 100 MW. The increase on the installed RES capacity is carried on until the appearance of the CEEP warning in the EnergyPLAN output, at which point it is considered that the installation of a larger RES capacity would not be efficient. The final installed capacity is seen in Table 6.17.

Table 6.17: Input of the RES data into the 2035 Scenario in EnergyPLAN

RES	**PV**	**Wind**
Capacity (MW)	3,500	700
Estimated production (TWh/year)	5.64	2.18
Estimated capacity factor	0.18	0.36

6.3.2 Results

With the inputs described in subsection 6.3.1, the model is simulated in EnergyPLAN and the output sheets of the EnergyPLAN simulation can be found in the Appendix A. The main output parameters to be taken into account according to Section 3.2.2 are shown in Table 6.18. Moreover, there are other important parameters and dynamics in the simulated energy system as well that are assessed further in this subsection.

Table 6.18: Main parameters of the Scenario 2035.

	Scenario 2035
CO_2 Emissions (Mt)	3.53
RES Share of Primary Energy (%)	36.3
RES Share of Electricity (%)	104.7
Fossil Fuels Consumption (TWh/year)	15.8

Comparing these main output parameters to the objectives established by the CCL for the year 2035, which are a 51% RES share of primary energy and 3,617 kt of CO_2 emissions (corresponding to the 55% reduction of the 2005 CO_2 emissions found in [CAIB, 2018b]), it is checked that the total CO_2 emissions of this 2035 Scenario are in fact lower than the set objective for this year. In regards of the RES share of primary energy, the simulated scenario is behind on the objectives marked by the CCL, although it is remarkable the RES share of electricity which is higher than 100%. This is due to the fluctuating production from the RES that, during the valley hours of the supply need to have the electricity demand covered by the NG fueled PP, while during the peak supply hours the production exceeds the demand and has to be exported via interconnectors. For a better understanding of these dynamics, in Figure 6.5 and Figure 6.6 it is appreciated the output graphics of the EnergyPLAN simulation, for a sample week in July..

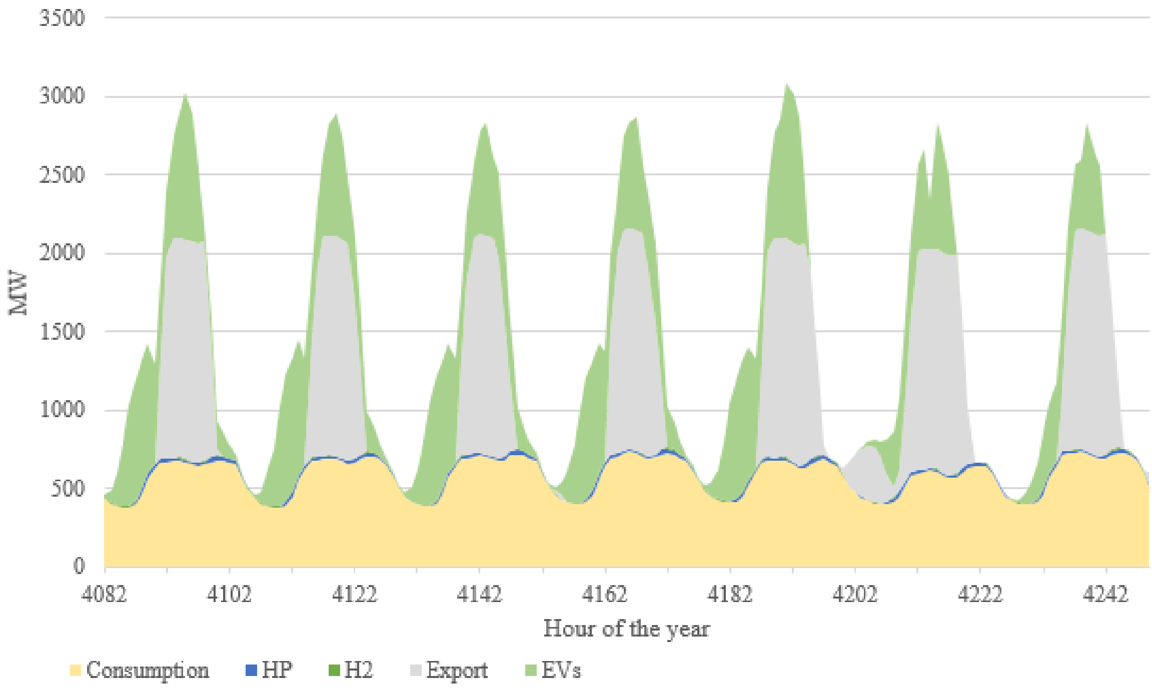

Figure 6.5: Graphic of the electricity demand during a week in July of the 2035 Scenario in EnergyPLAN.

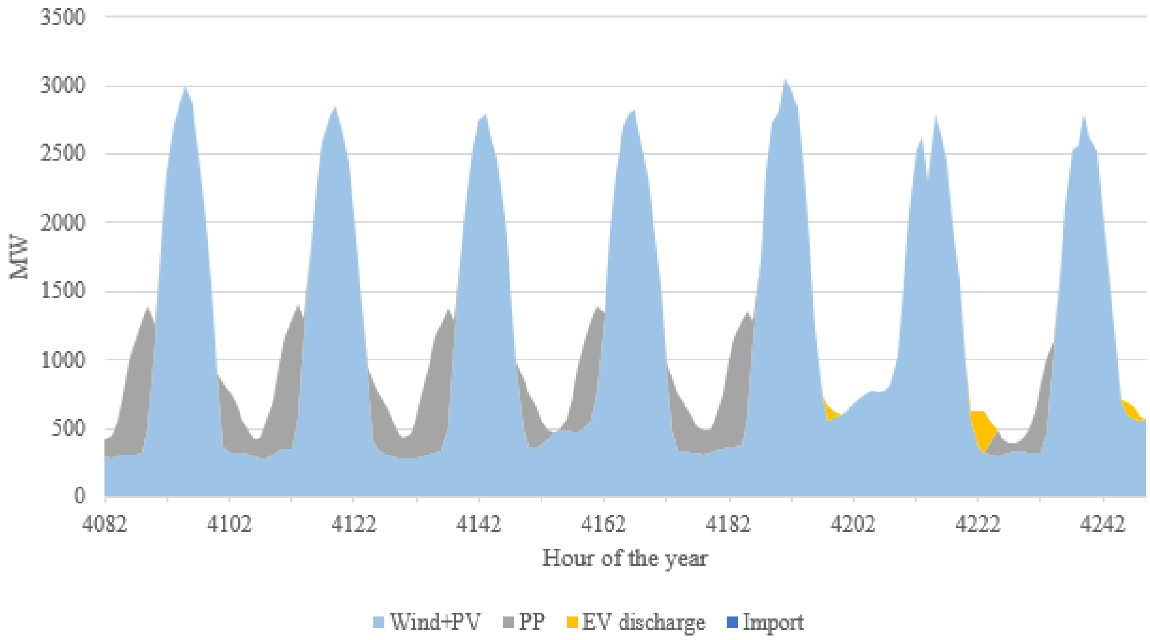

Figure 6.6: Graphic of the electricity production during a week in July of the 2035 Scenario in EnergyPLAN.

Looking at the graphs and results of this 2035 Scenario it is deducted that the path to follow for the transition has to look further into balancing of the electricity production rather than the installation of a higher RES capacity, as the already installed RES plants can cover the electricity demand if storage systems are introduced. Moreover, because of this unbalance between supply and demand of electricity from the RES, the NG consumption from the PP is still high as they are required to work during valley RE production hours. This, added to the fuel consumption of the industry sector and the jet fuel required by the planes, make the biggest obstacle to overcome in the transition towards a decarbonized island of Mallorca.

6.4 Scenario 2050

With the information displayed in Chapter 5 and the results and insights gathered after the simulation of the previous scenarios, the 2050 Scenario aims to fulfill the CCL objectives and to model a future energy system in which the transition towards the decarbonization and the RES implementation have been successful. However, to accomplish this, the model is subject to a series of limitations and obstacles that are further described in this Section.

6.4.1 Set Up of the 2050 Scenario

The electricity demand of the 2050 Scenario follows the same pattern as the one in the 2035 Scenario, this is, growing by 0.5% every year. Calculating the demand for the year 2050, the electricty demand is set to be an overall of 9.26 TWh/year. As with the increase in the electricity demand from the EVs and the individual heating this demand is not met, the input increase to 5.09 TWh per year in order to meet the expected amount. The distribution of the hourly electricity demand remains the same as in the previous scenarios. The input of the electricity demands is shown in Table 6.19.

Table 6.19: Input of the electricity demand data into the 2050 Scenario in EnergyPLAN.

	TWh/year
Electricity demand	5.09
Elec. for transportation	3.58
Electricity for ind. HP	0.59
Total electricity demand	9.26

The heat demand is assumed to continue with the growth calculated in the 2035 Scenario, therefore, it is calculated that the expected heat demand for Mallorca in the 2050 Scenario is 1.96 TWh/year. The COP of the individual HP and he distribution of the individual heat demand are not assumed to change and remain as in the 2035 Scenario. These inputs are shown in Table 6.20.

Table 6.20: Input of the heat demand data into the 2050 Scenario in EnergyPLAN.

	Input (TWh/year)	**Efficiency/COP**	**Heat demand (TWh/year)**
Biomass boilers	0.4634	0.75	0.35
HP	0.59	2.711	1.61
Total heat demand			1.96

One of the main fossil fuel consumers in the 2035 Scenario was the industry, accounting for 1.2115 TWh/year of oil input for its functioning. In 2050 this is expected to change, as the development of the technologies to substitute this oil-fuelled machinery is assumed to be ready. As explained in the 2018 Scenario, this industry consumption is taken as the sum of the consumption of the secondary and primary sectors of the island. When looking at the *Mallorca Energy Balance of 2018* [CAIB, 2018a], this oil consumption is mostly from the primary sector and the petcoke used for the cement plant. Taking into account that the cement plant is already decommissioned in the 2035 Scenario and therefore that petcoke consumption is already non-existent, the light petroleum products of the primary sector are accountable for the 87% of the oil consumption of the industry tab. This machinery is assumed to be the vehicles working in the primary sector, and therefore once the fuel cell vehicles are available in the market the transition to using them is assumed to be achievable. This vehicle consumption however, is not inputted into the transportation tab as the use distribution of these vehicles is not the same as the one of the personal transportation vehicles. The rest of the oil consumption of the industry, amounting to 0.16 TWh/year, is assumed to be substituted also for hydrogen. The biomass consumption is kept as in the 2035 Scenario. This is displayed in Table 6.21.

Table 6.21: Input of the industry fuel demand data into the 2050 Scenario in EnergyPLAN.

	Fuel Input (TWh/year)
Oil	0
NG	0
Biomass	0.0271
Hydrogen	0.74

Regarding the transport demand, the input of jet fuel for the aviation sector is set to be the same as in the previous scenarios. Even though it is proved in these previous scenarios that the jet fuel demand is one of the main polluting factors on the island and is accountable for the majority of the transportation's sector fossil fuel consumption, the fact that the possible alternative solutions might not be fully market available by 2050 and that the aviation sector is an external controlled factor for Mallorca, set an important obstacle for the transition of this type of vehicles. For the land vehicles, the demand in this 2050 Scenario is set to continue with the calculated growth following the tendency explained in the 2035 Scenario. According to the calculations, the land vehicles on the island in 2050 amount to 1,151,183. Assuming the same average capacity and power of the EVs as the one calculated in the previous scenario, the transport demand inputs are shown in Table 6.22 below.

Table 6.22: Input of the transport demand data into the 2050 Scenario in EnergyPLAN.

	Input
JP (Jet Fuel) (TWh/year)	6.064
Electricity demand for EVs (TWh/year)	3.58
Number of vehicles	1,151,183
Capacity of grid to battery connection (MW)	69,070
Battery storage capacity (GWh)	25.326

On the supply side, the interconnector capacity is kept as in the 2035 Scenario. For the traditional power plants fuelled by NG, in this 2050 Scenario it is assumed that the Son Reus power plant is set to be decommissioned and the only NG-fuelled power plant is the Cas tresorer power plant. The reasoning behind this is that it is not necessary in the future RES-based energy system to keep both power plants as just one of them can fulfill the purpose of supplying the necessary electricity when there is no meteorological conditions for the wind turbines or solar powered power plants to provide that electricty demand. Between decommissioning the Cas Tresorer power plant or the Son Reus power plant, it is decided to go with the latter as it is older and with a higher rated capacity (477 MW vs 611 MW respectively), therefore the decision is to keep for energy security purposes the newer NG power plant of Cas Tresorer that has enough capacity to provide such services. Moreover, the efficiency of the power plant is changed, as in the future it is assumed to have improved and it will be closer to an efficiency of 55% [Junjiang Bao, 2019]. The fuel distribution of the PP is set again to be variable to function as the energy system demands. These inputs are shown in the following Table 6.23.

Table 6.23: Input of the power plants and interconnector capacity data into the 2050 Scenario in EnergyPLAN

	MW-e
Electric Capacity PP1	477
Electric Efficiency PP1	0.55
Interconnector capacity	1400

Regarding the inclusion of RES, there are some changes with respect to the 2035 Scenario, these changes are based on sensitivity analyses carried out to find out the best combination of RES in order to increase the RES share and to minimize the CO_2 emissions and fossil fuels consumption of the energy system. Due to the increase in electricity demand and the decommissioning of one of the NG-fuelled power plants, the wind turbines and PV installed capacity is increased in this 2050 Scenario. Moreover, it is considered the installation of a concentrated solar power plant (CSP plant). The annual solar input is assumed to be defined by the same distribution of the PV panels and with the average annual solar irradiation of the Balearic Islands, which is 1.6 TWh/m^2. The installed capacity of the CSP plant is 100 MW and it has a 3 GWh storage capacity, this is the main reason why the CSP was chosen instead of increasing more the PV installed capacity, as the storage is supposed to give a higher flexibility to the energy system. The inputs into the EnergyPLAN model of the RES capacities are shown in Table 6.24.

Table 6.24: Input of the RES data into the 2050 Scenario in EnergyPLAN

RES	PV	Wind	CSP
Capacity (MW)	4,000	800	100
Estimated production (TWh/year)	6.44	2.49	0.48
CSP Storage (GWh)	x	x	3

In order to meet the hydrogen demand of the industry sector, the electrolyser capacity of the hydrogen power plant in Lloseta has to be increased to 106 MW. Moreover, a hydrogen storage is installed with a capacity of 5 GWh for the same reason as the CSP storage, in order to increase the flexibility of the energy system. The waste electricity production and the CO_2 content in the fuels are kept the same as in the 2035 Scenario.

6.4.2 Results

After running the simulation in EnergyPLAN the main parameters of the 2050 Scenario are shown in Table 6.25. The rest of the output parameters are found in the input/output sheets of the program in the Appendix A.

Table 6.25: Main parameters of the Scenario 2050.

	Scenario 2050
CO_2 Emissions (Mt)	2.38
RES Share of Primary Energy (%)	51
RES Share of Electricity (%)	100.4
Fossil Fuels Consumption (TWh/year)	9.76

Comparing these results to the objectives set by the CCL it is obvious that the modelled energy system is far from the thresholds that are supposed to be achieved by this 2050 Scenario. The CO_2 emissions are lower than in the 2035 Scenario, however they are far from the 0.8 Mt set by the CCL. The same happens with the RES share of primary energy, which is also higher than in the 2035 Scenario just half of the 100% share stated by the CCL.

This is mainly due to the jet fuel demand by the aviation sector. It amounts for more than half of the fossil fuels consumption of the island and CO_2 emissions. The other fossil fuel demand of the island is the NG used for the power plant. It is also noteworthy the amount of electricity from the RES exported via interconnectors, which amounts to 2.87 TWh/year. These energy system dynamics are observed better in Figure 6.7, Figure 6.8, Figure 6.9 and Figure 6.10 that show the graphs of the energy system's functioning during a sample week in July. These graphs and the energy system dynamics modelled by the EnergyPLAN are explained further below.

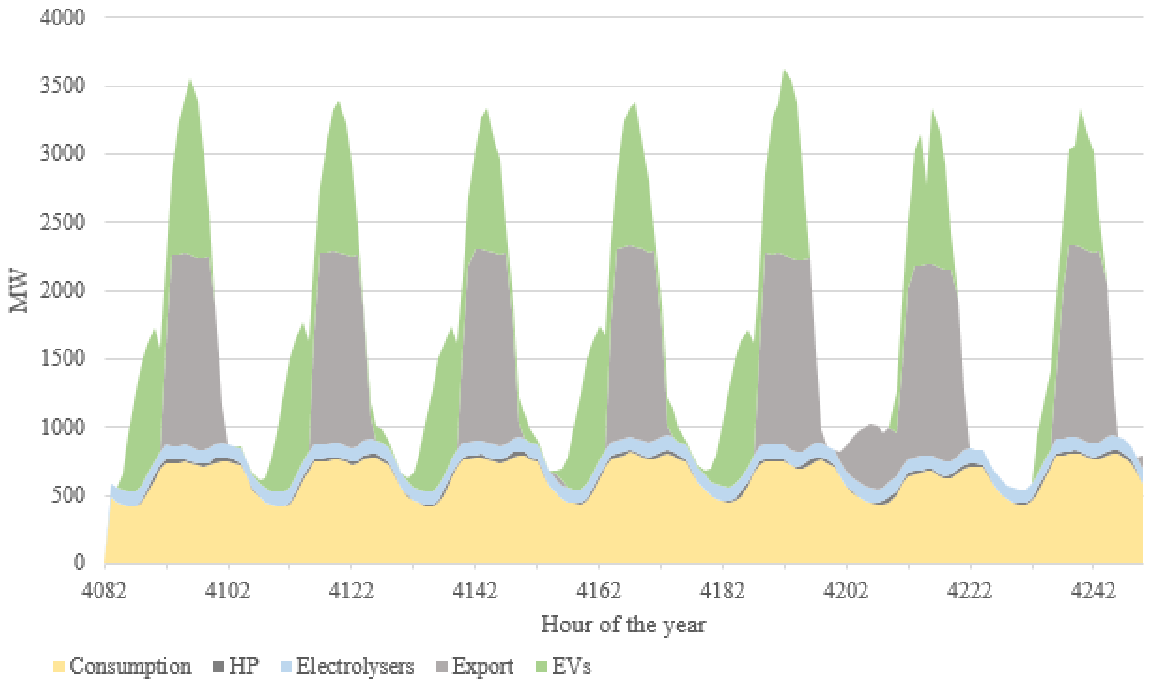

Figure 6.7: Graphic of the electricity demand during a week of July of the 2050 Scenario in EnergyPLAN.

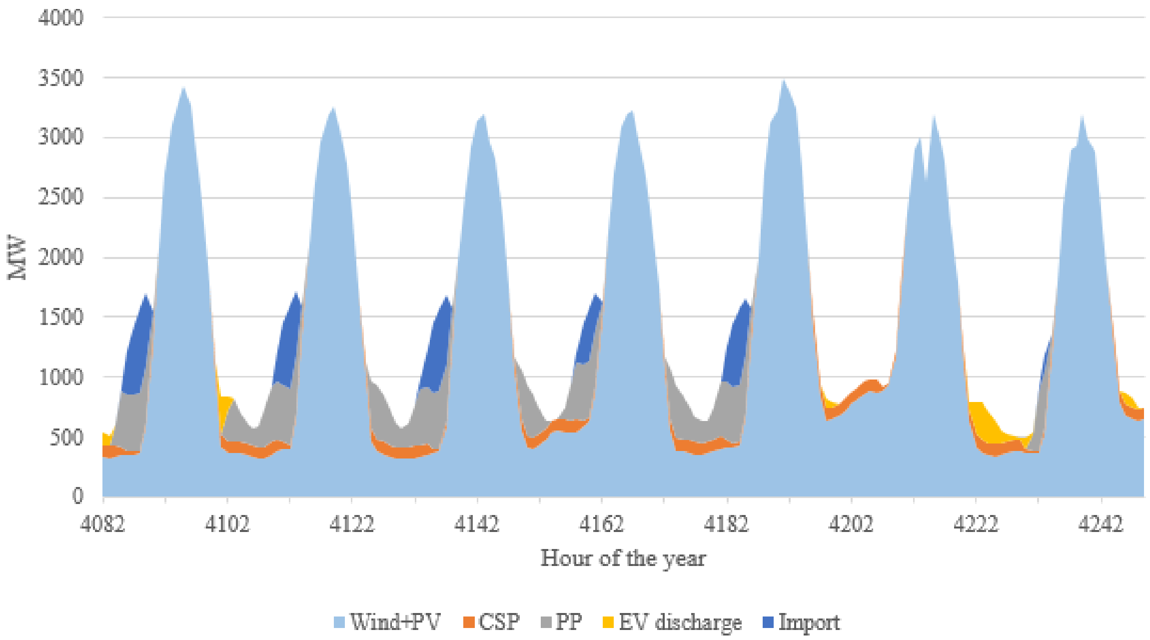

Figure 6.8: Graphic of the electricity production during a week of July of the 2050 Scenario in EnergyPLAN.

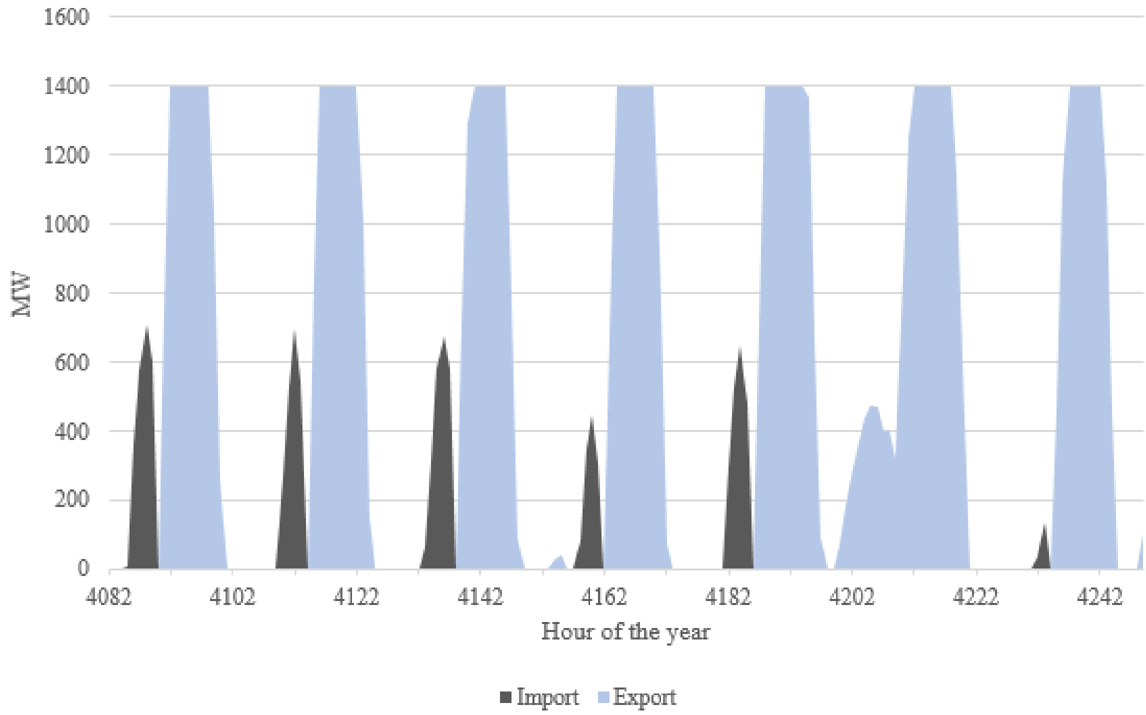

Figure 6.9: Graphic of the electricity imports and exports during a week of July of the 2050 Scenario in EnergyPLAN.

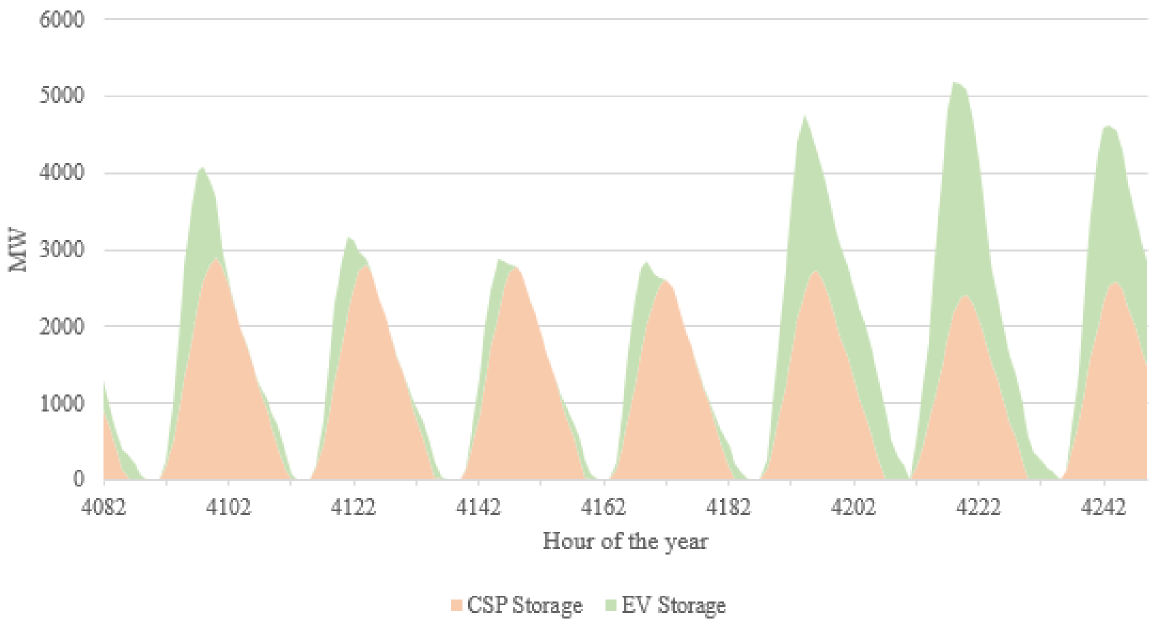

Figure 6.10: Graphic of the storage of the EV batteries and CSP plant during a week of July of the 2050 Scenario in EnergyPLAN.

The dynamics of the energy system is seen in these graphics. First, the EnergyPLAN model is prioritising the coverage of the demand with the RES supply. If the demand is not met by the RES production, then the system's next step is to use the stored electricity in the batteries of the EVs and discharge it into the grid. This is subjected to the conditions that there is enough stored electricity in the batteries after supplying the transport demand. If that is not possible, the PP starts functioning in order to fulfill the unbalance between supply and demand. However, there are times in which even with the PP producing the maximum it can, the demand is not met, that is when the system is forced to import the electricity via interconnectors. It is worth noting that this electricity from the nearby energy systems coming through the interconnectors is not counted as RES-based produced electricity. As explained in the Section 2.2.1, the neighbouring energy systems are not modelled, and therefore the program assumes that the electricity coming from other energy systems is generated using the same PP introduced in the inputs of the model as the PP1, in this case a NG-fueled PP.

There are times however, specially in the central hours of the day when the PV production is peaking, in which the supply of RES exceeds the electricity demand. In these cases, first the electricity produced via RES is used to supply the said electricity demand, it is noteworthy that the electricity produced by the CSP is stored to be used when needed even if there is no sun, this is a useful flexibility strategy. Then it is prioritised the electricity export of the surplus electricity, and when this export reaches the maximum capacity of the interconnectors, the batteries of the EVs are charged. This is an important aspect of the simulation, that the V2G is used for balancing the CEEP, thus not using the batteries' capacity to try to minimize the PP production but for the security and balance of the energy system. This can be changed if in the simulation strategy tab of the EnergyPLAN model is chosen V2G to balance the production from the PP and electricity exchange, then the situation changes and improves in terms of CO_2 emissions and PP usage, but a 3500MW interconnector capacity would be needed.

In the output sheets there is the warning of the CEEP, however it is due that during one single day of April there is an overproduction of 619 MW of RES electricity that can't be stored or exported. As it only happened on one day of the whole year, this minor inconvenience is considered not enough to dismiss the model, but it is interesting to explain the reason why it happened. As explained before, when there is an electricity surplus and the export capacity is full, the rest of that surplus is bound to charge the EV batteries. However, there are two hours in this model in which once the maximum export capacity of the interconnectors is met, the EV batteries connected at that moment to the grid are also at full capacity and can't deal with that surplus of electricity, therefore resulting in two hours of CEEP in which 142 MW and 692 MW of RES electricity production are lost, because in reality curtailment techniques would be applied in order not to cause harmful disturbances in the energy system.

This shows how important is the simulation of the energy system beforehand and the complexity of managing a future energy system with such a high implementation of RES. However, the benefits of it are clear when seeing the reduction on the CO_2 emissions that it implies the shift to a more renewable-based energy system.

6.5 Conclusions

In this chapter it is checked that the outputs of the model of the 2018 Scenario correspond to the real data from the government's statistics and therefore it can be used as the base scenario upon which the changes in the future scenarios are carried out. In the following 2035 Scenario the electrification of the heat and land transportation sector are carried out, as well as the decommissioning of the coal PP, the increase of the interconnector capacity and the installation of the hydrogen electrolyser and implementation of wind and PV. After running the simulation of the model in EnergyPLAN, the results show that in the middle of the transition the problem of flexibility on the electricity sector and the oil consumption from planes and industry are the main issues to take into account. In the final 2050 Scenario there is increased demands and RES capacity, including the installation of a CSP power plant with storage, just one PP with a better efficiency and an increase of capacity of the electrolyser as it is assumed to cover the former oil demand of the industry sector. The model aims to comply with the objectives posed by the CCL but falls short as the jet fuel and NG consumption still have a significant impact on the CO_2 emissions of the island.

7 Discussion

Looking at the results of the EnergyPLAN simulations, it shows the importance of planning future energy systems as the availability of RES needs to be accompanied by the correct management of the energy system in order to guarantee the security of supply and the overall correct and efficient functioning of it. The economic cost of the transition is also an important aspect that in this project is not looked into detail but it certainly influences the decision-making when designing a future energy system. Not only the cost of the installations and its operation and maintenance but the socio-economic outcome of, for example, the creation of a hydrogen plant in the place of a cement factory as it is planned to happen in Mallorca. This shift is looked in this project only from the point of view of emissions and energy supply, however, it implies the loss of jobs for people working in the factory and at the same time, the creation of new jobs for people that is going to work in the hydrogen plant.

This socio-economic impact of the transition is mentioned in the CCL and it is stated that the aim of the transition is "not to leave anyone behind" in the road to the new decarbonized island. However, these might be only empty words if not accompanied with specific measures as the ones displayed in regards of the CO_2 emissions quotas or the RES share of primary energy consumption. The increase of the qualified job offers that could come with the transition would help the island on not depending only on tourism as the main economic sector as well as help to decrease the seasonality associated to it, both for the jobs and the economic growth. This dependence on the tourism can be an aspect preventing the self-sufficiency of the island, which is also an objective of the CCL. For example in this same project it is shown that one of the main polluting factors on the island are the planes used for the arrival of tourists. The fact that these planes can not be decarbonized respond not only to the fact that the most mature technology nowadays in order to shift its fuel consumption is the use of biofuels which would consume a major area of the island if the demand had to be covered with them, but also to the need of the tourists arrival with those planes that belong to companies foreign to Mallorca, so that the influx of planes can not be just banned without posing a serious threat to the tourism.

Another aspect that is not taken into account in this project but it would be interesting to look further upon is the spread on the island of isolated microgrids for individual or small-scaled self-consumption as well as the shift of mentality in society in order to make more use of the public transportation. These aspects could take pressure off the island's energy system and make it more manageable, moreover, the government is actively promoting these aspects although in terms of public transportation there is still a long way to go for an efficient and useful network in Mallorca.

8 Conclusions

This chapter contains the conclusion of the project and answers the questions posed. In this project, the aim was to answer the following Research Question:

How can the energy system in Mallorca transition to comply with the objectives established by the Climate Change and Energy Transition Law?

Moreover, the following sub-question was aimed to help in the analysis of the institutional context:

How does the Climate Change and Energy Transition Law help to this transition?

In regards of the sub-question, the CCL plays an important role as allows the niche of the RES technologies to be introduced into the regime to meet the climate change landscape, giving this niche an official support from the government that sets the example, as well as legal requirements that have to be met or otherwise there will be sanctions. Moreover not only the energy system benefits but also the whole island's society as it poses the purpose of promoting public ownership and the democratization of the energy market, while taking into account the interest f the citizens. Furthermore, it sets the specific objectives that the energy system would have to meet in order to comply with the desired transition.

In order to carry out the aforementioned transition, the island of Mallorca has enough potential for having a full RES based energy system in order to lower the CO_2 emissions from the fossil fuels utilization, given the availability of sun, wind and areas where to place the PV panels and wind turbines. However, this change poses its difficulty as it has to to be taken into account the balancing and storage of the fluctuating electricity supply from these RES. The simulation of the future energy system scenarios with the EnergyPLAN program displayed that it is complicated to have a 100% decarbonized energy system in Mallorca, first, because of the jet fuel consumption which is not possible to shift without compromising the important touristic sector of the island, and second, because in order to have the desired RES-based energy system without CEEP, a high interconnector capacity is needed. Therefore, in addition to the already posed measures by the CCL, in order to achieve a fully decarbonized island, the interconnector capacity should be increased and a way should be found to ban the utilization of fossil fuels also in the aviation sector without affecting the tourism on the island which, as of today, sounds unattainable.

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Input and Output Sheets EnergyPLAN A

In these appendixes the input/output sheets of the different scenarios modelled and simulated on EnergyPLAN are displayed with all the information.

Input Mallorca2018Costs.txt

The EnergyPLAN model 14.1

Electricity demand (TWh/year):		Flexible demand	0,00
Fixed demand	4,63	Fixed imp/exp.	-1,15
Electric heating + HP	0,00	Transportation	0,00
Electric cooling	0,00	Total	3,48

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0,00	0,00	0,00	0,00
Solar Thermal	0,00	0,00	0,00	0,00
Industrial CHP (CSHP)	0,00	0,00	0,00	0,00
Demand after solar and CSHP	0,00	0,00	0,00	0,00

						Grid stabilisation share
Wind	0	MW	0,00	TWh/year	0,00	
Photo Voltaic	60	MW	0,1	TWh/year	0,00	
Wave Power	0	MW	0	TWh/year	0,00	
River Hydro	0	MW	0	TWh/year	0,00	
Hydro Power	0	MW	0	TWh/year		
Geothermal/Nuclear	0	MW	0	TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	Efficiencies COP
Group 2:					
CHP	0	0	0,40	0,50	
Heat Pump	0	0			3,00
Boiler		0		0,90	
Group 3:					
CHP	0	0	0,40	0,50	
Heat Pump	0	0			3,00
Boiler		0		0,90	
Condensing	1673		0,36		

Heatstorage: gr.2: 0 GWh gr.3: 0 GWh
Fixed Boiler: gr.2: 0,0 Per cent gr.3: 0,0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,27
Gr.2:	0,00	0,00
Gr.3:	0,00	0,00

Regulation Strategy:	Technical regulation no. 2	
CEEP regulation	000000000	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	0	MW

Distr. Name :		const.txt
Addition factor	0,00	EUR/MWh
Multiplication factor	1,00	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	1	EUR/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Efficiencies Ther.
Hydro Pump:	0	0	0,80	
Hydro Turbine:	0		0,90	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	0	0	0,80	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:		0,000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	12,99	0,00	0,00
Household	0,00	0,61	1,04	0,46
Industry	0,00	1,45	0,03	0,03
Various	0,00	0,00	0,00	0,00

Output

	District Heating Demand	District Heating Production									Electricity Consumption						Electricity Production							Electricity Balance					Exchange Payment	
	Distr. heating MW	Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba-lance MW	Elec. demand MW	Flex.& Transp. MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Tur-bine MW	RES MW	Hy-dro MW	Geo-thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Imp Million EUR	Exp Million EUR
January	0	0	0	0	0	0	0	0	0	0	461	0	0	0	0	0	0	8	0	0	21	0	321	100	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	539	0	0	0	0	0	0	6	0	0	14	0	377	100	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	490	0	0	0	0	0	0	12	0	0	30	0	334	100	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0	463	0	0	0	0	0	0	14	0	0	29	0	333	100	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	483	0	0	0	0	0	0	13	0	0	29	0	325	100	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	553	0	0	0	0	0	0	15	0	0	41	0	352	100	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	679	0	0	0	0	0	0	15	0	0	39	0	413	100	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	692	0	0	0	0	0	0	13	0	0	40	0	442	100	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	595	0	0	0	0	0	0	11	0	0	38	0	402	100	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	491	0	0	0	0	0	0	9	0	0	37	0	323	100	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	432	0	0	0	0	0	0	8	0	0	20	0	318	100	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	443	0	0	0	0	0	0	7	0	0	36	0	307	100	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0	527	0	0	0	0	0	0	11	0	0	31	0	354	100	0	0	0	0	Average price	
Maximum	0	0	0	0	0	0	0	0	0	0	970	0	0	0	0	0	0	60	0	0	53	0	789	100	0	0	0	0	(EUR/MWh)	
Minimum	0	0	0	0	0	0	0	0	0	0	262	0	0	0	0	0	0	0	0	0	1	0	149	100	0	0	0	0	1	1
TWh/year	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4,63	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,00	0,00	0,27	0,00	3,11		0,00	0,00	0,00	0,00	0	0

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Electro-Fuel	Wind	PV and CSP	Wind off Wave	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Imp/Exp Corrected Net	CO2 emission (Mt): Total	CO2 emission (Mt): Net
Coal	-	-	-	-	-	6,74	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6,74	0,00	6,74	2,39	2,39
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12,99	0,61	1,45	15,05	0,00	15,05	3,95	3,95
N.Gas	-	-	-	-	-	1,90	-	-	-	-	-	-	-	-	-	-	-	0,02	1,04	0,03	2,98	0,00	2,98	0,61	0,61
Biomass	-	-	-	-	-	-	-	-	0,27	-	-	-	-	-	-	-	-	-	0,46	0,03	0,76	0,00	0,76	0,03	0,03
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	-	0,10	-	-	-	-	-	-	0,10	0,00	0,10	0,00	0,00
H2 etc.	-	-	-	-	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	-	-	-	-	-	8,63	-	-	0,27	-	-	-	-	0,10	-	-	-	13,00	2,12	1,51	25,63	0,00	25,63	6,98	6,99

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Output specifications Mallorca2018Costs.txt The EnergyPLAN model 14.1

District Heating Production

Gr.1

	District heating MW	Solar MW	CSHP MW	DHP MW
January	0	0	0	0
February	0	0	0	0
March	0	0	0	0
April	0	0	0	0
May	0	0	0	0
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	0	0	0	0
November	0	0	0	0
December	0	0	0	0
Average	0	0	0	0
Maximum	0	0	0	0
Minimum	0	0	0	0
Total for the whole year TWh/year	0,00	0,00	0,00	0,00

Gr.2

	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW
January	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00

Gr.3

	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW
January	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00

RES specification

	RES1 Wind MW	RES2 Photo \ MW	RES3 Wave F MW	RES 4-7 r MW	Total MW
January	0	8	0	0	8
February	0	6	0	0	6
March	0	12	0	0	12
April	0	14	0	0	14
May	0	13	0	0	13
June	0	15	0	0	15
July	0	15	0	0	15
August	0	13	0	0	13
September	0	11	0	0	11
October	0	9	0	0	9
November	0	8	0	0	8
December	0	7	0	0	7
Average	0	11	0	0	11
Maximum	0	60	0	0	60
Minimum	0	0	0	0	0
Total for the whole year TWh/year	0,00	0,10	0,00	0,00	0,10

Own use of heat from industrial CHP: 0,00 TWh/year

ANNUAL COSTS (Million EUR)		
Total Fuel ex Ngas exchange =		688
Uranium =	0	
Coal =	69	
FuelOil =	48	
Gasoil/Diesel=	229	
Petrol/JP =	312	
Gas handling =	15	
Biomass =	16	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		80
Marginal operation costs =		8
Total Electricity exchange =		1
Import =	0	
Export =	0	
Bottleneck =	0	
Fixed imp/ex=	1	
Total CO2 emission costs =		200
Total variable costs =		978
Fixed operation costs =		6077
Annual Investment costs =		378
TOTAL ANNUAL COSTS =		7432

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Indi-vidual MW	Trans port MW	Indu. Var. MW	Demand Sum MW	Bio-gas MW	Syn-gas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Stor-age MW	Sum MW	Im-port MW	Ex-port MW
January	0	0	196	258	0	3	457	0	0	0	0	0	0	457	457	0
February	0	0	230	234	0	3	468	0	0	0	0	0	0	468	468	0
March	0	0	204	182	0	3	388	0	0	0	0	0	0	388	388	0
April	0	0	203	70	0	3	276	0	0	0	0	0	0	276	276	0
May	0	0	198	29	0	3	231	0	0	0	0	0	0	231	231	0
June	0	0	215	29	0	3	247	0	0	0	0	0	0	247	247	0
July	0	0	252	29	0	3	284	0	0	0	0	0	0	284	284	0
August	0	0	270	29	0	3	302	0	0	0	0	0	0	302	302	0
September	0	0	245	29	0	3	277	0	0	0	0	0	0	277	277	0
October	0	0	197	86	0	3	287	0	0	0	0	0	0	287	287	0
November	0	0	194	198	0	3	395	0	0	0	0	0	0	395	395	0
December	0	0	187	248	0	3	438	0	0	0	0	0	0	438	438	0
Average	0	0	216	118	0	3	337	0	0	0	0	0	0	337	337	0
Maximum	0	0	481	562	0	3	803	0	0	0	0	0	0	803	803	0
Minimum	0	0	91	2	0	3	123	0	0	0	0	0	0	123	123	0
Total for the whole year TWh/year	0,00	0,00	1,90	1,04	0,00	0,03	2,96	0,00	0,00	0,00	0,00	0,00	0,00	2,96	2,96	0,00

RES Share: 3,4 Percent of Primary Energy 8,0 Percent of Electricity 0,4 TWh electricity from RES

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Input Mallorca2035.txt

The EnergyPLAN model 14.1

Electricity demand (TWh/year):		Flexible demand	0,00
Fixed demand	4,63	Fixed imp/exp.	0,00
Electric heating + HP	0,54	Transportation	3,04
Electric cooling	0,00	Total	8,21

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0,00	0,00	0,00	0,00
Solar Thermal	0,00	0,00	0,00	0,00
Industrial CHP (CSHP)	0,00	0,00	0,00	0,00
Demand after solar and CSHP	0,00	0,00	0,00	0,00

					Grid stabilisation share
Wind	700	MW	2,18	TWh/year	0,00
Photo Voltaic	3500	MW	5,64	TWh/year	0,00
Offshore Wind	0	MW	0	TWh/year	0,00
Wave Power	0	MW	0	TWh/year	0,00
Hydro Power	0	MW	0	TWh/year	
Geothermal/Nuclear	0	MW	0	TWh/year	

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	0	0	0,40	0,50	
Heat Pump	0	0			3,00
Boiler		0		0,90	
Group 3:					
CHP	0	0	0,40	0,50	
Heat Pump	0	0			3,00
Boiler		0		0,90	
Condensing	1088		0,36		

Heatstorage: gr.2: 0 GWh gr.3: 0 GWh
Fixed Boiler: gr.2: 0,0 Per cent gr.3: 0,0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,27
Gr.2:	0,00	0,00
Gr.3:	0,00	0,00

Regulation Strategy: Technical regulation no. 2

CEEP regulation	000000000	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	1400	MW
Distr. Name :	const.txt	
Addition factor	0,00	EUR/MWh
Multiplication factor	1,00	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	1	EUR/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Ther.
Hydro Pump:	0	0	0,80	
Hydro Turbine:	0		0,90	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	10	0	0,80	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:		0,000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	6,06	0,00	0,00
Household	0,00	0,00	0,00	0,46
Industry	0,00	1,21	0,00	0,03
Various	0,00	0,00	0,00	0,00

Output

	District Heating										Electricity																		Exchange	
	Demand	Production									Consumption						Production							Balance					Payment	
	Distr. heating MW	Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba- lance MW	Elec. demand MW	Flex.& Transp. MW	HP MW	Elec- trolyser MW	EH MW	Hydro Pump MW	Tur- bine MW	RES MW	Hy- dro MW	Geo- thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Stab- Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Imp Million EUR	Exp Million EUR
January	0	0	0	0	0	0	0	0	0	0	461	341	135	4	0	0	0	830	0	0	21	0	331	100	5	247	0	247	0	0
February	0	0	0	0	0	0	0	0	0	0	540	350	122	4	0	0	0	581	0	0	14	0	540	100	13	133	0	133	0	0
March	0	0	0	0	0	0	0	0	0	0	491	365	95	4	0	0	0	949	0	0	30	0	301	100	7	334	0	334	0	0
April	0	0	0	0	0	0	0	0	0	0	463	340	36	4	0	0	0	1118	0	0	29	0	159	100	3	467	0	467	0	0
May	0	0	0	0	0	0	0	0	0	0	483	358	15	4	0	0	0	987	0	0	29	0	221	100	2	378	0	378	0	0
June	0	0	0	0	0	0	0	0	0	0	553	351	15	4	0	0	0	1094	0	0	41	0	202	100	1	414	0	414	0	0
July	0	0	0	0	0	0	0	0	0	0	679	340	15	4	0	0	0	1014	0	0	39	0	330	100	5	350	0	350	0	0
August	0	0	0	0	0	0	0	0	0	0	692	353	15	4	0	0	0	920	0	0	40	0	404	100	13	312	0	312	0	0
September	0	0	0	0	0	0	0	0	0	0	595	344	15	4	0	0	0	850	0	0	38	0	347	100	8	285	0	285	0	0
October	0	0	0	0	0	0	0	0	0	0	491	346	45	4	0	0	0	723	0	0	37	0	354	100	8	237	0	237	0	0
November	0	0	0	0	0	0	0	0	0	0	433	350	103	4	0	0	0	867	0	0	20	0	257	100	3	257	0	257	0	0
December	0	0	0	0	0	0	0	0	0	0	443	339	130	4	0	0	0	729	0	0	36	0	371	100	10	231	0	231	0	0
Average	0	0	0	0	0	0	0	0	0	0	527	348	62	4	0	0	0	889	0	0	31	0	318	100	7	304	0	304	Average price	
Maximum	0	0	0	0	0	0	0	0	0	0	970	2010	294	4	0	0	0	3909	0	0	53	0	1088	100	424	1400	0	1400	(EUR/MWh)	
Minimum	0	0	0	0	0	0	0	0	0	0	262	-713	1	4	0	0	0	1	0	0	1	0	0	100	0	0	0	0	1	1
TWh/year	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4,63	3,06	0,54	0,04	0,00	0,00	0,00	7,81	0,00	0,00	0,27	0,00	2,79		0,06	2,67	0,00	2,67	0	3

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon- version	Electro- Fuel	Wind	PV and CSP	Wind off Wave	Hydro	Solar.Th	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (Mt): Total	Net
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6,06	-	1,21	7,28	0,00	7,28	1,91	1,91
N.Gas	-	-	-	-	-	7,76	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7,76	-7,26	0,50	1,59	0,10
Biomass	-	-	-	-	-	-	-	-	0,27	-	-	-	-	-	-	-	-	-	0,46	0,03	0,76	0,00	0,76	0,03	0,03
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	2,18	5,64	-	-	-	-	-	-	7,81	0,00	7,81	0,00	0,00
H2 etc.	-	-	-	-	-	0,00	-	-	-	-0,03	-	-	-	-	-	-	-	-	-	0,03	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	-	-	-	-	-	7,76	-	-	0,27	-0,03	-	-	2,18	5,64	-	-	-	6,06	0,46	1,27	23,61	-7,26	16,35	3,53	2,04

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Output specifications Mallorca2035.txt The EnergyPLAN model 14.1

District Heating Production

Gr.1

	District heating MW	Solar MW	CSHP MW	DHP MW
January	0	0	0	0
February	0	0	0	0
March	0	0	0	0
April	0	0	0	0
May	0	0	0	0
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	0	0	0	0
November	0	0	0	0
December	0	0	0	0
Average	0	0	0	0
Maximum	0	0	0	0
Minimum	0	0	0	0
Total for the whole year TWh/year	0,00	0,00	0,00	0,00

Gr.2

	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW
January	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00

Gr.3

	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW
January	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00

RES specification

	RES1 Wind MW	RES2 Photo MW	RES3 Offsho MW	RES 4-7 ind MW	Total MW
January	366	464	0	0	830
February	212	369	0	0	581
March	260	689	0	0	949
April	310	808	0	0	1118
May	200	787	0	0	987
June	195	899	0	0	1094
July	140	874	0	0	1014
August	144	776	0	0	920
September	204	646	0	0	850
October	213	510	0	0	723
November	422	446	0	0	867
December	307	422	0	0	729
Average	248	642	0	0	889
Maximum	694	3500	0	0	3909
Minimum	1	0	0	0	1
Total for the whole year TWh/year	2,18	5,64	0,00	0,00	7,81

Own use of heat from industrial CHP: 0,00 TWh/year

ANNUAL COSTS (Million EUR)		
Total Fuel ex Ngas exchange =		285
Uranium =	0	
Coal =	0	
FuelOil =	40	
Gasoil/Diesel=	0	
Petrol/JP =	217	
Gas handling =	11	
Biomass =	16	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		211
Marginal operation costs =		7
Total Electricity exchange =		-3
Import =	0	
Export =	-3	
Bottleneck =	0	
Fixed imp/ex=	0	
Total CO2 emission costs =		101
Total variable costs =		601
Fixed operation costs =		6206
Annual Investment costs =		832
TOTAL ANNUAL COSTS =		7639

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Indi-vidual MW	Trans port MW	Indu. Var. MW	Demand Sum MW	Bio-gas MW	Syn-gas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Stor-age MW	Sum MW	Im-port MW	Ex-port MW
January	0	0	920	0	0	0	920	0	0	0	0	0	0	920	920	0
February	0	0	1500	0	0	0	1500	0	0	0	0	0	0	1500	1500	0
March	0	0	837	0	0	0	837	0	0	0	0	0	0	837	837	0
April	0	0	443	0	0	0	443	0	0	0	0	0	0	443	443	0
May	0	0	615	0	0	0	615	0	0	0	0	0	0	615	615	0
June	0	0	562	0	0	0	562	0	0	0	0	0	0	562	562	0
July	0	0	918	0	0	0	918	0	0	0	0	0	0	918	918	0
August	0	0	1121	0	0	0	1121	0	0	0	0	0	0	1121	1121	0
September	0	0	984	0	0	0	984	0	0	0	0	0	0	984	984	0
October	0	0	984	0	0	0	984	0	0	0	0	0	0	984	984	0
November	0	0	713	0	0	0	713	0	0	0	0	0	0	713	713	0
December	0	0	1032	0	0	0	1032	0	0	0	0	0	0	1032	1032	0
Average	0	0	883	0	0	0	883	0	0	0	0	0	0	883	883	0
Maximum	0	0	3022	0	0	0	3022	0	0	0	0	0	0	3022	3022	0
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0,00	0,00	7,76	0,00	0,00	0,00	7,76	0,00	0,00	0,00	0,00	0,00	0,00	7,76	7,76	0,00

RES Share: 36,3 Percent of Primary Energy 104,7 Percent of Electricity 8,1 TWh electricity from RES

31-mayo-2020 [18:33]

Input Mallorca2050.txt

The EnergyPLAN model 14.1

Electricity demand (TWh/year):		Flexible demand	0,00
Fixed demand	5,09	Fixed imp/exp.	0,00
Electric heating + HP	0,59	Transportation	3,58
Electric cooling	0,00	Total	9,26

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0,00	0,00	0,00	0,00
Solar Thermal	0,00	0,00	0,00	0,00
Industrial CHP (CSHP)	0,00	0,00	0,00	0,00
Demand after solar and CSHP	0,00	0,00	0,00	0,00

Wind	800 MW	2,49	TWh/year	0,00	Grid
Photo Voltaic	4000 MW	6,44	TWh/year	0,00	stabili-
Offshore Wind	0 MW	0	TWh/year	0,00	sation
Wave Power	0 MW	0	TWh/year	0,00	share
Hydro Power	0 MW	0	TWh/year		
Geothermal/Nuclear	0 MW	0	TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	0	0	0,40	0,50	
Heat Pump	0	0			3,00
Boiler		0		0,90	
Group 3:					
CHP	0	0	0,40	0,50	
Heat Pump	0	0			3,00
Boiler		0		0,90	
Condensing	477		0,55		

Heatstorage: gr.2: 0 GWh gr.3: 0 GWh
Fixed Boiler: gr.2: 0,0 Per cent gr.3: 0,0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,27
Gr.2:	0,00	0,00
Gr.3:	0,00	0,00

Regulation Strategy:	Technical regulation no. 2	
CEEP regulation	000000000	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	1400	MW

Distr. Name :		const.txt
Addition factor	0,00	EUR/MWh
Multiplication factor	1,00	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	1	EUR/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Efficiencies Ther.
Hydro Pump:	0	0	0,80	
Hydro Turbine:	0		0,90	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	106	5	0,80	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:	0,000			

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	6,06	0,00	0,00
Household	0,00	0,00	0,00	0,46
Industry	0,00	0,00	0,00	0,03
Various	0,00	0,00	0,00	0,00

Output WARNING!!: (1) Critical Excess;

	District Heating										Electricity																			Exchange	
	Demand	Production									Consumption						Production							Balance						Payment	
	Distr. heating MW	Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba- lance MW	Elec. demand MW	Flex.& Transp. MW	HP MW	Elec- trolyser MW	EH MW	Hydro Pump MW	Tur- bine MW	RES MW	Hy- dro MW	Geo- thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Stab- Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Imp Million EUR	Exp Million EUR
January	0	0	0	0	0	0	5	0	0	-5	507	404	147	105	0	0	0	978	0	0	21	0	244	100	173	253	0	253	0	0
February	0	0	0	0	0	0	5	0	0	-5	593	412	134	105	0	0	0	695	0	0	14	0	364	100	317	146	0	146	0	0
March	0	0	0	0	0	0	5	0	0	-5	539	435	104	105	0	0	0	1142	0	0	30	0	208	100	149	346	0	346	0	0
April	0	0	0	0	0	0	5	0	0	-5	510	403	40	105	0	0	0	1345	0	0	29	0	106	100	71	493	1	492	0	0
May	0	0	0	0	0	0	5	0	0	-5	531	425	17	105	0	0	0	1193	0	0	29	0	170	100	88	402	0	402	0	0
June	0	0	0	0	0	0	5	0	0	-5	608	416	17	105	0	0	0	1327	0	0	41	0	166	100	67	455	0	455	0	0
July	0	0	0	0	0	0	5	0	0	-5	746	405	17	105	0	0	0	1234	0	0	39	0	241	100	145	385	0	385	0	0
August	0	0	0	0	0	0	5	0	0	-5	761	416	17	105	0	0	0	1118	0	0	40	0	268	100	219	347	0	347	0	0
September	0	0	0	0	0	0	5	0	0	-5	654	407	17	105	0	0	0	1026	0	0	38	0	261	100	171	313	0	313	0	0
October	0	0	0	0	0	0	5	0	0	-5	539	409	49	105	0	0	0	871	0	0	37	0	270	100	185	261	0	261	0	0
November	0	0	0	0	0	0	5	0	0	-5	475	414	113	105	0	0	0	1030	0	0	20	0	214	100	113	269	0	269	0	0
December	0	0	0	0	0	0	5	0	0	-5	488	400	142	105	0	0	0	869	0	0	36	0	270	100	207	248	0	248	0	0
Average	0	0	0	0	0	0	5	0	0	-5	579	412	68	105	0	0	0	1070	0	0	31	0	232	100	159	327	0	327	Average price	
Maximum	0	0	0	0	0	0	5	0	0	-5	1067	2515	322	106	0	0	0	4568	0	0	53	0	477	100	1356	2019	619	1400	(EUR/MWh)	
Minimum	0	0	0	0	0	0	5	0	0	-5	288	-477	1	104	0	0	0	1	0	0	1	0	0	100	0	0	0	0	1	1
TWh/year	0,00	0,00	0,00	0,00	0,00	0,00	0,04	0,00	0,00	-0,04	5,09	3,62	0,59	0,93	0,00	0,00	0,00	9,40	0,00	0,00	0,27	0,00	2,04		1,39	2,87	0,00	2,87	1	3

FUEL BALANCE (TWh/year):	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon- version	Electro- Fuel	Wind	PV and CSP	Wind off Wave	Hydro	Solar.Th	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (Mt): Total	Net
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6,06	-	-	6,06	0,00	6,06	1,59	1,59
N.Gas	-	-	-	-	-	3,70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3,70	-2,69	1,02	0,76	0,21
Biomass	-	-	-	-	-	-	-	-	0,27	-	-	-	-	-	-	-	-	-	0,46	0,03	0,76	0,00	0,76	0,03	0,03
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	2,49	6,91	-	-	-	-	-	-	9,40	0,00	9,40	0,00	0,00
H2 etc.	-	-	-	-	-	0,00	-	-	-	-0,74	-	-	-	-	-	-	-	-	-	0,74	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	-	-	-	-	-	3,70	-	-	0,27	-0,74	-	-	2,49	6,91	-	-	-	6,06	0,46	0,77	19,93	-2,69	17,24	2,38	1,83

03-junio-2020 [17:16]

Output specifications   Mallorca2050.txt   The EnergyPLAN model 14.1

District Heating Production

Gr.1	District heating MW	Solar MW	CSHP MW	DHP MW
January	0	0	0	0
February	0	0	0	0
March	0	0	0	0
April	0	0	0	0
May	0	0	0	0
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	0	0	0	0
November	0	0	0	0
December	0	0	0	0
Average	0	0	0	0
Maximum	0	0	0	0
Minimum	0	0	0	0
Total for the whole year TWh/year	0,00	0,00	0,00	0,00

Gr.2	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW
January	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00

Gr.3	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW
January	0	0	0	0	0	5	0	0	0	-5
February	0	0	0	0	0	5	0	0	0	-5
March	0	0	0	0	0	5	0	0	0	-5
April	0	0	0	0	0	5	0	0	0	-5
May	0	0	0	0	0	5	0	0	0	-5
June	0	0	0	0	0	5	0	0	0	-5
July	0	0	0	0	0	5	0	0	0	-5
August	0	0	0	0	0	5	0	0	0	-5
September	0	0	0	0	0	5	0	0	0	-5
October	0	0	0	0	0	5	0	0	0	-5
November	0	0	0	0	0	5	0	0	0	-5
December	0	0	0	0	0	5	0	0	0	-5
Average	0	0	0	0	0	5	0	0	0	-5
Maximum	0	0	0	0	0	5	0	0	0	-5
Minimum	0	0	0	0	0	5	0	0	0	-5
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	0,00	0,04	0,00	0,00		-0,04

RES specification	RES1 Wind MW	RES2 Photo MW	RES3 Offsho MW	RES 4-7 ind MW	Total MW
January	418	530	0	0	978
February	242	422	0	0	695
March	297	788	0	0	1142
April	355	923	0	0	1345
May	229	899	0	0	1193
June	223	1028	0	0	1327
July	160	999	0	0	1234
August	165	886	0	0	1118
September	233	738	0	0	1026
October	244	583	0	0	871
November	482	509	0	0	1030
December	351	482	0	0	869
Average	283	733	0	0	1070
Maximum	793	4000	0	0	4568
Minimum	1	0	0	0	1
Total for the whole year TWh/year	2,49	6,44	0,00	0,00	9,40

Own use of heat from industrial CHP: 0,00 TWh/year

ANNUAL COSTS (Million EUR)

Total Fuel ex Ngas exchange =		238
Uranium =	0	
Coal =	0	
FuelOil =	0	
Gasoil/Diesel=	0	
Petrol/JP =	217	
Gas handling =	5	
Biomass =	16	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		100
Marginal operation costs =		5
Total Electricity exchange =		-1
Import =	1	
Export =	-3	
Bottleneck =	0	
Fixed imp/ex=	0	
Total CO2 emission costs =		68
Total variable costs =		411
Fixed operation costs =		6257
Annual Investment costs =		901
TOTAL ANNUAL COSTS =		7569

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Indi-vidual MW	Trans port MW	Indu. Var. MW	Demand Sum MW	Bio-gas MW	Syn-gas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Stor-age MW	Sum MW	Im-port MW	Ex-port MW
January	0	0	444	0	0	0	444	0	0	0	0	0	0	444	444	0
February	0	0	662	0	0	0	662	0	0	0	0	0	0	662	662	0
March	0	0	379	0	0	0	379	0	0	0	0	0	0	379	379	0
April	0	0	192	0	0	0	192	0	0	0	0	0	0	192	192	0
May	0	0	309	0	0	0	309	0	0	0	0	0	0	309	309	0
June	0	0	302	0	0	0	302	0	0	0	0	0	0	302	302	0
July	0	0	438	0	0	0	438	0	0	0	0	0	0	438	438	0
August	0	0	488	0	0	0	488	0	0	0	0	0	0	488	488	0
September	0	0	475	0	0	0	475	0	0	0	0	0	0	475	475	0
October	0	0	491	0	0	0	491	0	0	0	0	0	0	491	491	0
November	0	0	390	0	0	0	390	0	0	0	0	0	0	390	390	0
December	0	0	492	0	0	0	492	0	0	0	0	0	0	492	492	0
Average	0	0	421	0	0	0	421	0	0	0	0	0	0	421	421	0
Maximum	0	0	867	0	0	0	867	0	0	0	0	0	0	867	867	0
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0,00	0,00	3,70	0,00	0,00	0,00	3,70	0,00	0,00	0,00	0,00	0,00	0,00	3,70	3,70	0,00

RES Share: 51,0 Percent of Primary Energy 100,4 Percent of Electricity 9,7 TWh electricity from RES

03-junio-2020 [17:16]