Development of a flexible model for the sector buildings, adaptable for different scales (local, regional, national)

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Master Dissertation

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“Don't compare yourself with other people; compare yourself with who you were yesterday.”

Jordan Peterson

Abstract

With the intention to safe keep a prosperous future for the following generations, it is of the most importance to reduce the emission of pollutant gases. In order to achieve this, it is necessary both to maximize the efficiency of employed technologies to minimize the expended energy and to change the nature of technologies, including fuel switch, with heavy consideration of the total emission that result of its utilization. These changes need to be made at the different levels of the energy system, from the transformation of primary to final energy as well as in the conversion from final to useful energy. In reality, the availability of resources is limited hence the necessity to create a model of the energy system with the intent to make the energy system more efficient.

The objectives to reach neutrality are already established in the Paris agreement, which has multiple intermediate targets. Until now all set goals were achieved, namely the reduction of emissions by 22% until 2020 relative to 1990, setting the course for the planned 55% reduction of emissions until 2030 and other energy-related objectives, including energy efficiency.

The existing open-sourced and free models of energy systems describe other countries or, more commonly only represent the energy system from the primary energy level to the final, not representing the end use demand and related technologies in detail. This section of the energy system is extremely relevant since it determines how the end-uses are supplied, influencing the final energy carriers consumption in terms of fuel quantity and type. The full representation of the system is necessary to analyze what are the required changes for the entire energy system in order to reach the set goals for carbon neutrality.

The main goal of this work is to develop a flexible model of the energy system, which represents the building sectors, residential and services, up to the useful energy. This representation of end-use technologies will allow for the modelling of different options at the end-user level, and the techno-economic assessment of buildings related measures that are envisaged to be relevant in the achievement of the global carbon neutrality objectives.

This model corresponds to an extension of an already existing model in OSeMOSYS, representing the energy system for Portugal, from primary to final energy for all sectors. The expanded model provides a representation of the whole energy system from primary to final energy, with a higher disaggregation for the residential and services sectors. Taking the existing model as the starting point, a more extensive and comprehensive model was developed, detailing the different paths energy can take from final energy to useful energy, in order to fulfil the specific end-use service. The new model can then be used to simulate the evolution of end-use technologies in the service and residential sectors up to 2050, as well as their techno-economic viability. For it to be a simulation closer to reality, economic factors must be also considered such as initial cost and O&M costs.

Finally, the results of different scenarios were compared, and the data outputs of the model was analysed to conclude on the evolution of the energy system and the impact of limitations imposes on the model.

Keywords: Energy systems, GHG emissions, RNC2050, PNEC30, Modelling, End use Energy

Resumo

Com a intenção de garantir um futuro próspero para as gerações seguintes, é da maior importância reduzir a emissão de gases poluentes. Para o conseguir, é necessário tanto maximizar a eficiência das tecnologias empregadas para minimizar a energia consumida, como alterar a natureza das tecnologias, incluindo a mudança de combustível, com grande consideração pelas emissões totais resultantes da sua utilização. Estas mudanças têm de ser feitas a diferentes níveis do sistema energético, desde a transformação da energia primária em energia final, bem como na conversão da energia final em energia útil. Na realidade, a disponibilidade de recursos é limitada, daí a necessidade de criar um modelo do sistema energético com o intuito de tornar o sistema energético mais eficiente.

O objetivo de alcançar a neutralidade já está estabelecido no acordo de Paris, que tem múltiplos objetivos intermédios. Até agora todas as metas estabelecidas foram alcançados, nomeadamente a redução das emissões em 22% até 2020 em relação a 1990, que a União Europeia alcançou, estabelecendo o rumo para a planeada redução de 55% das emissões até 2030 e outros objetivos relacionados com a energia, incluindo a eficiência energética.

Os modelos existentes de sistemas energéticos, de acesso livre, descrevem outros países ou representam apenas o sistema energético desde o nível de energia primária até à final, não descrevendo a procura de utilização final e tecnologias relacionadas. Esta secção do sistema energético é a mais impactante uma vez que determina a quantidade e tipo de combustível necessário, com a sua descrição torna-se possível analisar as mudanças necessárias de todo o sistema energético para alcançar os vários objetivos intermediários estabelecidos para a neutralidade de carbono.

O principal objetivo deste trabalho é desenvolver um modelo flexível do sistema energético, que representa os edifícios dos setores residencial e de serviços, até à energia útil. Esta representação das tecnologias de utilização final permitirá a modelação de diferentes cenários do consumo energético final, e a avaliação técnico-económica das medidas relacionadas com os edifícios que se prevê serem relevantes para a realização dos objetivos globais de neutralidade carbónica.

Este modelo corresponde a uma extensão de um modelo já existente no OSeMOSYS, representando o sistema energético de Portugal, desde a energia primária até à energia final para todos os setores. O modelo alargado fornece uma representação de todo o sistema energético, desde a energia primária até à energia final, com uma desagregação mais fina para os setores residencial e de serviços. Tendo o modelo existente como ponto de partida, foi desenvolvido um modelo mais extenso e específico, detalhando os diferentes fluxos de energia desde a energia final até à energia útil, a fim de cumprir o serviço específico de utilização final. O novo modelo pode então ser utilizado para simular a evolução das tecnologias finais nos setores dos serviços e residencial até 2050, bem como a sua viabilidade tecno-económica. Para que seja uma simulação mais próxima da realidade, devem também ser considerados fatores económicos tais como o custo inicial e os custos de O&M.

Por último, os resultados dos diferentes cenários foram comparados e os dados obtidos no modelo foram analisados para tirar conclusões sobre a evolução do sistema energético e o impacto das limitações impostas ao modelo.

Palavras-chave: Sistemas de energia, Emissões de GHG, RNC2050, PNEC30, Modelação, Energia de uso final.

Acknowledgment

This last months, this dissertation has proven to be challenging requiring a great deal of effort, tenacity, patience and focus. This as enabled growth at the personal and professional level. However, I was not without company and those who would guide and support me in various ways, to them I only have a genuine feeling of gratitude.

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Nomenclature

GHG: Greenhouse gas

INE: “Instituto Nacional de Estatística”

DGEG: “Direção-Geral de Energia e Geologia”

Lb: Pounds

Mton: Metric tons,

MMBtu: Million British thermal unit

Gal: Gallon

Scf: standard cubic foot

PNEC2030: “Plano Nacional de Energia e Clima 2030”

RNC2050: “Roteiro para Neutralidade Carbónica 2050”

1 Introduction

1.1 Background and motivation

As the impact of greenhouse gases (GHG) emissions, became more evident, being widely recognized as the main driving force behind the climate change, ambitious targets for the reduction of emissions have been adopted at the global scale. For instance, the European Green Deal establishes the objective of achieving carbon neutrality by 2050 at the European level.

The achievement of these targets implies significant changes in the whole energy system, on the way energy is transformed and used, as the current system is unsustainable and greatly dependent on fossil fuels. [2] From available national data, in 2019, 73% of primary energy was still produced with the use of fossil foil, namely 6% by coal, 24% by natural gas and the remaining 43% by oil. All these raw materials must be imported since Portugal does not possess these resources naturally, consequently the massive imports have a detrimental effect in the national economy, and it creates an energy dependency of other countries, like Russia for natural gas, an unfavorable strategic and economic situation. The domestic production of energy is dominated by wind, hydropower, and biofuels, the last being mostly consumed, roughly three quarters, by the residential sector, due to the common use of biomass boilers. [6]

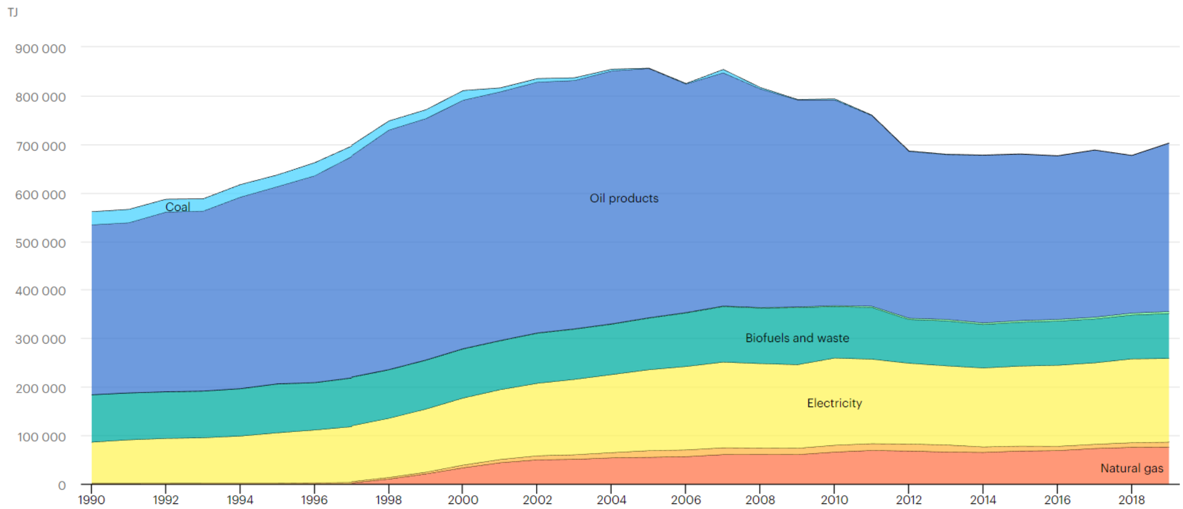

Figure 1-1: Evolution of the energy consumption per final energy carrier, in Portugal, between 1990 and 2019 [4]

Despite the global commitment towards climate change mitigation, the actions that were already implemented to reduce emissions have not been sufficient to counteract the increase in energy related emissions due to the continuous rise in energy demand. The increase in world's population coupled with the increased access to energy services, has led to a substantial rise in the energy demand. Furthermore, the world's energy system still largely relies on fossil fuels, both for direct use and for transformation in other forms of energy. Both in developed and developing countries, even with the continuous struggle for a greener system, fossil fuels still correspond to a relevant share of the overall energy use, resulting in ever increasing emission of pollutants, namely carbon dioxide and nitrous oxides.

In order to accelerate this transition and support decision making, there is the need to assess the different available options and respective impacts in an integrated and comprehensive manner. Energy system modelling tools are extremely relevant for such planning process, as they allow for the simulation of the system evolution over time, considering different context conditions.

Considering that the desired transition towards carbon neutrality implies changes over the whole energy chain, from primary energy sources to the end-use services, it is important to ensure that the modelling tools are able to represent the energy system as a whole in order to assess potential synergies and trade-offs between actions at different levels of the energy system.

Nonetheless, most of the existing modelling tools represent the energy chain up to the final energy consumption of the different sectors and subsectors. Albeit a good starting point to show how much energy goes into each sector/subsector, it does not take into consideration of the employed technologies efficiencies and, consequently, does not portrait a realistic representation of the energy demand by different end uses. The knowledge related to the useful energy per demand allows to study the impact of implementation of different technologies and to estimate the emissions associated to each end use in order to select the priorities for action, to maximize the reduction in GHG emissions. The modelling of the technologies adequate to satisfy the different end-uses with a detailed characterization of their technical and economic properties allows for a better understanding of which technology, or combination of, that are more impactful in the current and future settings, be it in terms of efficiency, the associated cost, the technologies lifetime, fuel use, etc.

Buildings are responsible for a large share of the world’s energy use, and respective GHG emissions. In the case of Portugal, the residential sector is responsible for 15,8% of the total energy consumption and the service sector for 11,4% [3]. The relevance of the buildings sectors energy use at national level has been increasing over time, with a significant increase in the commercial and services buildings.

Considering that a large share of the necessary measures to decrease the energy-related emissions in the buildings sectors are associated with the final user, including the substitution of end-use technologies and behavioral changes, currently available models are not able to properly represent these measures and estimate their impact in the energy system.

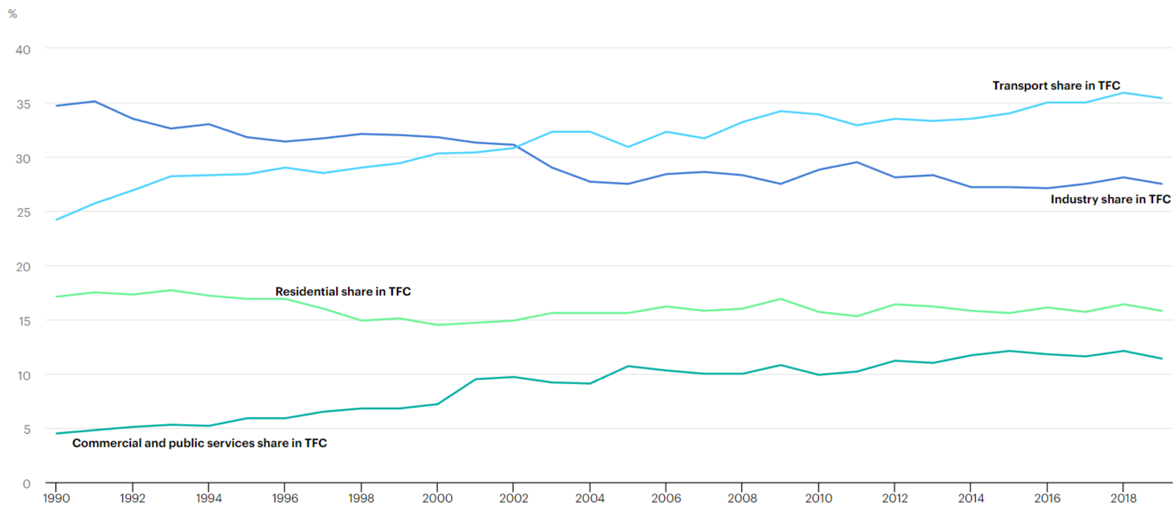

Figure 1-2: Distribution of the final energy consumption per sector (%) in Portugal, between 1990 and 2019 [4]

This work aims at going a step further in the representation of the buildings sectors, by modelling these sectors up to the end-uses. To do so, it disaggregates the demand of the building sectors, by subsectors and in each subsector by end-uses. The model includes a techno-economic characterization of the different technologies that can supply the different end-uses within the different sectors, including conversion efficiency, capital and marginal cost, maximum annual operation time. Taking into account the projected evolution of the different end-use services, and imposing restrictions in terms of GHG emissions or renewable energy sources, the model is able to simulate the optimal solution (e.g. the combination of end-use technologies) to achieve carbon neutrality, or other related goals.

1.2 Objectives

The principal objective of this dissertation is the creation of a model, using OSeMOSYS, which can provide a detailed representation of the buildings sectors up to the end-use services, allowing to simulate the evolution in the distribution of the available end-use technologies, both in terms of their share in the overall stock and required investment.

The end model aims to be flexible, so that it can be easily applied to different scales and/or different geographical contexts, solely implying the adjustment of the input parameters, regarding the demand for end-use services and the technologies' characteristics. This flexibility makes the model a relevant tool to support energy management and planning in various settings, helping to create a more sustainable world, with less emissions and wasted energy, without necessarily decreasing the energy consumption by end use.

In order to achieve this result, it is first necessary to identify building types and characterize the respective demand profiles, to ensure a robust representation with the limited amount of data available. In order to do so, there is the need to collect an extensive amount of in information, that being:

- Disaggregation of the service sector into subsectors according to the energy usage profile;
- Characterization of the energy demand at the end use level, including the final energy demand per end-use and respective disaggregation per end-use technology;

- Collection of the technical and economical proprieties of the various technologies included in the model, as e.g. efficiency, lifetime, investment and maintenance costs, etc.;

Then, there is the need to project the future energy system, by identifying some key evolution trends in terms of technology evolution and final and useful energy demand. The quality of the prediction of the system evolution is crucial to guarantee the fidelity and usefulness of the results.

Achieved the representation of the natural evolution of the system, alternative scenarios are also built to assess different technology and political paths. This step implies the identification of the various national objectives desired in national agreements and plans;

With the previous data, can the final objective of this work be obtained, that being the comparison of the results for different parameters to reach a consensus for the best course of action to take.

1.3 Structure

This dissertation is divided into the following 6 chapters:

- Introduction: background and goals for this dissertation, as well as the structure of this work;
- State of the Art: description of the current situation and of the national and European Unions Objective, as well as a synthesis of literature allusive to the topics of this dissertation;;
- Model description (focused on the characterization of the energy system):
  - Model overview (scheme of the energy system, with the disaggregation);
  - Disaggregation of the sectors/subsectors according to the energy use profile: Listing and explanation of the partition of the sector or lack thereof, and disaggregation of the energy demand per end-use: Energy demand by sector/subsector and each end use as well as an explanation for its variation throughout the seasons and years;
  - Identification and characterization of the technologies per end use: Description of different types of technologies employed by the different sector/subsectors and their impactful properties; Emissions by technology: listing of the emission of gases by the various technologies; Stock: Initial capacity of each technology and the its associated rate of deterioration;
- Scenarios description:
  - o Business as Usual (assumptions on demand evolution, technologies uptake, etc.) ;
  - Carbon neutrality 2050 (assumptions, and imposed restrictions);
- Results and Discussion: exhibit of obtained results after different treatment of data and a critical analysis of them;
- Conclusions and Future Works: relevant conclusion and possible future works that could continue to complete and increase the proximity of the model to reality.

2 State of the art

With the increased pressure to decrease overall GHG emissions, at national and international level, it is crucial to assess the possible solutions to identify the most adequate measures and establish action plans that guarantee their implementation. Given the importance of this topic, several academics and practitioners have contributed to the improvement of existing tools, including energy system modelling.

This section provides a short overview of existing modelling tools, with a clear identification of the current gaps and opportunities for improvement.

2.1 Existing models

2.1.1 JRC-EU-TIMES model

The JRC-EU-TIMES is a bottom-up linear optimization technology model that made use of the TIMES model generator from the ETSAP1 of the IEA.

This model was created with the intent to analyze the impact of energy technologies and their evolution on Europe's path to carbon neutrality. It is a useful tool for work that assess the impact of energy policies that require quantitative modelling at the energy system level with a significant detail of the technologies characteristics, since the model simulates the use of different technologies and their interaction with the wider energy system.

This model represents the energy system, disaggregating the demand over the following sectors: primary energy supply, electrical production, industry, agriculture, transportation, residential and commercial.

Since part of the technologies described and represented in this model are also accounted for in the model developed in this dissertation, this model's database has been used as reference, specifically the technical and economic information related to the various employed technologies. With this data it is possible to determine the input and output activity ratio of each technology as well as the lifetime and associated costs. This data enabled a detailed characterization of each technology in a precise fashion. [7]

2.1.2 PRIMES model

The PRIMES (Price-Induced Equilibrium System) is a model designed for medium to long term system predictions of energy system, covering a timeframe up to 2050, for both demand and supply. The model is able do support the impact assessement of specific energy and environmental policies and plans, at national and european level, such as technologies promotion policies, RES supporting policies, taxation, technological standarts, etc.. PRIMES is capable to represent concrete measures in different sectors, including market design options for the EU electrical and gas markets. Policies analysis draws on comparing results of alternative scenarios against a reference projection. [8]

2.2 Overview of OSeMOSYS

OSeMOSYS (Open-Source energy Model SYStem) is an open-source modelling tool meant for creating energy model that allows prediction of technologic employed and the evolution of energy consumption, addressing the needs for an energy plan for different scales, while being devoid of charges since no proprietary software or commercial programming languages and solvers are used. There is a lack of other modelling tools that possess these characteristics, having a unique position as it allows groups of students, government specialist, energy research, etc. to easily work on their models without necessitating a considerable initial investment.

OSeMOSYS calculates the energy supply mix in terms of generating capacity and energy delivery so that the energy demands are satisfied in every year and time step in the case in study, while minimizing the total costs. It also as the capacity to encompass all energy sectors or isolate one, including heat, electricity, etc. allowing a geographic, temporal, and spatial scale defined by the user. The energy demand can be met by multiple different technologies which must be defined by techno-economic properties and make use of a set of resources that are defined by certain parameters. OSeMOSYS default configuration assumes a singular decision maker with perfect foresight and competitive markets, like most optimization modelling tools do. [9-14]

2.2.1 Set and Parameter Inputs

OSeMOSYS, as most similar programmes, defines sets, parameters and variables. The sets define the structure of the model, most often being independent of the to be executed scenarios. The sets provide the time interval, the spacial coverage, time split, technologies to be considered and the energy vectors. The sets technology and fuel were used for the construction of this model, the first comprises all the components that trasform a commodity to another in the energy system, the second, fuel, comprises every energy vector, service or proxy entering or departing technology. These fuels can be aggregated into groups, individual flows, or artificially divided, depending on the system requirements.

Parameters are numerical inputs difined by the user. For the case of multiple scenarios and/or sensitivity studies, it is standard practice to modify the values of some parameters, even if the sets remain constant or similar. There exist various types of global parameters: demand, performance, technology costs, storage, capacity constraint, activity constraints, reserve margin, generation target and emissions. The high level of specificity of the OSeMOSYS is demonstrated by the fact that each these parameters are established for ll different technologies [9-14]. In the following table the parameters used to define the sets and a brief description are listed.

Table 2-1: OSeMOSYS parameters [9-14]

Parameters		Description
Demand	Specified annual demand	Total specified demand per year
	Specified annual profile	Fraction fraction of energy-service or commodity demand that is required in each time slice. For each year, all the defined Specified Demand Profile input values should sum up to 1
Emissions	Emission activity ratio	Emission factor of a technology per unit of activity, per mode of operation
Technology costs	Variable Cost	Cost of a technology for a given mode of operation (Variable O&M cost), per unit of activity
	Fixed Cost	Fixed O&M cost of a technology, per unit of capacity
	Capital Cost	Capital investment cost of a technology, per unit of capacity
Performance	Operational Life	Useful lifetime of a technology, expressed in years
	Input Activity Ratio	Rate of use of a commodity by a technology, as a ratio of the rate of activity
	Capacity Factor	Capacity available per each Time Slice expressed as a fraction of the total installed capacity, with values ranging from 0 to 1. It gives the possibility to account for forced outages
	Capacity To Activity Unit	Conversion factor relating the energy that would be produced when one unit of capacity is fully used in one year
	Output Activity Ratio	Rate of commodity output from a technology, as a ratio of the rate of activity

2.2.2 OSeMOSYS interfaces:

As a consequecnce of the large amount of data necessary to input in the model and the complex proces to map the conversion chains up to their end uses, developing an energy system model on OSeMOSYS is a challenging task. It is necessary to facilitit this task the use of an opnensource, userfriendly whilst beirng competent in its function, interface.

2.2.2.1 Otoole

Otoole offers OSeMOSYS users an interface with command lines, being a Python module. Otoole is a tool for experienced users, with various support methods to input data and outputs, such as databases, datapackages, csv files, and excel workbooks, as well as implementation of the OSeMOSYS model. This interface offers the users resources that centralize the pre and post processing procedures in relation to OSeMOSYS [9-14].

2.2.2.2 ClicSand

ClicSand (Simple and Nearly Done) is a graphical user interface aimed for beginners. The data is entered directly in a standardized Excel spreadsheet. This spreadsheet is then used to run the simulation, through the use of GLPK or CBC, as the solver, both open source. The results are presented in a different Excel spreadsheet, also with a predefined template. This interface is limited to 200 technologies, five categories of emissions and 50 commodities. Considering the complexity of the buildings sectors and the intention of introducing a high level of detail, this interface is not suitable for the proposed exercise [9-14].

2.2.2.3 MoManI

This interface, MoManI (Model Management Infrastructure), is an open source and browser based interface for energy systems modelling. This interface is used for constructing models, manipulating data and equations, designing and analysing the scenarios and results. Its structure allows severals teams to interact concurrently in different locations. MoManI is aimed for more experienced users, making use of GPLK solver. Alltogh this interface is not aimed for newer users it was choosen for this work [9-14].

2.3 Previous Work

In the present day there is no open energy model for Portugal which encompasses the entire residential and service sectors energy system, starting in the primary energy level up to the useful energy level. The existing models are either closed or doing the portrait of a specific country or, more commonly, to Europe in its entirety.

For a model to represent a portuguese energy system in its entirety, it is necessary for it to start on the primary energy, such as petroleum products, imported electricity and other fuels like natural gas, etc., up to the useful energy of each end use. This thesis focuses on the residential and service sectors, to disagregate both energy systems by defining their employed technologies, energy consumption throughout the years and, if necessary, further divide the energy system.

This work has partially been completed. Recently, a model of Portugals energy system was started, including modelling starting from primary energy vectors up to the final energy demand for the various sector, they being the agriculture, residential, services, trasportation, and industry sectors. In the next figure can be seen the representation of the previous model.

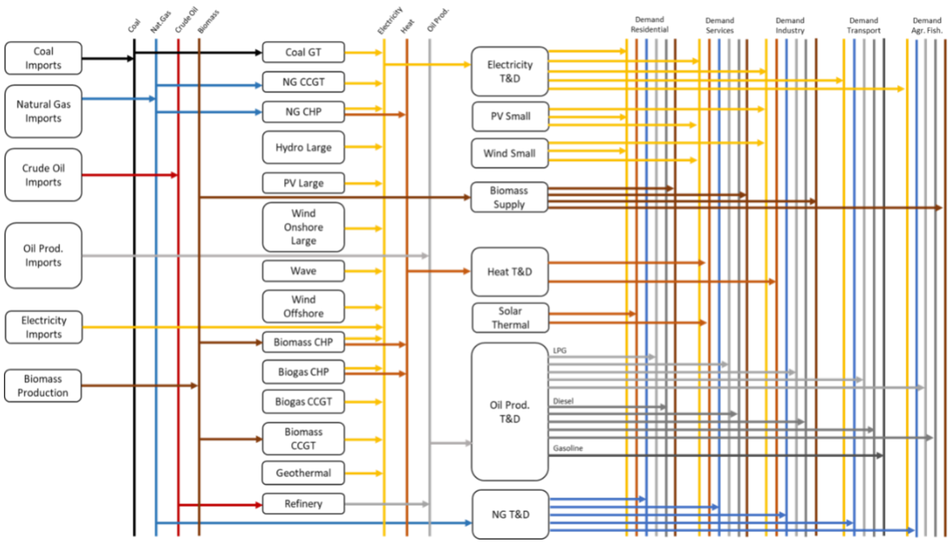

Figure 2-1: Schematic representation of the already existing OSeMOSYS model for Portugal, from primary to final energy demand, up to 2050

Due to the internal variation of the service sector, it is necessary to further divide it in subsector before beginning the construction of its energy system model. The creation of such model for both sectors requires a substantial amount of data on multiple technologies properties, both technical and economical, energy uses, etc. from sources which can be inconsistent.

3 Model description

As referred in the previous chapter, the model developed as part of this work results from the expansion of the already existing OSeMOSYS model, representing the Portuguese energy system from primary to final energy demand. The final energy demand of residential and service sectors is disaggregated per end-use, with the identification of all the different technologies that can be used to supply each end-use. In the specific case of services buildings, given the diversity of consumption profiles associated with the different economic activities, there was the need to further disaggregate the services sector into several subsectors. These subsectors were chosen based on the consumption profiles and typical end-uses of the different activities, while also taking into account the available data and most common disaggregation.

The expansion of the residential and services sector modules up to end-use services implied the identification of the different end-uses for each sector/subsector, and the technologies that are (or can be) used to supply the different uses. Each end-use is then characterised in terms of current and future demand, and related technologies are characterised in terms of their specific technical and economic properties. The final disaggregation resulted in six services subsectors: Commercial and other services; Education; Restaurants and Hotels; Public buildings; Sports facilities; and Health facilities.

The model cover a 35 years timeframe, starting in 2015 and going up to 2050, in order to cover the transition period towards carbon neutrality. For modelling purposes, each year is split into four seasons (with a similar duration) and each day is divided into two periods, day and night, with no differentiation between different days of the week.

Given the large amount of data necessary to feed into the model, there was the need to combine different data sources and additional assumptions had to be made. Nonetheless, there was an effort to guarantee some coherence among the different data inputs, to ensure robust and credible results.

3.1 Model structure overview

The following figure exemplifies the expansion exercise that was performed to the existing energy system structure, with the disaggregation of both residential and services buildings sectors.

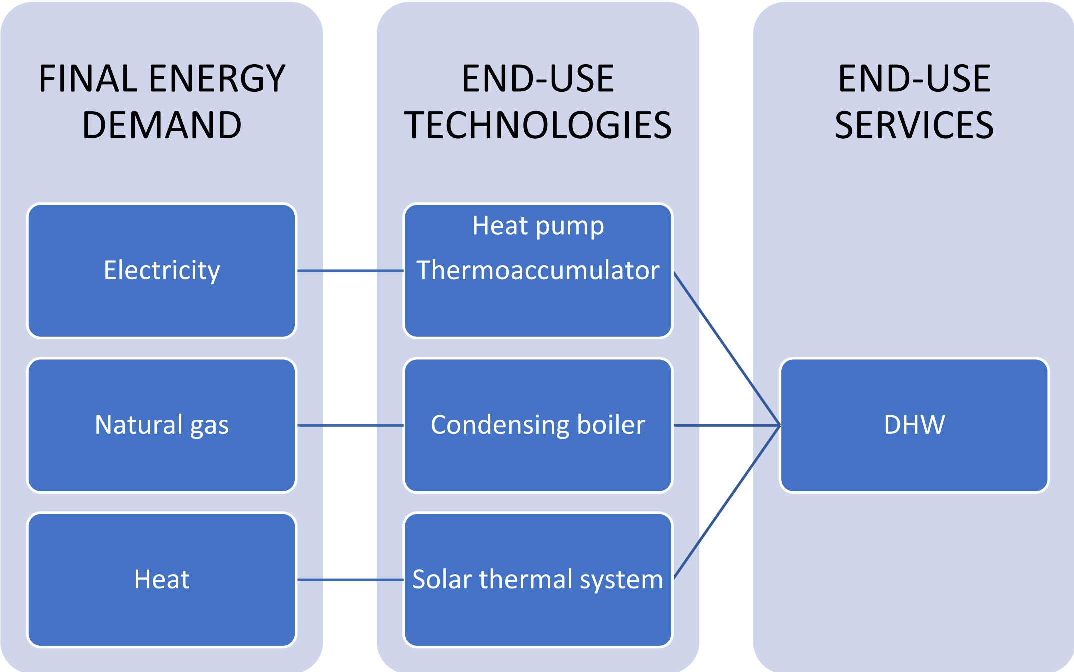

Figure 3-1: Example of the expansion process performed for each sector/subsector and end-use service

For the residential sector, Figure 3-2 shows the system structure from final energy up to the end use services, including all the end uses considered for this sector and the respective end-use technologies.

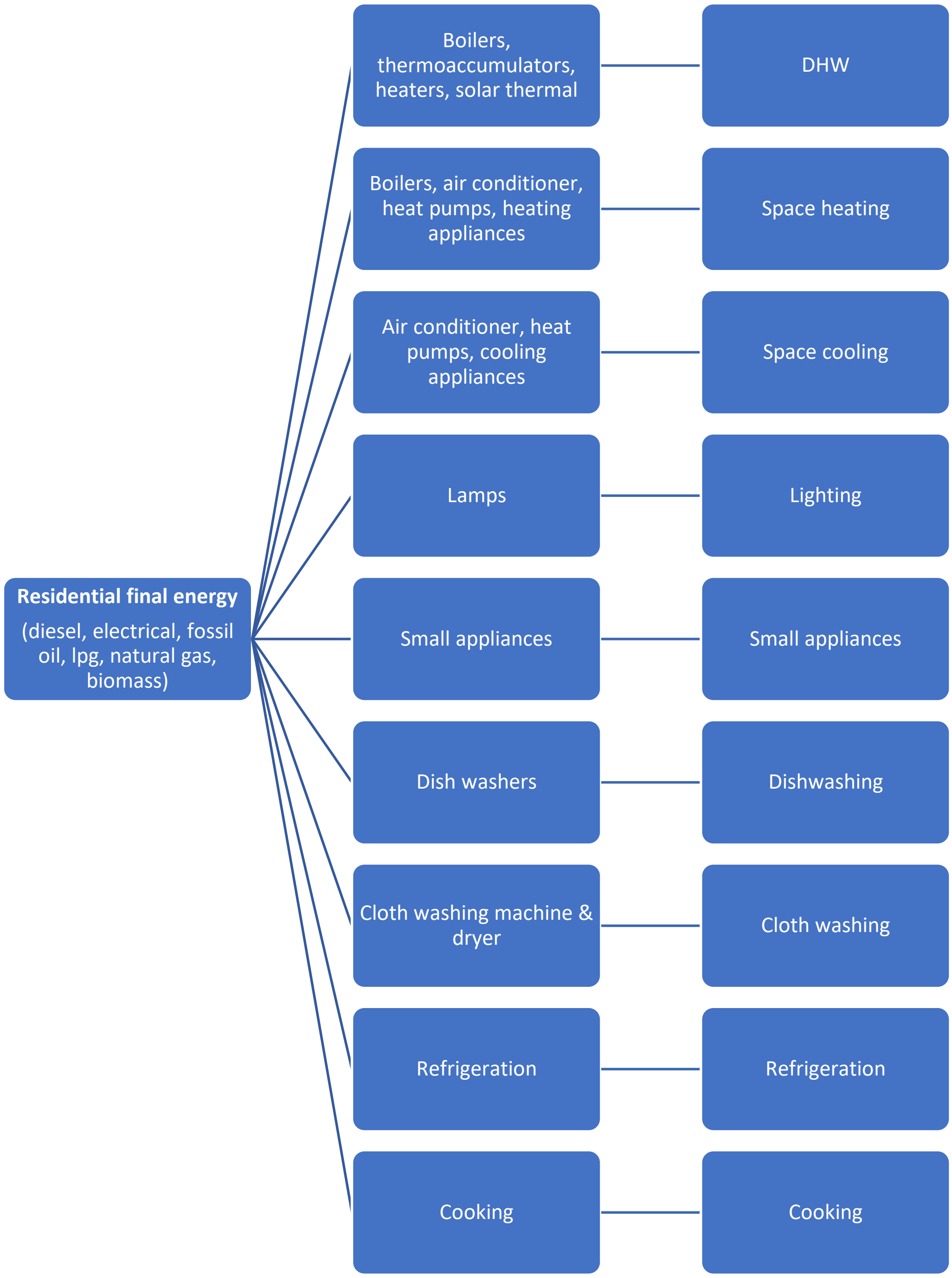

Figure 3-2: Scheme of the model for the residential sector

In the case of the services buildings sector, as previously referred, the disaggregation exercise was performed individually for six subsectors, in order to accommodate the different energy use profiles. The subsectors were defined as follows:

- Education: includes all education facilities, public and private, from primary school, to secondary, high school and university;
- Commercial & Other Services: refers to both gross and retail commercial activities, as well as all smaller services activities which are not included in the remaining categories (as banks, cultural activities, insurance companies, etc.);
- Restaurants/hotels: corresponds to restaurants and hotels as well as other similar buildings;

- Public services buildings: includes all buildings related to public services that are not covered in other subsector, the most relevant being public administration;
- Sport Facilities: refers to buildings where sports or physical activities occur, including gyms, sport facilities, stadiums, etc.;
- Health related services: refers to hospitals, clinics and other health facilities, both public and private.

The respective expansion modules were developed following the same methodology as the one described for the residential buildings sector. Figure 3-3 shows the end-use services that were considered for each subsector. The listing of all the represented end-use technologies for each specific end-use service is presented in detail in subchapter 3.3 along with the technical and economic characterization of the different technologies.

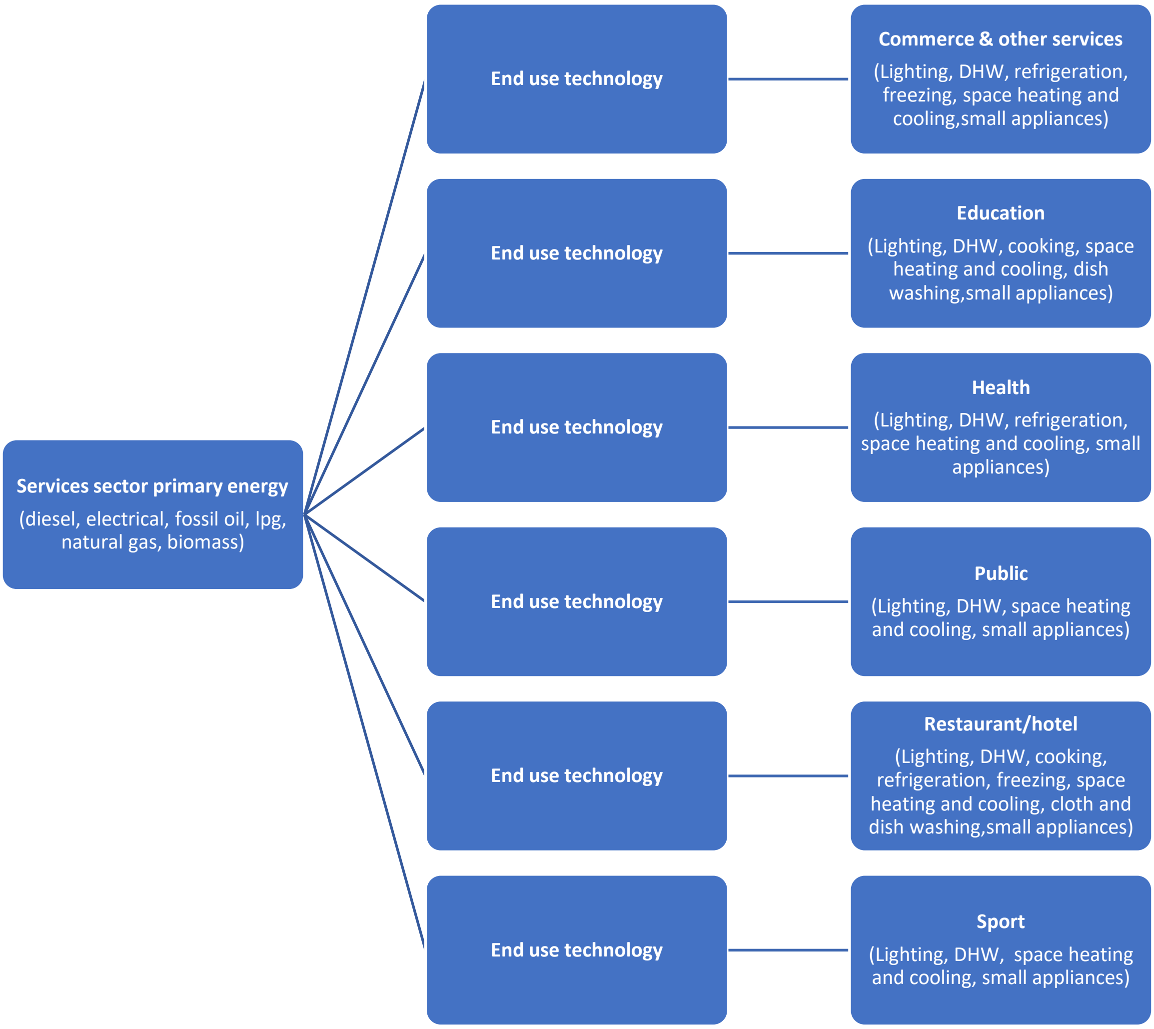

Figure 3-3: Scheme of the model for the services sector

It is important to note that it could be beneficial to further disaggregate the residential and services sectors into additional subsectors, to obtain a better representation of the actual system and consequently obtain more detailed results. However, due to the scarcity of detailed data on energy use and type of technologies used to meet each end-use service, it was decided to limit the level of disaggregation in order to guarantee the robustness of the results.

Further disaggregation of the services sector, may be considered if additional data becomes available. The same is valid for the residential sector, where additional subgroups could be considered, as the separation between urban and rural dwellings, the distinction of building typology (detached house, semi-detached house, apartment, etc.) or according to the socio-economic conditions of the household.

3.2 Energy Demand

In OSeMOSYS, the characterization of the energy demand includes the identification of the annual demand per end-use service, in terms of useful energy, and the characterization of the consumption profile (i.e. the distribution of the demand through the different time periods considered). This section is dedicated to the demand characterization of both residential and services buildings sectors.

3.2.1 Final energy demand per sector

In order to accomplish a robust characterization of the energy demand of the buildings sectors, different sources with energy consumption statistics and databases were analyzed. For the overall energy use per sector/subsector, the main sources were Eurostat, INE and DGEG. INE databases also allowed for the disaggregation of the demand in the services sector by its subsectors. Data was collected for the years between 2015 and 2019, the most recent data which is published as final. Table 3-1 provides a snapshot of the values in 2019.

Table 3-1: Final energy demand (PJ) associated with the residential and services buildings sectors in Portugal, in 2019 [15,16,17]

	2019
Residential buildings	122
Service buildings	374
Commerce & other Services	62,9234
Education	45,2284
Sport	34,4563
Health	126,0490
Public	135,2304
Restaurant/hotel	4,7930

In appendix A, the activities included in each subsector are listed along with the respective final energy consumption collected from DGEG Energy Statistics, so that can be made an analysis of what was taken into account in each subsector in a more detail fashion.

In the first 5 years, in the period 2015-2020, the value of energy consumed in Portugal, differentiated by residential sector and services sector, exist, being provided by DGEG (initially the difference is minimal, but in the last years it became significant due to the effects of the COVID pandemic).

Table 3-2: Residential sector energy consumption 2015-2020 [15]

Residential	2015	2016	2017	2018	2019	2020 (provisional)
Consumption (GWh)	12 756	12 973	12 604	13 351	13 223	13 702
Relative to 2019 (%)	96.47	98.11	95.32	100.97	100	103.62

Table 3-3: Services sector energy consumption 2015-2020 [15]

Services	2015	2016	2017	2018	2019	2020 (provisional)
Consumption (GWh)	15 998	16 300	16 207	16 454	16 307	14 894
Relative to 2019 (%)	98.11	99.96	99.38	100.9	100	91.33

3.2.2 Energy demand per end use

The end-use services within the buildings sectors are very similar across the residential and services sectors, and across the different services subsectors. Among the most relevant are the following uses: space heating, space cooling, lighting, domestic hot water, refrigeration, and small appliances (electrical appliances not included in the other energy services, including computers, printers, etc.).

Other end-uses are more relevant in specific sectors, such as cooking with a more significant weight in the residential sector and in the services buildings from restaurant/hotel and education subsectors. In addition to the three sectors/subsectors mentioned previously, in the commercial & other services subsector there is still Refrigeration demand, albeit in the last-mentioned and the restaurant/hotel subsectors, a distinction was made between refrigeration demand and freezing demand, since freezing units are of a higher size, and subsequently, with different characteristics, and their consumption represents a significant percentage of the total consumption of the subsector concerned, unlike other subsector.

For the residential sector, the overall demand was disaggregated into nine end-use services, as presented in Table 3-2. Most of the specific demand values could be found on databases made available by national and international institutions (DGEG, INE and Eurostat).

However, a differentiation between small appliances and other home appliances was not found, which required further research to complete the demand break down.

Table 3-4: Useful energy demand (PJ) of the Residential sector per end-use service for Portugal, 2019 [15, 16, 18]

End-use service	Useful energy (PJ)
Lighting	2,350238
DHW	21,53154
Cooking	44,04179
Space Cooling	0,73403
Space Heating	33,52069
Cloth washing and drying	2,501866
Dishwashing	2,213772
Refrigeration	5,716384
Small Appliances	9,605648

For the services subsectors, apart from the sport subsector, specific data on the weight of the different end-use services on the overall energy demand was based on [Setting course for demand response in the service sector], an academic paper, which provides a thorough description of the energy use in the services buildings in Germany.

The services categories do not correspond completely with the categorization used in this work. Nonetheless, a correspondence was achieved with slight adaptations. Education, health and restaurant/hotel subsectors are equivalent to the categories identified as schools, hospitals and hotels, restaurants. The commercial and other services subsector refers to two categories of buildings, office like and retail trade buildings. A weighted average of these two categories was used to estimate the distribution of the subsector demand per end-use service. On the other hand, office like buildings were also used to obtain the distribution per end use for the public subsector. Table 3-5 presents the distribution of final energy demand per end-use service, according to the previously mention academic paper.

Table 3-5: Demand of end uses per subsector as presented in source [19]

Buildings	Lights	DHW	Space heating	AC	ICT	Process cool	Mechanical power	Process Heat
officelike	0,45	0,03	0,037288136	0,03051	0,36949	0,023728814	0,044067797	0,01355932
retail trade	0,49	0,03	0,062222222	0,02222	0,08444	0,186666667	0,093333333	0,02666667
hospital	0,2	0,05	0,016393443	0,04918	0,09836	0,016393443	0,278688525	0,27868852
schools	0,48	0,02	0,016393443	0	0,06557	0	0,016393443	0
hotels restaurant and homes	0,29	0,07	0,075675676	0,01081	0,05405	0,135135135	0,259459459	0,11351351

The correlation between the end-uses used in this work and the ones presented by [19] was performed as presented in Table 3-6. A last assumption was made regarding the share of energy for small appliances. In this specific case, it was assumed that, when present, the distribution of small appliances would be equal to that in the residential sector.

Table 3-6: Correlation between source and this work end uses

Source end use	End use
Lights	Lighting
DHW	DHW
Space heating	Space heating
AC	Space heating
ICT	Small appliances
Process cool	Refrigeration
Mechanical power	Space heating & cooling
Process Heat	Space heating

With the information above, the energy demand per end use can be reached for all the services subsectors, with exception of the sport subsector. Table 3-7 provides a summary of the retrieved information.

Table 3-7: Final energy demand (PJ) per end use services for the different services subsectors in Portugal, 2019

	Final Energy Demand (PJ)					
End Use Service	Education	Health	Public sector	Restaurants and Hotels	Commercial and other services	Sports
Lighting	9,60	24,80	60,97	0,87	30,54	10,77
DHW	0,33	6,20	4,13	0,21	1,95	6,67
Cooking	10,46	-	-	1,72	-	-
Space Cooling	0,01	1,68	0,36	0,03	0,27	4,01
Space Heating	0,65	76,84	16,60	1,37	12,13	9,73
Dish washing	0,15	-	-	0,03	-	-
Clothes washing and drying	-	-	-	0,03	-	-
Small appliances	1,32	12,40	49,97	0,30	6,99	3,28
Refrigeration	2,51	2,07	-	0,11	7,77	-
Freezing	-	-	-	0,12	3,02	-
Total	20,19	126,05	135,23	4,79	62,92	34,46

For the subsectors where there is a significant energy consumption associated with freezing needs, it was necessary to estimate the percentage of cooling demand that corresponds to freezing. With this intent, it was used a study of the energy consumption per end use of a generic commercial space. With this information the energy consumption of refrigeration vs freezing can be achieved, as it is represented in the following table.

Table 3-8: Energy consumption of refrigeration vs. freezing [20, 21]

	Energy consumption (%)
Refrigeration	72
Freezing	28

For the Sports subsector, a different source was used to estimate the disaggregation per end-use service, this belonging to the Join Research Commission - Integrated Database of the European Energy System (JRC-IDEES), the science branch of the European Union, which details by year and country the capacity and efficiency by end use and fuel.

3.2.3 Intra-annual distribution of Demands

Consumption in the various sectors and subsectors is rarely constant throughout the year, and it is of interest to take this factor into consideration to analyze the peaks of consumption, as well as the relation between the distribution of supply and demand. Indeed, each type of fuel (as electricity/heat) is associated with it a distribution/transport network. These networks have maximum values and if consumption exceeds this value, it would require an investment in infrastructure for the transport of the fuel in question. Moreover, the availability of primary energy resources also varies throughout the year. This disaggregation allows for the model to take into consideration the balance between demand and supply, and the need to include additional generation capacity and/or energy storage.

3.2.3.1 Residential sector

To estimate the distribution of residential energy consumption throughout the year, the average consumption profile made available by the electricity DSO was used as the starting point. In the mentioned database, the residential energy use is disaggregated into 15 minutes intervals, for the whole year. It was considered the daytime period would encompass 12 hours, from 7:15 to 19:15, by adding the value of day and night consumption of each month the following results were obtained. It is important to note that these data refers only to electricity consumption, not considering the consumption of natural gas or other fuel like LPG, nonetheless, it was considered to be the best available data.

Table 3-9: Residential sector energy consumption per month (day/night) [23]

Month	Day consumption	Night consumption
Jan	14,5329587	91,2883642
Feb	6,9166237	81,8977378
Mar	2,2867001	85,4316684
Apr	0,0711154	74,0555386
May	0,0004557	68,1393181
Jun	0,000441	61,8470422
Jul	0,0004557	66,1354934
Ago	0,0017802	73,6104939
Set	0,4294781	80,0840198
Out	4,3781799	89,9239104
Nov	13,1156181	87,2823562
Dec	16,949785	91,261126

These values were used to estimate the disaggregation of the overall consumption per season, day and night, considering that each season corresponds to three months, being: (1) spring from March to May; (2) summer from June to August; (3) autumn from September to November; and (4) winter from December to February. For space heating and cooling, it was assumed that heating is concentrated in autumn and winter, and cooling in the summer period. The estimated of the distribution of the different end-use services per period is presented in the following table.

Table 3-10: Residential sector intra-annual variation per end use

Residential	A-D	A-N	W-D	W-N	Sp-D	Sp-N	S-D	S-N
Lighting	0.018	0.254	0.038	0.259	0.002	0.226	0.001	0.202
DHW	0.018	0.254	0.038	0.259	0.002	0.226	0.001	0.202
Cooking	0.018	0.254	0.038	0.259	0.002	0.226	0.001	0.202
Space Cooling	0	0	0	0	0	0	0.005	0.995
Space Heating	0.031	0.446	0.067	0.455	0	0	0	0
cloth	0.018	0.254	0.038	0.259	0.002	0.226	0.001	0.202
dish	0.018	0.254	0.038	0.259	0.002	0.226	0.001	0.202
cooling Appliances	0.018	0.254	0.038	0.259	0.002	0.226	0.001	0.202
small Appliances	0.018	0.254	0.038	0.259	0.002	0.226	0.001	0.202

Some demands, including refrigeration and freezing, have a uniform profile, since machines for this purpose work 24 hours a day to keep the products inside in the desired conditions. In reality, energy consumption of the associated technologies would vary with the variation of the ambient temperature, although in service buildings the indoor temperature remains fairly similar throughout the year, varying the consumption for cooling and heating of the space. As we have no way of knowing the variation of temperature inside residential and service buildings, we consider the energy consumption of refrigeration and freezing uniformly distributed throughout the year.

Space heating only applies for the colder seasons, autumn and winter, and as we have not been able to differentiate between these two seasons, we consider an equal division between the two. In the case of space cooling, it is only needed in the summer months, being the only season where this demand is present.

In the following two subsectors, Health services and Restaurant and Hotels services, since they function in a continuously manner, without interruption, its consumption was considered to be divided in a similar way between day and night, as it can be seen in the following table

Table 3-11: Restaurant/hotel subsector intra-annual variation per end use

Restaurant/hotel	A-D	A-N	W-D	W-N	Sp-D	Sp-N	S-D	S-N
Lighting	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
DHW	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Cooking	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Space Cooling	0	0	0	0	0	0	0.5	0.5
Space Heating	0.25	0.25	0.25	0.25	0	0	0	0
Cloth Washing	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Dishwashing	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Refrigeration	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Small Appliances	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Freezing	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125

Table 3-12: Health subsector intra-annual variation per end use

Health	A-D	A-N	W-D	W-N	Sp-D	Sp-N	S-D	S-N
Lighting	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
DHW	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Space Cooling	0	0	0	0	0	0	0.5	0.5
Space Heating	0.25	0.25	0.25	0.25	0	0	0	0
Refrigeration	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Small Appliances	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125

In the remaining subsectors, it was considered that, since most operate only during the day, apart from refrigeration and freezing technologies, which must work without interruption, there is only daytime consumption, and the nighttime consumption throughout the year is null. The other considerations made for the previous subsectors were also made for these, namely the consumption of heating and cooling spaces.

Table 3-13: Education subsector intra-annual variation per end use

Education	A-D	A-N	W-D	W-N	Sp-D	Sp-N	S-D	S-N
Lighting	0.25	0	0.25	0	0.25	0	0.25	0
DHW	0.25	0	0.25	0	0.25	0	0.25	0
Cooking	0.25	0	0.25	0	0.25	0	0.25	0
Space Cooling	0	0	0	0	0	0	1	0
Space Heating	0.5	0	0.5	0	0	0	0	0
Dishwashing	0.25	0	0.25	0	0.25	0	0.25	0
Small Appliances	0.25	0	0.25	0	0.25	0	0.25	0

Table 3-14: Public subsector intra-annual variation per end use

Public	A-D	A-N	W-D	W-N	Sp-D	Sp-N	S-D	S-N
Lighting	0.25	0	0.25	0	0.25	0	0.25	0
DHW	0.25	0	0.25	0	0.25	0	0.25	0
Space Cooling	0	0	0	0	0	0	1	0
Space Heating	0.5	0	0.5	0	0	0	0	0
small Appliances	0.25	0	0.25	0	0.25	0	0.25	0

Table 3-15: Commerce & other services subsector intra-annual variation per end use

Commerce & other services	A-D	A-N	W-D	W-N	Sp-D	Sp-N	S-D	S-N
Lighting	0.25	0	0.25	0	0.25	0	0.25	0
DHW	0.25	0	0.25	0	0.25	0	0.125	0
Space Cooling	0	0	0	0	0	0	1	0
Space Heating	0.5	0	0.5	0	0	0	0	0
Refrigeration	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
small Appliances	0.25	0	0.25	0	0.25	0	0.25	0
Freezing	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125

Table 3-16: Sport subsector intra-annual variation per end use

Sport	A-D	A-N	W-D	W-N	Sp-D	Sp-N	S-D	S-N
Lighting	0.25	0	0.25	0	0.25	0	0.25	0
DHW	0.25	0	0.25	0	0.25	0	0.25	0
Space Cooling	0	0	0	0	0	0	1	0
Space Heating	0.5	0	0.5	0	0	0	0	0
Small Appliances	0.25	0	0.25	0	0.25	0	0.25	0

3.2.4 Evolution of the energy demand between 2015 and 2050

The evolution of the energy demand in the buildings sectors takes into account several factors, the most relevant being population, GDP, among others. It is expected that the demand for the different end-use services, throughout the different sectors, will vary over the years.

In this specific work, 2019 was used as the reference year, being the most recent year that had complete published data on national energy consumption, by DGEG, without being under provisional regime and as such susceptible to changes. As such, all assumptions carried out in order to obtain the consumption projection by sector were made on the basis of the year 2019.

For the projections from 2020 onwards, the projections made available by REN in the plans for investment in the electricity and natural gas network [24], were used to estimate energy demand per sector between 2020 to 2040.

Table 3-17: Evolution in overall energy demand 2020-2030, according to [24]

Year	Consumption (GWh)	Year	Consumption (GWh)	Year	Consumption (GWh)
2020	44910	2024	47127	2028	49004
2021	46205	2025	47453	2029	49647
2022	46569	2026	47908	2030	50351
2023	46833	2027	48420		

For the period between 2030 and 2050, we only have values for the year 2035, so it was considered that consumption would change following a linear evolution, obtaining using the data related to the year 2035 and previous years.

Table 3-18: Energy consumption prediction 2031-2050 [24]

Year	Consumption (GWh)	Year	Consumption (GWh)	Year	Consumption (GWh)	Year	Consumption (GWh)
2031	51292,2	2036	55888,2	2041	60044,2	2046	64200,2
2032	52233,4	2037	56719,4	2042	60875,4	2047	65031,4
2033	53174,6	2038	57550,6	2043	61706,6	2048	65862,6
2034	54115,8	2039	58381,8	2044	62537,8	2049	66693,8
2035	55057	2040	59213	2045	63369	2050	67525

We are now able to reach a value for each year that compared consumption with the year 2020 of the DGEG estimate, which is presented in the nest table:

Table 3-19: Projection of the final energy demand for the buildings sectors in Portugal up to 2050, relative to 2020

Year	Relative to 2020, forecast (%)	Year	Relative to 2020, forecast (%)	Year	Relative to 2020, forecast (%)
2020	100,00	2031	114,21	2041	133,70
2021	102,88	2032	116,31	2042	135,55
2022	103,69	2033	118,40	2043	137,40
2023	104,28	2034	120,50	2044	139,25
2024	104,94	2035	122,59	2045	141,10
2025	105,66	2036	124,44	2046	142,95
2026	106,68	2037	126,30	2047	144,80
2027	107,82	2038	128,15	2048	146,65
2028	109,12	2039	130,00	2049	148,51
2029	110,55	2040	131,85	2050	150,36
2030	112,12				

These values were subsequently multiplied by the value that related 2020 to our reference year, 2019, for the services sector and for the residential sector, thus obtaining a prevision of the energy consumption for each year related to that of the last year with published, non-provisional, data.

Table 3-20Evolution of the final energy demand for the residential sector, relative to 2019

Year	Relative to 2019 (%)	Year	Relative to 2019 (%)	Year	Relative to 2019 (%)	Year	Relative to 2019 (%)
2015	96,47	2025	109,49	2035	127,04	2045	146,21
2016	98,11	2026	110,54	2036	128,95	2046	148,13
2017	95,32	2027	111,72	2037	130,87	2047	150,05
2018	100,97	2028	113,07	2038	132,79	2048	151,97
2019	100,00	2029	114,55	2039	134,71	2049	153,89
2020	103,62	2030	116,18	2040	136,62	2050	155,80
2021	106,61	2031	118,35	2041	138,54		
2022	107,45	2032	120,52	2042	140,46		
2023	108,06	2033	122,69	2043	142,38		
2024	108,74	2034	124,86	2044	144,30		

Table 3-21Evolution of the final energy demand for the services sector, relative to 2019

Year	Relative to 2019 (%)	Year	Relative to 2019 (%)	Year	Relative to 2019 (%)	Year	Relative to 2019 (%)
2015	98,11	2025	96,51	2035	111,97	2045	128,88
2016	99,96	2026	97,43	2036	113,66	2046	130,57
2017	99,39	2027	98,47	2037	115,35	2047	132,26
2018	100,90	2028	99,66	2038	117,04	2048	133,95
2019	100,00	2029	100,97	2039	118,73	2049	135,64
2020	91,34	2030	102,40	2040	120,42	2050	137,33
2021	93,97	2031	104,31	2041	122,11		
2022	94,71	2032	106,23	2042	123,80		
2023	95,25	2033	108,14	2043	125,49		
2024	95,84	2034	110,06	2044	127,19		

The estimated changes were multiplied by the different end-use services demands of the different sectors/subsectors, resulting in a projection of the evolution the energy demand associated with the different end uses between 2015 and 2050. The full extent of results is presented in Appendix B.

3.3 Technologies per end use & Technologies properties

Each end-use service demand can be suppressed by a diversified set of technologies, having different characteristics that need to be collected and inserted into the model. Moreover, it is important to highlight that similar technologies may have different performance and investment characteristics, according to the sector they are use in, due to the different scale of the technology employed and the type of usage. Additionally, some technologies that satisfy two demands must have an efficiency associated for each demand.

The characterization of the different end-use technologies comprises the following features: conversion efficiency, investment cost, operation and maintenance costs, and the average operation lifetime. Moreover, if the technologies have some usage restriction, including the number of hours they can operate per year, or the restrictions associated with the availability of resources (as in the case of solar related technologies), these should also be characterized and included in the model as an input.

For this data it was mostly used the JRC TIMES database [7] since it lists both technical and economical information of most technologies added to the developed model. The exception is the lighting technologies since in the previous source their efficiency is presented in lumen/watt, consequently it was used two academic articles to obtain this information [25, 26].

Since the scale of technologies employed in the service sector are, commonly, larger in scale, they have different associated properties, namely its efficiency and economic characteristics. So, it is necessary to describe their service counterparts, although there are a minority of employed technologies that have constant properties in varied settings, the most notorious being the different types of lighting technologies. Even in the case of these similar technologies it was decided to describe each technology employed by the different subsectors, for an easier perception of the present technologies in the different types of buildings.

The following tables present in detail the technical and economic features that were used as input for the modelling exercise for each subsector. Given the lack of available data regarding the evolution of these features over time, these were considered to be constant until 2050. This assumption is clearly an oversimplification with a strong impact on the modelling outputs. However, it is assumed that this will not compromise the relevance of the work performed.

Table 3-22: Residential sector employed technologies [7, 25, 26]

Fuel	Technology	End use	Efficiency (%)	Initial cost (Million eur/GW)	O&M cost (Million eur/GW)	Lifetime (years)
Electricity	LEDs	Lighting	83,3	17,62	0	22.8
Electricity	Incandescent	Lighting	9,2	0	0	2
Electricity	Halogens	Lighting	11,9	0,01	0	5
Electricity	Fluorescent	Lighting	51,2	0,01	0	8
Electricity	Thermoaccumulators	DHW	1	135	1,49	15
Electricity	Dishwasher high efficiency	Dishwasher	2	0,36	0	15
Electricity	Dishwasher low efficiency	Dishwasher	1	0,17	0,01	15
Electricity	Cloth washing machine & dryer (high efficiency)	Cloth washing	1,41	1,41	0,01	15
Electricity	Cloth washing machine & dryer (low efficiency)	Cloth washing	1	0,62	0,01	15
Electricity	Refrigeration Appliances (high efficiency)	Refrigeration	2,92	0,84	0,01	15
Electricity	Refrigeration Appliances (low efficiency)	Refrigeration	1,56	0,84	0,01	15
Electricity	Small Appliances	Small Appliances	2,92	0,84	0,03	15
Electricity	Cooking electrical	Cooking	1	0,9	0,02	15
Electricity	Heat pumps	Space Heating	5.8	1529	76,5	1 5
		Space Cooling	5.8			
Electricity	Heating appliances (small heater,…)	Space Heating	1	233	2,56	15
Electricity	Cooling appliances (fans,…)	Space Cooling	0.4	151,99	7,6	10
Electricity & Heat	Solar thermal	DHW	1	2302,68	46,05	20
Electricity	Air conditioner	Space Heating	2,025	481	24,05	10
		Space Cooling	2,025			
Oil	Boiler oil	DHW	0.38	314,11	15,71	20
		Space Heating	1			

Fuel	Technology	End use	Efficiency (%)	Initial cost (Million eur/GW)	O&M cost (Million eur/GW)	Lifetime (years)
Oil	Heater oil	Space Heating	0.7	170	8,5	15
LPG	Boiler LPG	DHW	0.659	182,05	9,1	20
		Space Heating	0.91			
LPG	Cooking LPG	Cooking	0.6	0,23	0	15
LPG	Heater LPG	DHW	0.73	60,8	3,04	15
NG	Boiler NG	DHW	0.663	236,88	11,84	20
		Space Heating	0.905			
NG	Heater NG	DHW	0.76	153	7,65	15
NG	Cooking NG	Cooking	1	0,34	0,01	15
Biomass	open fireplace	Space Heating	0.55	185,77	0	15
Biomass	close fireplace	Space Heating	0.61	103,58	0	15
Biomass	Boiler Biomass	DHW	0,418	487	24,35	20
		Space Heating	0,85			
Biomass	Heater Biomass	DHW	0,5	184,64	9,23	20

Table 3-23: Restaurant/Hotel subsector employed technologies [7, 25, 26]

Fuel	Technology	End use	Efficiency (%)	Initial cost (Million eur/GW)	O&M cost (Million eur/GW)	Lifetime (years)
Electricity	LEDs	Lighting	83,3	17,62	0	22.8
Electricity	Incandescent	Lighting	9,2	0,01	0	2
Electricity	Halogens	Lighting	11,9	0	0	5
Electricity	Fluorescent	Lighting	51,2	0	0	8
Electricity	Thermoaccumulator	DHW	1	75	0,83	15
Electricity	Dishwasher high efficiency	Dishwasher	2	0,36	0	15
Electricity	Dishwasher low efficiency	Dishwasher	1	0,17	0,01	15
Electricity	Cloth washing machine & dryer (high efficiency)	Cloth washing	1,41	1,41	0,01	15
Electricity	Cloth washing machine & dryer (low efficiency)	Cloth washing	1	0,62	0,01	15
Electricity	Refrigeration Appliances (high efficiency)	Refrigeration	2,86	2,86	0,01	15
Electricity	Refrigeration Appliances (low efficiency)	Refrigeration	1,54	0,43	0,02	15
Electricity	Small Appliances	Small Appliances	1	0,84	0,01	15
Electricity	Cooking electrical	Cooking	1	0,9	0,02	15
Electricity	Heat pumps	Space Heating	4,8	1351,02	67,55	15
		Space Cooling	4,8			
Electricity	Freezing Appliances high efficiency	Freezing	3,01	0,6	0,01	15
Electricity	Freezing Appliances low efficiency	Freezing	1,62	0,43	0,01	15
Electricity & Heat	Solar thermal	DHW	1	1711,67	34,23	20
Electricity	Air conditioner	Space Heating	3	481	24,05	10
		Space Cooling	3			
Electricity	Centralized Air conditioner	Space Heating	2,93	333	2,66	15
		Space Cooling	2,93			
Oil	Boiler oil	Space Heating	0,85	77,34	3,87	20
		DHW	0,418			

Fuel	Technology	End use	Efficiency (%)	Initial cost (Million eur/GW)	O&M cost (Million eur/GW)	Lifetime (years)
Oil	Heater oil	Space Heating	0,58	83,31	4,17	15
LPG	Boiler LPG	Space Heating	0,3	182,05	9,1	20
		DHW	0,1			
LPG	Cooking LPG	Cooking	0,6	0,23	0	15
LPG	Heater LPG	DHW	0,73	60,8	3,4	15
NG	Boiler NG	Space Heating	0,95	179,39	12,56	20
		DHW	0,663			
NG	Heater NG	DHW	0,76	115,87	5,79	15
NG	Cooking NG	Cooking	1	0,34	0,01	15
Biomass	close fireplace	Space Heating	0,61	103,58	0	15
Biomass	Boiler Biomass	DHW	0,418	487	24,35	20
		Space Heating	0,85			
Biomass	Heater Biomass	DHW	0,5	184,64	9,23	20

Table 3-24:Commerce & other services subsector employed technologies [7, 25, 26]

Fuel	Technology	End use	Efficiency (%)	Initial cost (Million eur/GW)	O&M cost (Million eur/GW)	Lifetime (years)
Electricity	LEDs	Lighting	83,3	17,62	0	22.8
Electricity	Incandescent	Lighting	9,2	0,01	0	2
Electricity	Halogens	Lighting	11,9	0	0	5
Electricity	Fluorescent	Lighting	51,2	0	0	8
Electricity	Thermoaccumulators	DHW	1	75	0,83	15
Electricity	Refrigeration Appliances (high efficiency)	Refrigeration	2,86	2,86	0,01	15
Electricity	Refrigeration Appliances (low efficiency)	Refrigeration	1,54	0,43	0,02	15
Electricity	Small Appliances	Small Appliances	1	0,84	0,01	15
Electricity	Heat pumps	Space Heating	4,8	1351,02	67,55	15
		Space Cooling	4,8			
Electricity	Freezing Appliances high efficiency	Freezing	3,01	0,6	0,01	15
Electricity	Freezing Appliances low efficiency	Freezing	1,62	0,43	0,01	15
Electricity & Heat	Solar thermal	DHW	1	1711,67	34,23	20
Electricity	Air conditioner	Space Heating	3	481	24,05	10
		Space Cooling	3			
Electricity	Centralized Air conditioner	Space Heating	2,93	333	2,66	15
		Space Cooling	2,93			
Oil	Boiler oil	Space Heating	0,85	77,34	3,87	20
		DHW	0,418			
Oil	Heater oil	Space Heating	0,58	83,31	4,17	15
LPG	Boiler LPG	Space Heating	0,734	182,05	9,1	20
		DHW	0,817			
LPG	Heater LPG	DHW	0,73	60,8	3,4	15
NG	Boiler NG	Space Heating	0,95	179,39	12,56	20
		DHW	0,663			
NG	Heater NG	DHW	0,76	115,87	5,79	15

Fuel	Technology	End use	Efficiency (%)	Initial cost (Million eur/GW)	O&M cost (Million eur/GW)	Lifetime (years)
Biomass	close fireplace	Space Heating	0,61	103,58	0	15
Biomass	Boiler Biomass	DHW	0,418	487	24,35	20
		Space Heating	0,85			
Biomass	Heater Biomass	DHW	0,5	184,64	9,23	20

Table 3-25: Education subsector employed technologies [7, 25, 26]

Fuel	Technology	End use	Efficiency (%)	Initial cost (Million eur/GW)	O&M cost (Million eur/GW)	Lifetime (years)
Electricity	LEDs	Lighting	83,3	17,62	0	22.8
Electricity	Incandescent	Lighting	9,2	0,01	0	2
Electricity	Halogens	Lighting	11,9	0	0	5
Electricity	Fluorescent	Lighting	51,2	0	0	8
Electricity	Thermoaccumulators	DHW	1	75	0,83	15
Electricity	Dishwasher high efficiency	Dishwasher	2	0,36	0	15
Electricity	Dishwasher low efficiency	Dishwasher	1	0,17	0,01	15
Electricity	Small Appliances	Small Appliances	1	0,84	0,01	15
Electricity	Cooking - electrical	Cooking	1	0,9	0,02	15
Electricity	Heat pumps	Space Heating	4,8	1351,02	67,55	15
		Space Cooling	4,8			
Electricity & Heat	Solar thermal	DHW	1	1711,67	34,23	20
Electricity	Air conditioner	Space Heating	3	481	24,05	10
		Space Cooling	3			
Electricity	Centralized Air conditioner	Space Heating	2,93	333	2,66	15
		Space Cooling	2,93			
Oil	Boiler oil	Space Heating	0,85	77,34	3,87	20
		DHW	0,418			
Oil	Heater oil	Space Heating	0,58	83,31	4,17	15
LPG	Boiler LPG	Space Heating	0,734	182,05	9,1	20
		DHW	0,817			
LPG	Cooking LPG	Cooking	0,6	0,23	0	15
LPG	Heater LPG	DHW	0,73	60,8	3,4	15
NG	Boiler NG	Space Heating	0,95	179,39	12,56	20
		DHW	0,663			
NG	Heater NG	DHW	0,76	115,87	5,79	15
NG	Cooking - NG	Cooking	1	0,34	0,01	5
Biomass	close fireplace	Space Heating	0,61	103,58	0	15

Fuel	Technology	End use	Efficiency (%)	Initial cost (Million eur/GW)	O&M cost (Million eur/GW)	Lifetime (years)
Biomass	Boiler Biomass	DHW	0,418	487	24,35	20
		Space Heating	0,85			
Biomass	Heater Biomass	DHW	0,5	184,64	9,23	20

Table 3-26: Public services buildings subsector employed technologies

Fuel	Technology	End use	Efficiency (%)	Initial cost (Million eur/GW)	O&M cost (Million eur/GW)	Lifetime (years)
Electricity	LEDs	Lighting	83,3	17,62	0	22.8
Electricity	Incandescent	Lighting	9,2	0,01	0	2
Electricity	Halogens	Lighting	11,9	0	0	5
Electricity	Fluorescent	Lighting	51,2	0	0	8
Electricity	Thermoaccumulators	DHW	1	75	0,83	15
Electricity	Small Appliances	Small Appliances	1	0,4	0,01	15
Electricity	Heat pumps	Space Heating	4,8	1351,02	67,55	15
		Space Cooling	4,8			
Electricity & Heat	Solar thermal	DHW	1	1711,67	34,23	20
Electricity	Air conditioner	Space Heating	3	481	24,05	10
		Space Cooling	3			
Electricity	Centralized Air conditioner	Space Heating	2,93	333	2,66	15
		Space Cooling	2,93			
Oil	Boiler oil	Space Heating	0,85	77,34	3,87	20
		DHW	0,418			
Oil	Heater oil	Space Heating	0,58	83,31	4,17	15
LPG	Boiler LPG	Space Heating	0,734	182,05	9,1	20
		DHW	0,817			
LPG	Heater LPG	DHW	0,73	60,8	3,4	15
NG	Boiler NG	Space Heating	0,95	179,39	12,56	20
		DHW	0,663			
NG	Heater NG	DHW	0,76	115,87	5,79	15
Biomass	close fireplace	Space Heating	0,61	103,58	0	15
Biomass	Boiler Biomass	DHW	0,418	487	24,35	20
		Space Heating	0,85			
Biomass	Heater Biomass	DHW	0,5	184,64	9,23	20

Table 3-27: Health subsector employed technologies [7, 25, 26]

Fuel	Technology	End use	Efficiency (%)	Initial cost (Million eur/GW)	O&M cost (Million eur/GW)	Lifetime (years)
Electricity	LEDs	Lighting	83,3	17,62	0	22.8
Electricity	Incandescent	Lighting	9,2	0,01	0	2
Electricity	Halogens	Lighting	11,9	0	0	5
Electricity	Fluorescent	Lighting	51,2	0	0	8
Electricity	Thermoaccumulators	DHW	1	75	0,83	15
Electricity	Small Appliances	Small Appliances	1	0,84	0,01	15
Electricity	Heat pumps	Space Heating	4,8	1351,02	67,55	15
		Space Cooling	4,8			
Electricity	Refrigeration Appliances (high efficiency)	Refrigeration	2,86	2,86	0,01	15
Electricity	Refrigeration Appliances (low efficiency)	Refrigeration	1,54	0,43	0,02	15
Electricity & Heat	Solar thermal	DHW	1	1711,67	34,23	20
Electricity	Air conditioner	Space Heating	3	481	24,05	10
		Space Cooling	3			
Electricity	Centralized Air conditioner	Space Heating	2,93	333	2,66	15
		Space Cooling	2,93			
Oil	Boiler oil	Space Heating	0,85	77,34	3,87	20
		DHW	0,418			
Oil	Heater oil	Space Heating	0,58	83,31	4,17	15
LPG	Boiler LPG	Space Heating	0,734	182,05	9,1	20
		DHW	0,817			
LPG	Heater LPG	DHW	0,73	60,8	3,4	15
NG	Boiler NG	Space Heating	0,95	179,39	12,56	20
		DHW	0,663			
NG	Heater NG	DHW	0,76	115,87	5,79	15
Biomass	close fireplace	Space Heating	0,61	103,58	0	15
Biomass	Boiler Biomass	DHW	0,418	487	24,35	20
		Space Heating	0,85			
Biomass	Heater Biomass	DHW	0,5	184,64	9,23	20

Table 3-28: Sport subsector employed technologies [7, 25, 26]

Fuel	Technology	End use	Efficiency (%)	Initial cost (Million eur/GW)	O&M cost (Million eur/GW)	Lifetime (years)
Electricity	LEDs	Lighting	83,3	17,62	0	22.8
Electricity	Incandescent	Lighting	9,2	0,01	0	2
Electricity	Halogens	Lighting	11,9	0	0	5
Electricity	Fluorescent	Lighting	51,2	0	0	8
Electricity	Thermoaccumulators	DHW	1	75	0,83	15
Electricity	Small Appliances	Small Appliances	1	0,84	0,01	15
Electricity	Heat pumps	Space Heating	4,8	1351,02	67,55	15
		Space Cooling	4,8			
Electricity & Heat	Solar thermal	DHW	1	1711,67	34,23	20
Electricity	Air conditioner	Space Heating	3	481	24,05	10
		Space Cooling	3			
Electricity	Centralized Air conditioner	Space Heating	2,93	333	2,66	15
		Space Cooling	2,93			
Oil	Boiler oil	Space Heating	0,85	77,34	3,87	20
		DHW	0,418			
Oil	Heater oil	Space Heating	0,58	83,31	4,17	15
LPG	Boiler LPG	Space Heating	0,734	182,05	9,1	20
		DHW	0,817			
LPG	Heater LPG	DHW	0,73	60,8	3,4	15
NG	Boiler NG	Space Heating	0,95	179,39	12,56	20
		DHW	0,663			
NG	Heater NG	DHW	0,76	115,87	5,79	15
Biomass	close fireplace	Space Heating	0,61	103,58	0	15
Biomass	Boiler Biomass	DHW	0,418	487	24,35	20
		Space Heating	0,85			
Biomass	Heater Biomass	DHW	0,5	184,64	9,23	20

Solar Technologies

A notorious and distinct feature of technologies that give use to solar energy is the inconstancy of its availability, since they can only operate during the day, with the number of hours of sunshine vary throughout the year, in addition the intensity of solar radiation varies with the seasons reducing the potential of these machines. In this work, the year was divided into 4, by the different seasons, so that these properties can be considered. The following table shows the efficiency in which the technology in question work during the day in the 4 seasons:

Table 3-29: Solar efficiency per season

Season	Efficiency	Season	Efficiency
Autumn	0.186	Spring	0.252
Winter	0.153	Summer	0.279

In the model this efficiency it's called capacity factor, which must be define in every year covered by the model (2015-2050), that characterizes the availability of a technology during a different season and time of the day (night or day), although a different property the results are equal to the proper efficiency. We can see in the next figure the in-model input.

TION	TIMESLICE	DAILYTIMEBRACKET	FUEL	REGION	2015	2016	2017
	-	-	-	-	1	1	
	AD	-	-	-	0.186	0.186	0.18
	AN	-	-	-	0	0	
	SpD	-	-	-	0.252	0.252	0.25
	SpN	-	-	-	0	0	
	SuD	-	-	-	0.279	0.279	0.27
	SuN	-	-	-	0	0	
	WD	-	-	-	0.153	0.153	0.15
	WN	-	-	-	0	0	

Figure 3-4: Solar technology capacity factor input

3.4 End-use technologies initial stock

In order to properly represent the buildings sector in Portugal, there is the need to define the current stock for each end-use technology per sector and subsector, and provide an estimation of the its renovation over time. If a residual stock is not introduced in the mode as an input, the model will assume an investment in the most cost-effective technologies for the first year, resulting in a biased result. So, it is necessary to guarantee that the initial stock represents the current energy system and is able to satisfy the needs of the sectors and subsectors initially.

For the residential sector, the consumption of each fuel per end use [7, 15, 16, 19], coupled with the usage of each type of lamp [22] and the knowledge of the capacity and efficiency of each technology uses, by fuel, for most demands [22] were necessary to create a base to divide the energy consumption by technology. In addition, the distinction between high and low efficiency appliances in terms of satisfying the sectors demand [18,27] was necessary so that the stock for the year 2015 for this sector could be reached.

For the various service subsector, the energy consumption per fuel, technology and end use it was used the JRC-IDEES, for some demand, namely lighting and appliances, when present, the information was not available, so it was necessary to make the assumption that the partition of the stock would be akin to that of the residential sector.

In all sectors and subsectors, since the energy demand of space heating is superior to the one of DHW in all cases, for fossil oils, natural gas, biomass, and LPG, it was first considered boiler instead of heater since the first can satisfy both demands, only on the case that the DHW demand is superior to the space heating or a fuel is only consumed for DHW that it was considered heater for the initial stock.

It was considered that the investment of this technologies in the years previous that precede the model were done in a linear fashion and, consequently, the decay of the technologies (the rate at which they are required to be replaced) is likewise linear. The rate of decay depends on the lifetime of the technologies, ones with a more extensive lifetime will take longer to go deplete the initial stock. This decay can be seen in the Appendix C.

The stock of each technology present in the year 2015 and the residual stock in the following year in the residential sector and the various services sector subsectors are presented in the Appendix D.

3.5 Emissions by fuel

Certain technologies, namely those that have some type of combustion in their operation, have CO2 and NOx emissions directly, and it is necessary for the model to account for this to perform a realistic model.

Except for biomass combustion related emissions, the figures were taken from data by the EPA (environmental protection agency) the U.S. government institution responsible for environmental preservation and related matters, such as emissions. The values in the model must be submitted in Mton/PJ. In actuality there are other dangerous gases emitted by the combustion of the regarded fuels, such as CO (carbon monoxide), that for a less complex model must be presented as CO2e (CO2 equivalent).

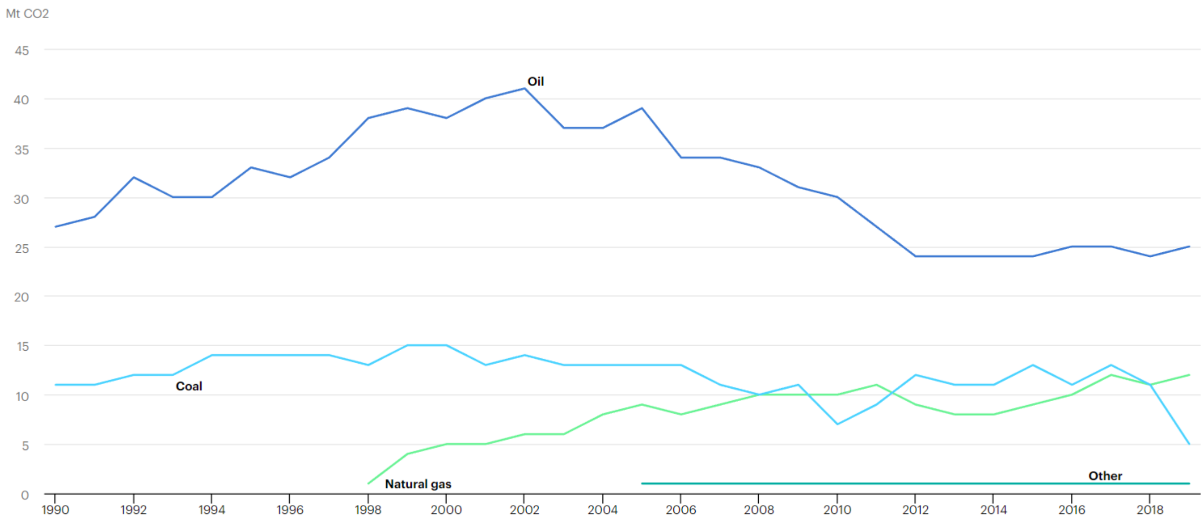

Figure 3-5: Portuguese emissions per fuel [4]

3.5.1 Liquified Petroleum Gas

This fuel includes both butane and propane, widely uses fuels, so it is necessary to use the average value of emissions of the two fuels since is no data available that differentiates the use of each, being commonly represented by LPG. The values are presented in the source in lbs./10^3gal, to obtain the desired mass of emissions per unit of energy, it is necessary to divide by the values suggested by the source for this purpose, 102 MMBtu/10^3gal for butane and 91.5 MMBtu/10^3gal for propane (1lb/MMBtu=429.923 Mton/PJ). [28]

Table 3-30: Gas emissions of LPG combustion [28]

	lbs./10^3gal	lbs./10^3gal	lbs./MMBtu	lbs./MMBtu	Mton/PJ	Mton/PJ
Fuel	CO2	NOx	CO2	NOx	CO2	NOx
Butane	14300	15	140,196	0,147	60,27*10^3	63,224
Propane	12500	14	136,612	0,153	58,73*10^3	65,781
Average					59,50*10^3	64,502

3.5.2 Fuel oil

The values of emissions for combustion of FO are differentiated by combustions in the residential sector and in the service sector, with conversion coefficients between lb/10^3gal and lbs./MMBtu 150 for combustions in the service sector and 140 for residential [29,]. The results are presented in the next table:

Table 3-31: Gas emissions of FO combustion [29, 30]

	lbs./10^3gal	lbs./10^3gal	lbs./MMBtu	lbs./MMBtu	Mton/PJ	Mton/PJ
	CO	NOx	CO	NOx	CO2-e	NOx
Services	22500	55	162	0,367	69644	157,6
Residential	22500	18	162	0,129	69644	55,3

3.5.3 Natural Gas

For natural gas it is first necessary to convert from the lbs./10^-6scf (standard cubic foot) unit to lbs./MMBtu (divided by 1.02 to reach lbs./MMBtu) and then convert to Mton/PJ, similar to the FO, the emissions are different for the residential and service sector [31], the results are presented in the next two tables.

Table 3-32: Gas emissions of NG combustion in Residential sector [30, 31]

Residential	lbs./10^-6scf	lbs./MMBtu	Mton/PJ
CO	176,4	172,94	74,4*10^3
NOx	588	576,5	247,8*10^3

Table 3-33: Gas emissions of NG combustion in Services sector [30, 31]

Service	lbs./10^-6scf	lbs./MMBtu	Mton/PJ
CO	84	82,35	35,4*10^3
NOx	197,4	193,53	83,2*10^3

3.5.4 Biomass

This was not taken from EPA but from an article published on the behest of the Dutch government, Emission biomass (as quoting 1 pag, made for the Dutch gov if I'm not mistaken)

It was made use of the conversion presented in the source material, it being gCO2/KWh=277,78*10^6 Mton/PJ. In the source material the emissions associated to the combustion of biomass depend if there are system to retain, or avoid, emissions employed or not [32], the result can be seen in the following table:

Table 3-34: Gas emissions of Biomass combustion [32]

	gCO2e/KWh	Mton/PJ
Without avoided emissions	102	28,33*10^3
With avoided emissions	4	1,11*10^3

Since it was not possible to determine the percentage of technologies with this fuel that employ a system that allows avoid some emissions it was decided to use the emission values without avoided emissions.

4 Scenarios description

In order to validate the model developed, this work comprised also the creation of different scenarios and respective simulations run. This chapter presents the rationale and main assumptions made to define the different scenarios.

4.1 Emissions, Plans and Treaties

The largest contributor for GHG emissions, for Portugal, is the transports sector, being responsible for a quarter of the total national emissions, followed by shipping and aviation at 11%. There a been a decrease of the total GHG emission on the 2005-2014 interval but since it grew and have become more volatile.

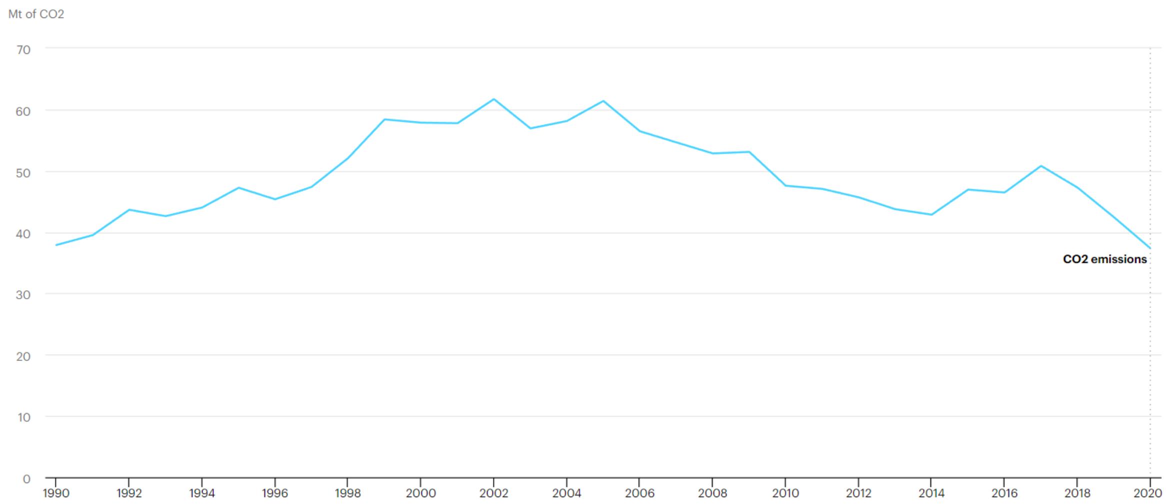

Figure 4-1: Evolution of CO_2 emissions for Portugal, between 1990 and 2020 [4]

There are existing directives, national laws and regulation that were established with the goal to reduce GHG emissions. On the medium-term, the National Energy and Climate Plan (PNEC2030 - Plano Nacional de Energia e Clima) establishes different objectives for 2030, including 45% to 55% reduction of total GHG emissions, 47% of the energy consumed being produced by renewable energy sources, and 35% increase in energy efficiency. There are also sector specific targets regarding GHG emissions reduction compared to the values of 2005, namely 70% for the service sector and 25% for the residential buildings. On the long-term, the Roadmap towards Carbon Neutrality (RNC2050 - Roteiro para a Neutralidade Carbónica) aims for a reduction of the total GHG emissions between 85% and 90% by 2050, compared to 2005 levels.

Moreover, in 2015, the Paris Agreement was established with the long-term objective of limiting the global temperature rise below 2ºC over preindustrial levels. The European Union member states committed to make every effort possible to ensure that the increase of global temperature does not exceed 1.5ºC, the maximum increase possible that does not pose a harm to life on Earth [1]. In order to combat consequences of climate change it was outlined objectives to increase the capacity to adapt and to mobilize financial resources for low emission and resilient development.

As part of this dissertation, three scenarios are studied, These scenarios aim to replicate the different paths envisaged in the national energy and climate strategies, and include the following: (1) business as usual; (2) PNEC 2030; and (3) carbon neutrality by 2050;. The first corresponds to the natural evolutions of the energy system, i.e. a no plan situation, while the second and third aim to replicate the objectives of PNEC 2030 and of RNC 2050, respectively. The first scenario is defined according to the parameters mentioned in Chapter 3, the other two scenarios were created as described in the following sections.

4.2 PNEC30 scenario conditions

PNEC 2030 sets various goals for the year 2030 at the national level, such as the reduction of GHG emissions, of these some are impossible to implement in the model since they are outside the scope for an energy model. The ones that are to be implemented are: an efficiency of 35%; and a reduction of emissions by 70% for the service sector and 35% for the residential sector compared to the values of 2005; all goals are aimed to be achieved by the year 2030. [33, 34]

The total GHG emissions of Portugal and the sectors in question are shown in the following table:

Table 4-1: Total energy-related GHG emissions for Portugal, in 2005 and 2020 ($ktCO_{2\ eq.}$) [33, 34]

	2005	2020
Total GHG emissions	87130	59496
Residential sector GHG emissions	2695	2427
Services sector GHG emissions	3164	1178

According to the targets established under the PNEC 2030, the maximum level of GHG emissions for the residential and services sector are presented in the following table:

Table 4-2: GHG emissions reduction targets, as published in PNEC 2030 [33, 34]

	2005	2030
Reduction		35%
Residential sector (kt CO2e)	2695	1752
Reduction		70%
Services sector (kt CO2e)	3164	950
Total (kt CO2e)	5859	2702

For the service sector the GHG emissions limit was further divided by the various subsectors. This disaggregation was made by considering the reduction in emissions should be equivalent to the share of the energy consumption of each subsector vs the total energy consumption of the service sector. The subsector targets are presented in the table below.

Table 4-3: GHG emissions reduction targets aligned with PNEC 2030, for the service sector, disaggregated per subsector

Reduction		70%
Commerce & other Services	kt CO2e	146
Education	kt CO2e	105
Sport	kt CO2e	86
Health	kt CO2e	293
Public	kt CO2e	314
Restaurant/hotel	kt CO2e	15

The second goal that needs to be fulfilled within this scenario, 35% efficiency in comparison to the PRIMES model of 2007. In practice 35% efficiency in these context means 35% reduction of the primary energy consumption compared to the prediction of PRIMES model of 2007, the maximum primary energy for the year 2030 then is 634 PJ. The table below presents both the estimation of the primary energy consumption for the year 2030, according to PRIMES 2007, and the targeted levels according to PNEC 2030.

Table 4-4: Primary energy consumption predictions according to PRIMES model of 2007 [35], and respective Energy Efficiency target according to PNEC 2030

	PRIMES model 2007		PNEC 2030
	MTep	PJ	PJ
Primary Energy	20,2	845	550
Final Energy	17,7	741	-

To achieve the desired GHG emissions it was imposed in the model a limitation of the total emissions for the year 2030, this limitation was considered the sum of the residential and services sector GHG emission limit. To enforce the reduction of primary energy, as it is impossible to dictate consecutive values or limitation for the demands it was established in the model that only the most efficient technologies (thermoaccumolaters, LED lamps and heat pumps) would be employed starting in the year 2030 to decrease the final and consequently the sum of primary energy without changing the value of the end use energy demands.

4.3 RNC2050 scenario conditions

RNC 2050 sets a goal for the reduction of GHG emissions between 85% to 90% compared to the year 2005 [15] which should be achieved by 2050. The remaining emissions would be compensated with actions like increasing the forests area, but that is outside the scope of this work. The roadmaps also establish other objectives with the intent to define the evolution of emissions up to 2050. These objectives comprise the reduction of overall GHG emissions between 45% and 55% up to 2030 and between 65% and 75% up to 2040, comparative to the emissions of 2005 [36, 37]. The specific GHG emissions reduction targets for the services and residential buildings sectors is shown in the table below.

Table 4-5: GHG emissions reduction targets for the residential buildings sector, according to RNC2050

	2005	2030		2040		2050	
Reduction		45%	55%	65%	75%	85%	90%
Residential sector (kt CO2e)	2695	1482	1213	943	674	404	270
Services sector (kt CO2e)	3164	1740	1424	1107	791	475	316

For the service sector the GHG emissions limit was further divided by the various subsector. This division was made by considering the total energy consumption of which subsector vs the total energy consumption of the service sector. The results are presented in the following table:

Table 4-6: GHG emissions reduction targets for the services buildings sector, according to RNC2050, with disaggregation per subsector

		2030		2040		2050	
Reduction		45%	55%	65%	75%	85%	90%
Commerce & other Services	kt CO2e	268	220	171	122	73	49
Education	kt CO2e	192	157	122	87	52	35
Sport	kt CO2e	158	130	101	72	43	29
Health	kt CO2e	536	439	341	244	146	98
Public	kt CO2e	576	472	367	262	157	105
Restaurant/hotel	kt CO2e	28	23	18	13	8	5

With the intent to reach these scenario goals, it was added a limitation for the GHG emissions of 55%, 75% and 90% for the years 2030, 2040 and 2050 to the model, the values used were the sum of the sectors GHG emissions limit for each year.

5 Results and Discussion

For a better analysis of the results, it is first necessary to examine the evolution of the end-uses demand that were obtained in the subchapter 3.2.4. In the next two figures it is shown the residential and service sector demand evolution, which are constant in all three scenarios, in that order:

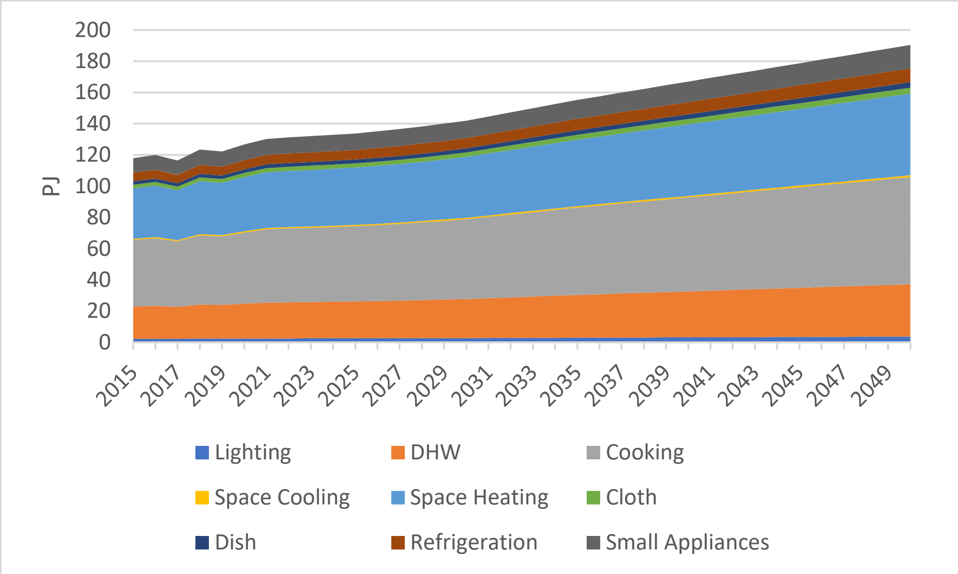

Figure 5-1: End-use demand evolution in the residential buildings sector

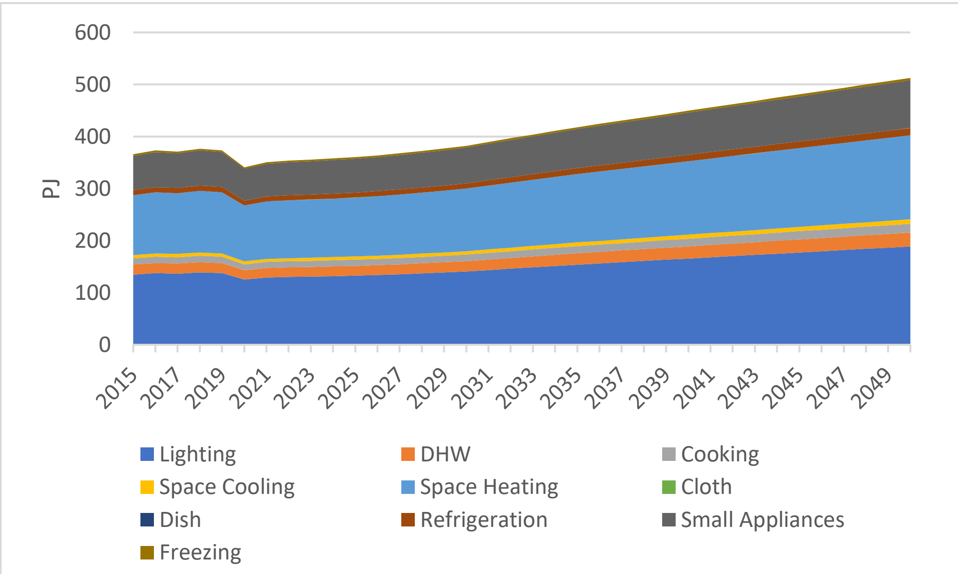

Figure 5-2: End-use demand evolution in the services buildings sector

5.1 Business as Usual Scenario

This subchapter is dedicated to presenting the results of the expanded model considering the natural evolution of the energy system that shows what would be the evolution of the system if no policy actions were taken and the choices were solely based on the techno-economic optimization of the system. It will serve as a basis for comparison with the results of the scenarios with imposed restrictions for achieving the set goals of RNC2050 and PNEC2030.

In the following figure, it is presented the new annual capacity of end-use technologies for the residential and service sectors together. The new annual capacity is directly linked with the shift in end-use technologies in both sectors, as discussed above. It can also be observed the link between new capacity and the different technologies lifetime; in the first years, the new capacity is reduced due to the existing stock, and the observed frequency of the spikes in new annual capacity is associated with the average technologies' lifetime, making visible the renovation cycles. In the Appendix E it is listed the quantitative counterpart of this data.

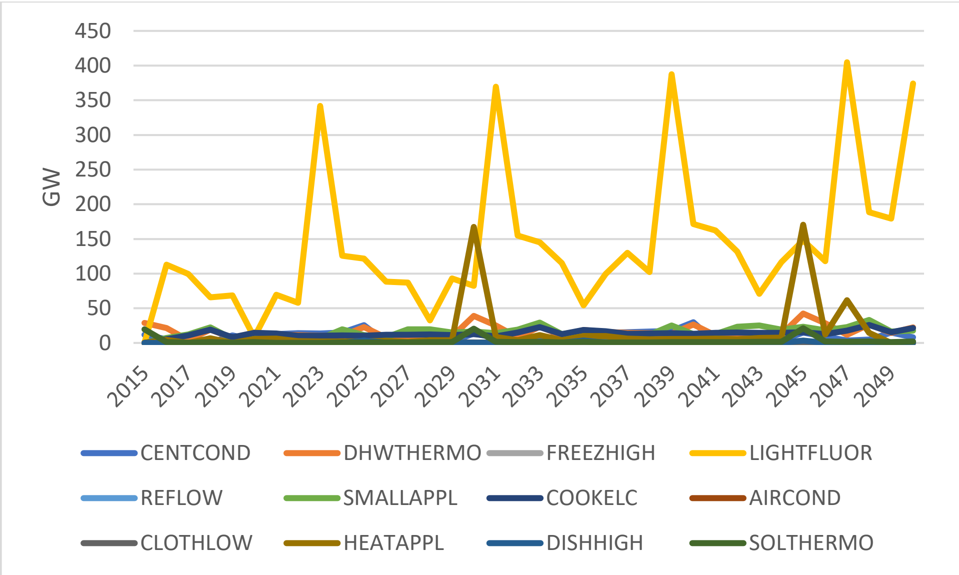

Figure 5-3: New annual capacity per end-use technologies for the residential and services sectors

Figure 5-4 shows the accumulated new capacity of end-use technologies for the buildings sector through the simulation period. This shows the total investment in end-use technologies (in GW) between 2015 and 2050, and the shift towards non-efficient end-use technologies such as fluorescent lamps for lighting purposes and small heat appliances for space heating. These choices can be justified by the fact that the objective function minimizes cost, and the technologies associated costs were assumed as constant over time. More detailed results are presented in Appendix E.

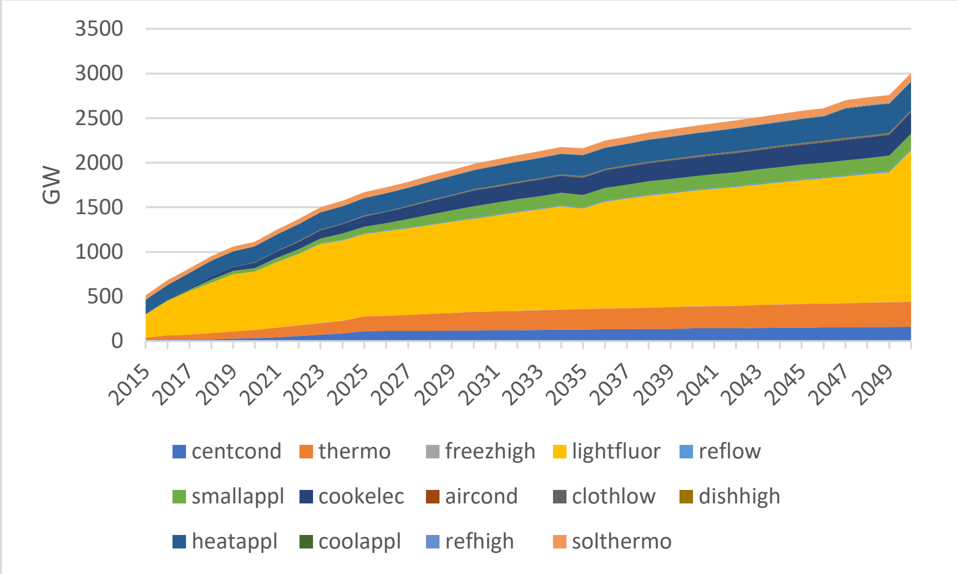

Figure 5-4: Accumulated annual new capacity per end-use technology for the residential and services sectors

In the following figure it is represented the annual investment, the monetary amount necessary for purchasing new end-use technologies to satisfy the residential and services sectors energy demands.

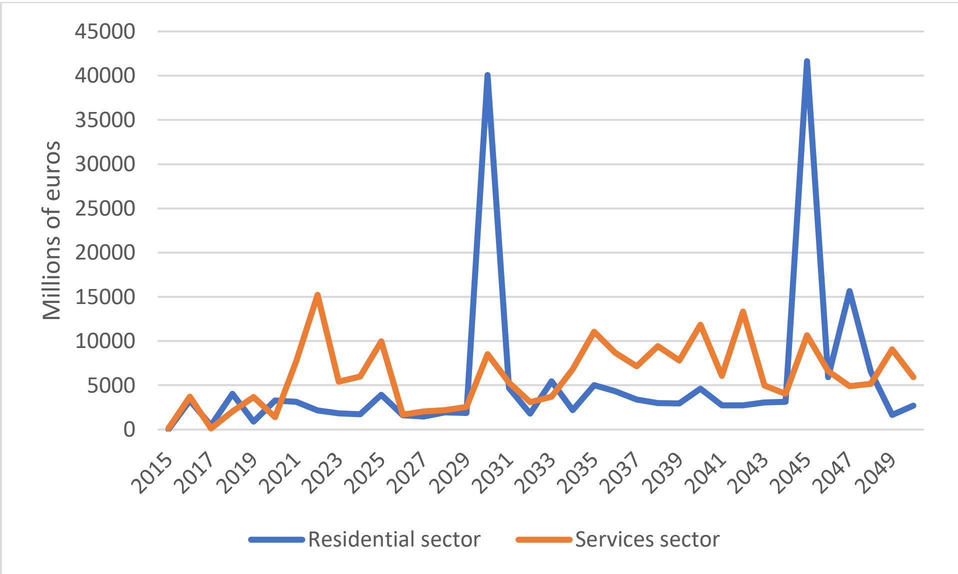

Figure 5-5: Annual investment in end-use technologies for the residential and services sectors

The spikes shown in the previous figure can be justified by the added technologies in the same year as the spikes and its associated cost of investment, the spikes of the residential sector match the years where small heating appliances are employed as for the services sector the spikes match the years with thermoaccumulators and air conditioners investments. There is no spike correlated to the adding of lighting technologies even though they represent the biggest added capacity since their cost is significant lower than the remaining technologies.

It is important to show the evolution of the electricity production in the energy system as it can have a significant impact in the overall efficiency of the system and its GHG emissions, especially after its electrification. These data are represented in the next figure and, in a more extensive manner, in Appendix E.

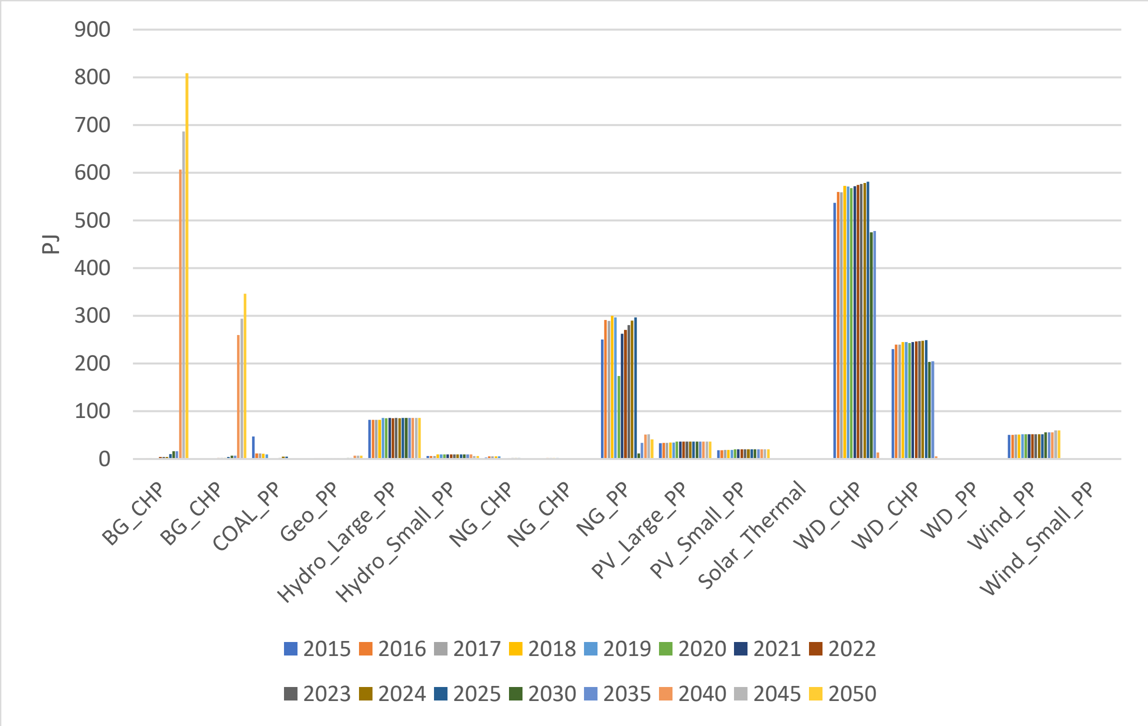

Figure 5-6: Evolution of electricity production per generation technology, between 2015 and 2050

In the figure 5-5 it is represented the evolution of the CO2 evolution, it can be seen a decrease as the initial stock of technologies degrades and are replaced with others. In the year 2030 there were 38,9 Mton of CO2e emissions and 0,19 Mton of NOx, changing to 15,7 and 0,26 of Mton of CO2 and NOx respectively.

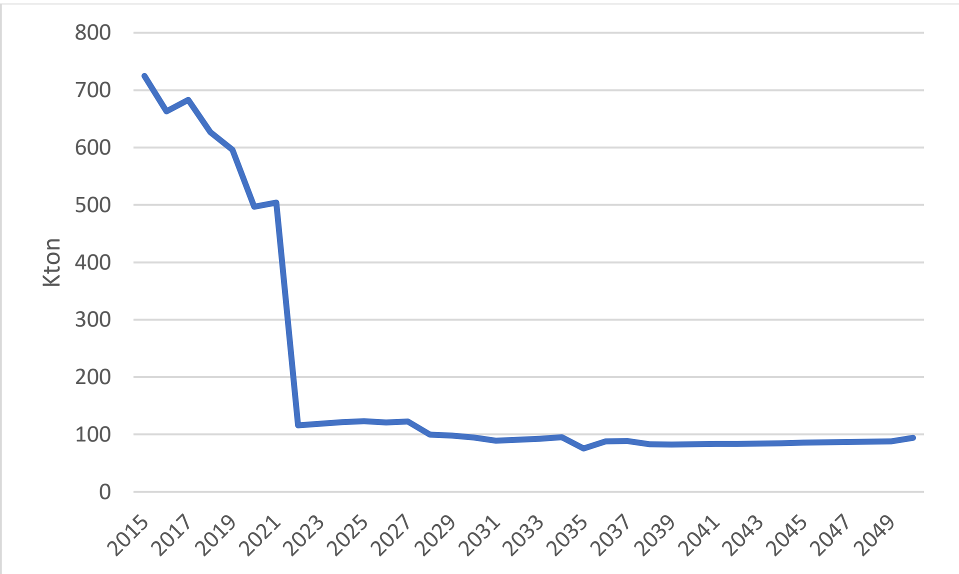

Figure 5-7: Evolution of the GHG emissions (in ktCO2e) between 2015 and 2050, in the Business as Usual scenario

5.2 PNEC30

In this subchapter, the most relevant results obtained with the simulation of the PNEC 2030 scenario are presented.

In the following figure, it is presented the new annual capacity of end-use technologies for the buildings sectors, which refers to the new end-use technologies added to the energy system throughout the modelling timeframe, in terms of GW. More extensive data is presented in the Appendix F.

It can be concluded that the limitation imposed on the model in this scenario result in various different technologies employed compared to the business-as-usual scenario, such as the implementation of heat pumps, LEDs and high efficiency appliances.

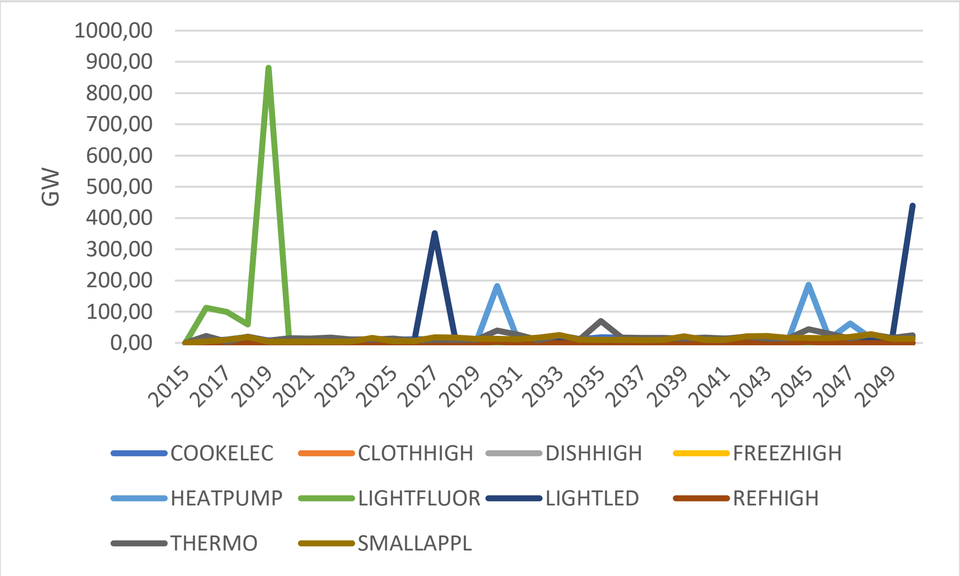

Figure 5-8: New annual capacity per end-use technology for the residential and services sectors, in the PNEC2030 scenario

In Figure 5-9 it is shown the accumulated new capacity of technologies within the buildings sectors, including residential buildings and buildings from all services subsectors. The analysis of these results show the accumulated investment in new capacity of end-use technologies (in GW), being significantly different from the investment observed in the business as usual scenario. For example, heat pumps and LEDs replace cheaper alternatives due to their higher efficiency. Here, as additional restrictions were included, the model choices are not solely based on cost efficiency, considering also other factors as associated emissions and energy efficiency. Quantitative data of the accumulated new capacity is presented in Appendix F.

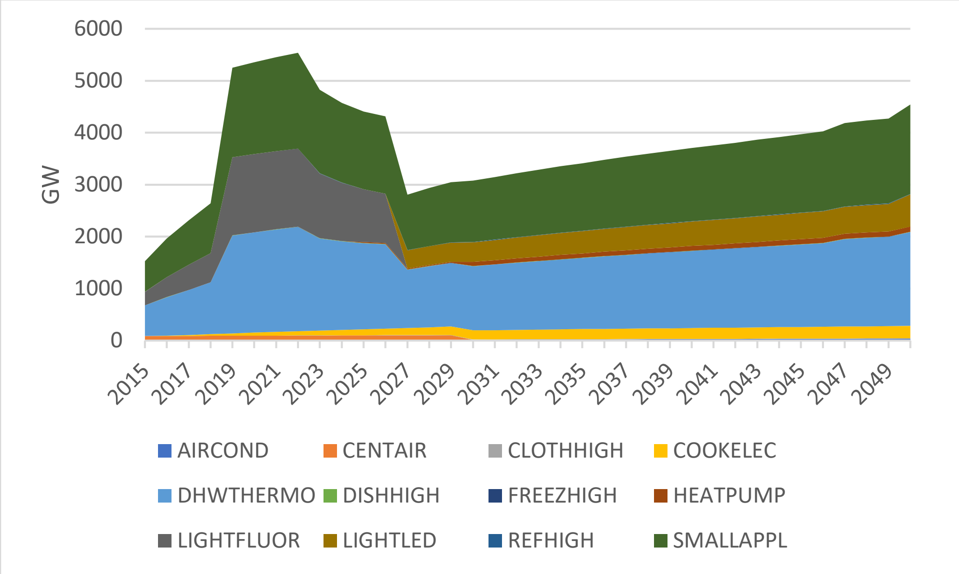

Figure 5-9: Accumulated new capacity per end-use technology for the residential and services sectors, in PNEC2030 scenario

The difference in terms of new annual capacity will also imply a difference regarding the annual investment required to employ these technologies. The annual investment associated with residential, and services end-use technologies is presented in the next figure.

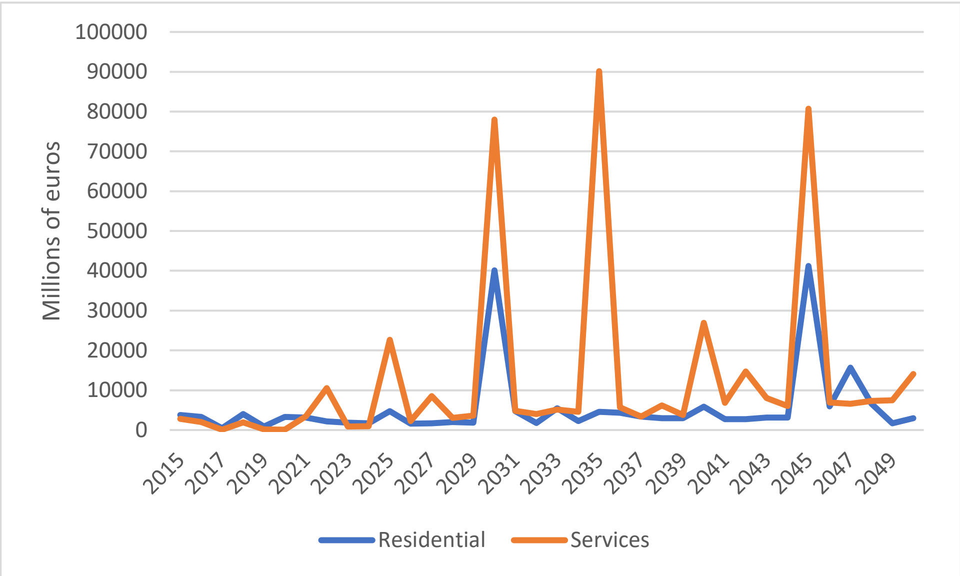

Figure 5-10: Annual investment in the residential and services sectors in PNEC2030 scenario

Most spikes correlate to the investment of heat pumps and thermoaccumulators, the remaining spikes will correspond to years where the new capacity was lower in terms of GW but the mix of employed technologies are made of the most expensive ones.

With the objective of having a broader perspective of the evolution of the energy system as a whole, figure 5-11 shows the evolution of the power system, with the total electricity produced per transformation technology. This analysis is useful to understand both the evolution of primary energy demand, as well as of the carbon intensity of the electricity mix. This data is also relevant to guarantee the achievement of the 35% energy efficiency goal, as this refers to primary energy savings.

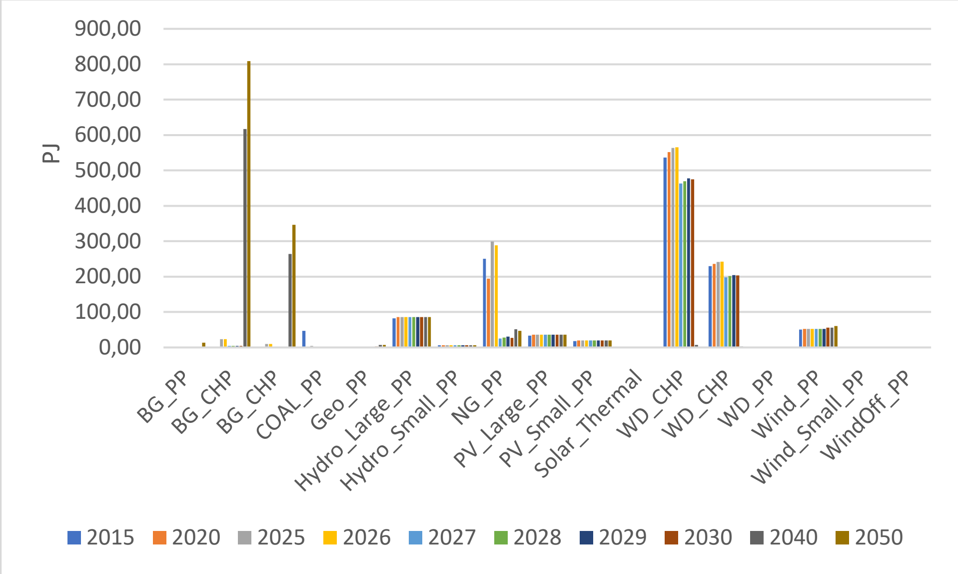

Figure 5-11: Evolution of electricity production per generation technology, in the PNEC2030 scenario

From this data it can be conclude that the primary energy in the year 2030 amounts to 921 PJ, not achieving the aimed 550 PJ.

Lastly it is presented in the figure 5-10 the evolution of CO2E emissions in this model with the PNEC30 scenario limitations. It can be seen that the CO2e emissions decrease in steps throughout the years, this is a result of the limitation of the employed technologies in the year 2030, and due to different lifetime of technologies that are replaced and employed, there are years with major decreases of GHG emissions unlike others. This evolution results of both the imposed limitations, technologies properties and minimization of costs.

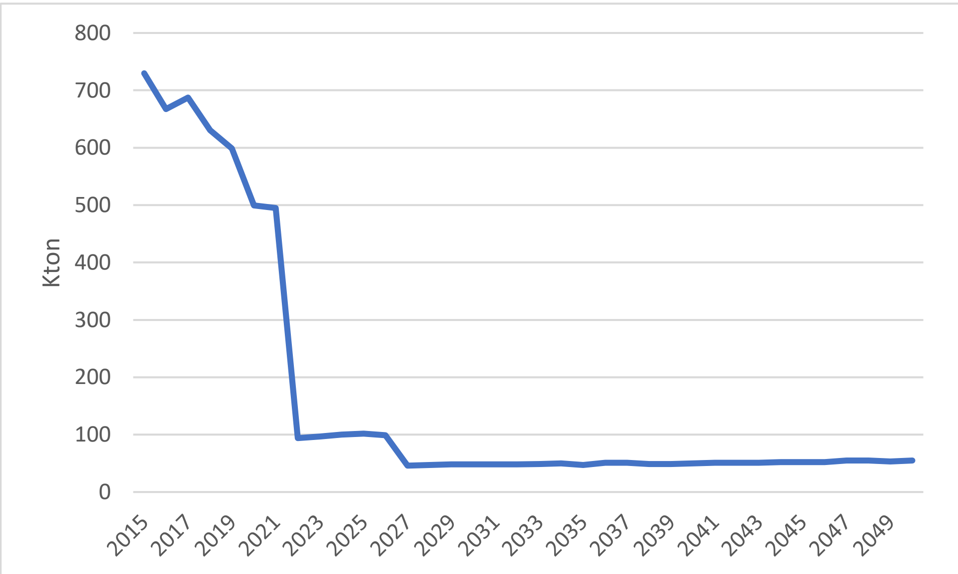

Figure 5-12: Evolution of GHG emissions (ktCO2e) between 2015 and 2050, in PNEC2030 scenario

In the table 5-1 the emissions of CO2e are shown, confirming that the GHG emissions limitations have been achieved with a significant margin between the results and maximum emissions.

Table 5-1: CO2 emissions in PNEC30 scenario (Kton)

EMISSION	2015	2018	2020	2023	2025	2028	2030	2040	2050
CO2e	729	630	500	97	102	47	48	50	55

5.3 RNC2050

In this subchapter it is presented the results of the developed model with limitations to achieve the stated goals of RNC1050. First it is shown in the next figure the new capacity per technology, the quantitative information of this topic is presented in Appendix G.

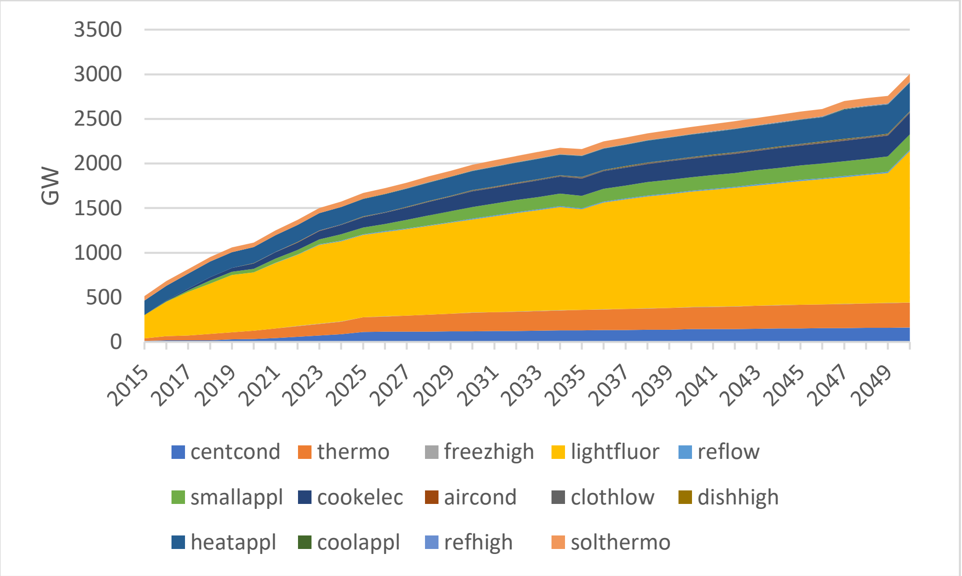

Figure 5-13: Accumulated new capacity per end-use technology for the residential and services sectors, in RNC2050 scenario

To further characterize the technologies added in the model and which are active throughout the years, it is necessary to analyze the accumulated annual new capacity as it is presented in Appendix G and in the following figure:

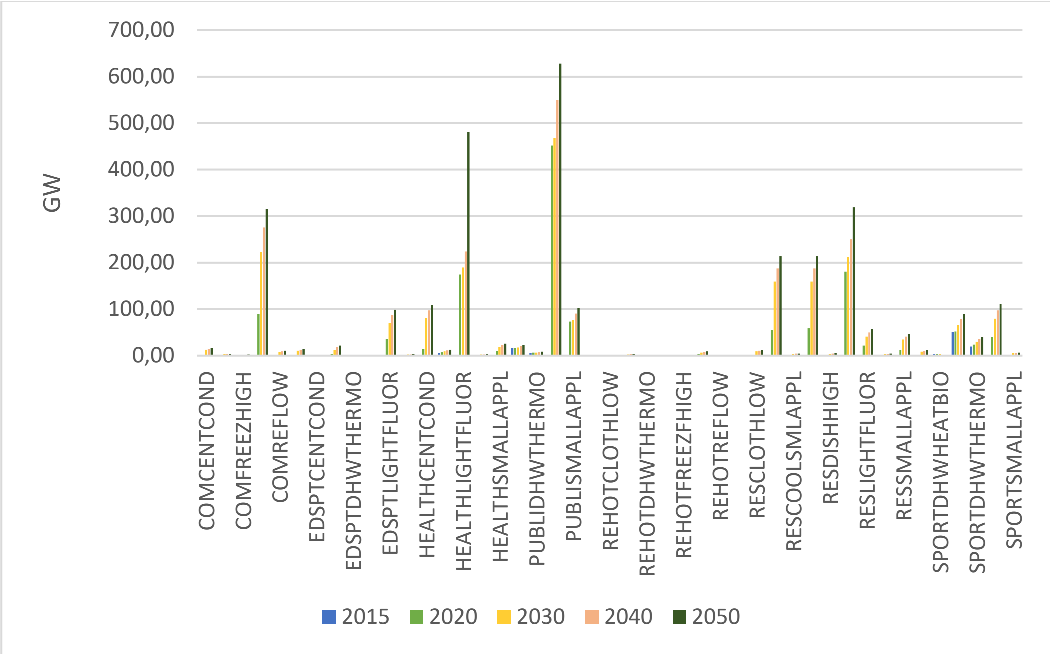

Figure 5-14: Accumulated new capacity per end-use technology for the residential and services sector, in RNC2050 scenario

Now it can be seen in the figure 5-15 and in the table F-3 the data related to the necessary investment for replacing technologies in the studied sectors. It can be seen the correlation of the investment costs and the new capacity except for lighting technologies, which have much lower investment cost, and as such do not have a significant impact in this data.

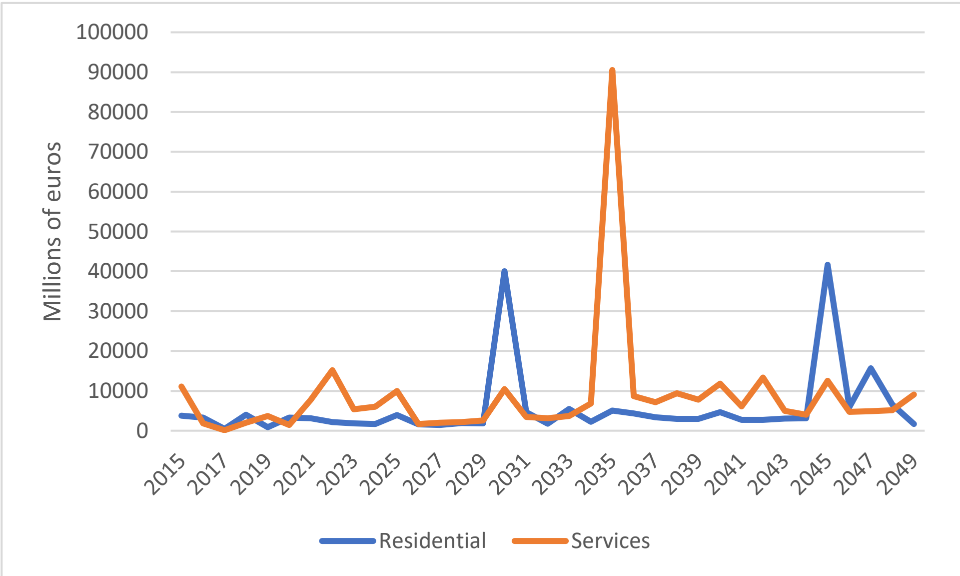

Figure 5-15: Annual investment in the residential and services sectors in RNC2050 scenario

The three major spikes correlate with the employment of the most expensive technologies employed in this scenario: thermoaccumulators, solar for DHW and centralized air conditioner.

With the electrification of the residential and services subsector it becomes even more important to analyze the evolution of the electricity production. It can be seen an increase especially in cogeneration of biomass and biogas especially and reduction of natural gas power plants. The data related to this topic can be seen in Appendix G and in the next figure:

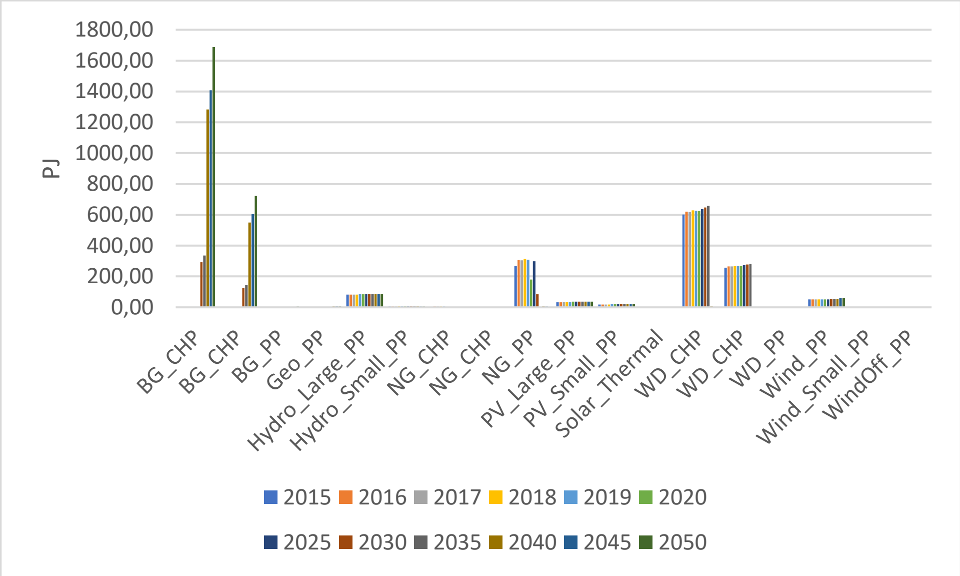

Figure 5-16: Evolution of electricity production per generation technology in the RNC2050 scenario

The results in terms of GHG emissions are shown in figure 5-15 and table 5-2. It can be seen a significant decrease of CO_2 and NOx, especially after the year 2020. The most ambitious goals of the RNC2050 in terms of reduction of GHG emissions were met, whilst leaving a big margin between GHG maximum emissions and predicted emissions in 2030, 2040 and 2050.

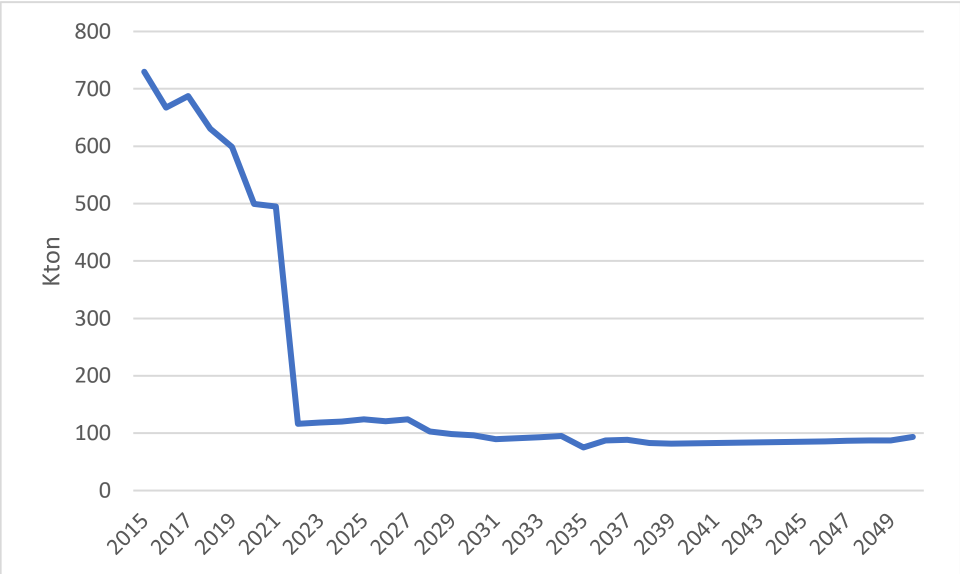

Figure 5-17: Projected evolution of CO2 emissions in Portugal, between 2015 and 2050, considering the restrictions of the RNC2050 scenario

Table 5-2: Projected Global GHG emissions for 2030, 2040 and 2050 in Portugal, according to the RNC2050 scenario restrictions

EMISSION	2015	2020	2030	2040	2050

CO2e	729	499	96	82	93

In the figure below, it is represented the evolution of the final energy consumption for the three different scenarios. It can be seen that, with the same end-use demands, the evolution of the final energy depends heavily on the employed technologies and that exists a correlation between the stringency of the imposed goals of the scenario and the evolution of the final energy consumption.

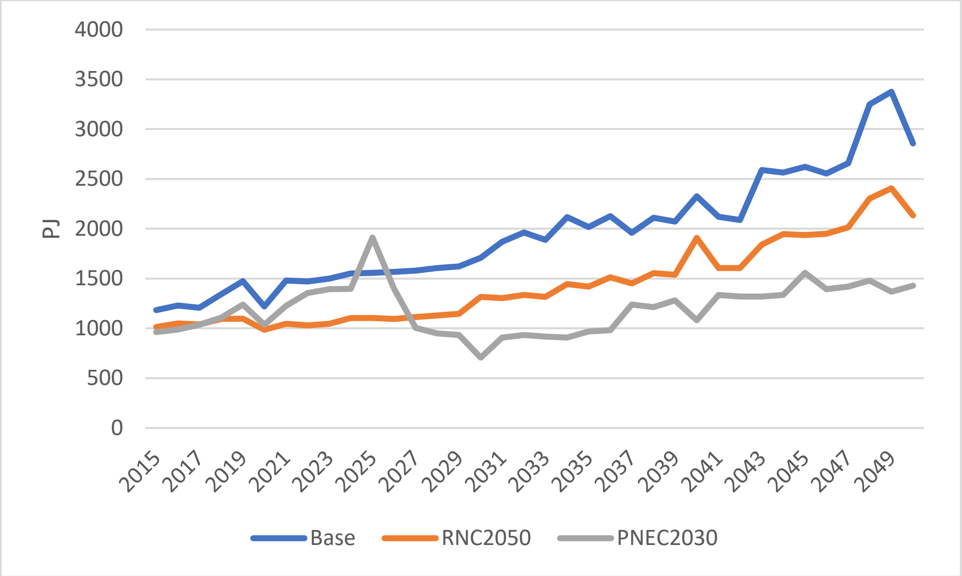

Figure 5-18: Comparison of final energy consumption of the three different scenarios

In the last figure, it is shown the different evolutions of the GHG emissions of the three scenarios. The results of the PNEC2030 show a more notorious decrease of the GHG emissions due to the more ambitious goals set for 2030 and the impact of employing the most efficient technologies

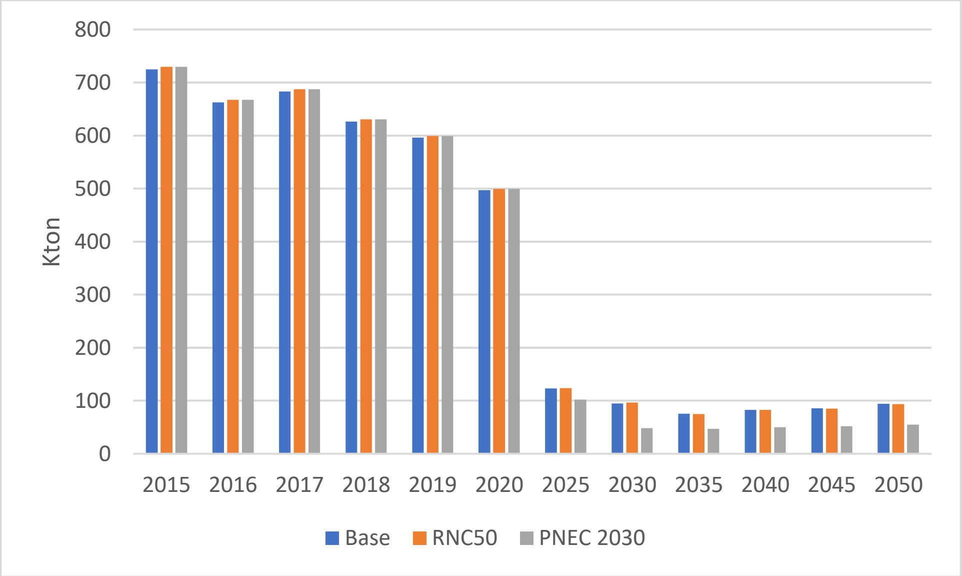

Figure 5-19: Comparison of GHG emissions of the three different scenarios

6 Conclusions and Future Works

6.1 Conclusions

This dissertation is dedicated to the development of a model of the Portuguese energy system, with the disaggregation up to the end uses level for the residential and services sectors. The model was validated through the simulation of three different scenarios, including one that corresponds to the natural evolution of the energy system, and two that are aligned with the targets established in the national plans for 2030 (PNEC 2030) and 2050 (RNC 2050), respectively.

The development of the model, *per si*, already constitutes a significant advancement compared to the state-of-the-art, as it provides a detailed representation of the buildings sectors, with the characterization of the end-use technologies and the end-use services that they provide. This expansion allows for the simulation of the different alternative scenarios, including actions up to the end-user, such as technologies replacement, and consequently, the assessment of their techno-economic viability.

Data (un)availability had some implications on the final result, as it prevented a higher disaggregation of the sectors and end-uses, as well as a more realistic representation of the evolution of the technical and economic characteristics of the different end-use technologies. These drawbacks have a direct impact on the modelling results, which are not always realistic and coherent with the observed trends. Nonetheless, these shortcomings can be easily improved as soon as new data is available.

Specifically on three scenario simulations, the modelling outputs show alternative paths towards carbon neutrality, as well as what would be the natural evolution of the energy system if cost-efficiency was the only criteria taken into account.

In the case of the Business-as-Usual scenario, one of the highlighted outcomes refers to the increasing electrification of the energy demand in the buildings sectors, which occurred in all three situations. This can be explained by the average efficiency of fully electrical technologies, being higher than those that have a different input (natural gas, LPG, etc). Of all the run scenarios, this is the one with higher GHG emissions and primary energy consumption, as no restrictions were imposed. Whilst having significantly less emissions after the year 2020, it employed many technologies based on their costs and not on their performance (fluorescent lamps instead of the more efficient LED lamps). On the level of primary energy, as it happened in the other situations, there is a focus on renewable and cogeneration plants, since their price is compensated by the impact they have in terms of GHG emission.

In the PNEC2030 scenario, as limitations to the GHG emissions were imposed for the year 2030 along with upper limits for the use of less efficient technologies, different results were obtained. The GHG emissions were lower than the maximum value established in the PNEC2030 but the second goal could not be achieve in this model. The sum of primary energy in this situation was 921 PJ, higher than the aimed 550 PJ. -Nonetheless, it was a significant decrease from the previous years, as well as compared to the Business-as-Usual scenario, due to limiting the model to use the most efficient technologies. With similar changes in the other sectors not included in this model up to the end use level or other changes outside the scope of these model (more efficient buildings, for example) this goal could be achieved.

In the last modelled scenario, the RNC2050, it can be seen again an electrification trend of the end use technologies. The technologies employed are similar to those of the business as usual scenario as the GHG emissions in 2030, 40 and 50 were lower than the more pronounced limitation defined in the PNEC2030. This scenario limitations can be respected whilst using some low efficiency technologies and, as and consequence necessitating less investment.

Summarizing, the result of the different simulations has shown the possibility of reaching the necessary changes to achieve carbon neutrality with the available technology and without changing personal behaviours. Nonetheless, it should be stated that are other actions, that could not be implemented in this model that would have a significant impact in a beneficial fashion on the energy system.

6.2 Future Works

In order to continue the development of a model of Portuguese energy system, some of the proposed suggestions for future works are:

- The creation of a similar model with a similar development for all sectors as it was done for the residential and services sectors in this dissertation for a better output of the necessary changes for achieving carbon neutrality and other goals.
- The study of other possible changes that have an impact on the energy system to achieve a more robust model
- Expansion of the existing model in order to comprise the quantification of sufficiency measures, including changes in behaviour, such as the reduction of the household area per inhabitant, the use of passive measures to heat/cool the buildings, etc.
- Improvement of input data, in order to represent the expected evolution in costs and efficiency of the different end-use technologies.

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Appendixes

Appendix A – Type of services per sector/subsector

Table A-0-1: Services per sector/subsector [15]

Commerce & other Services Subsector					
Activity:	Demand (PJ)	Activity:	Demand (PJ)	Activity:	Demand (PJ)
Comércio por grosso, exceto automóveis e motociclos	48,5852	Atividades de rádio e de televisão	0,2207	Atividades auxiliares de serviços financeiros e seguros	0,0002
Comércio a retalho, exceto automóveis e motociclos	8,4506	Telecomunicações	0,7403	Agências de viagem, operadores turísticos	0,9888
Teatro, música e dança	0,0202	Atividades de serviços financeiros	3,9175		
Total	62,9234				
Sport Subsector		Public Subsector		Health Subsector	
Activity:	Demand (PJ)	Activity:	Demand (PJ)	Activity:	Demand (PJ)
Atividades desportivas, de diversão e recreativas	34,4563	Serviços administrativos e de apoio às empresas	19,3985	Atividades de saúde humana	126,0490
Atividades desportivas, de diversão e recreativas	34,4563	Serviços administrativos e de apoio às empresas	19,3985	Atividades de saúde humana	126,0490
		Administração pública e defesa; segurança social obrigatória	115,8319		
Total	34,4563	Total	135,2304	Total	126,0490
Restaurant/hotel Subsector		Education Subsector			
Activity:	Demand (PJ)	Activity:	Demand (PJ)		
Alojamento	0,1838	Educação	45,2284		
Restauração e similares	4,6092				
Total	4,7930	Total	45,2284		

Appendix B - Demands evolution

Residential Sector

Table B-0-1: Residential sector demand evolution

Demand PJ	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
lighting	2,267234	2,305803	2,240217	2,372988	2,350238	2,435374	2,505599	2,525338	2,539655	2,555598	2,573276	2,59795	2,625714	2,657383	2,692252	2,730428	2,781468	2,832507
DHW	20,77111	21,12446	20,5236	21,73997	21,53154	22,31151	22,95488	23,13571	23,26687	23,41293	23,57489	23,80094	24,0553	24,34543	24,66488	25,01463	25,48222	25,94982
Cooking	42,48635	43,20911	41,98009	44,46812	44,04179	45,63719	46,95316	47,32305	47,59133	47,89009	48,22137	48,68373	49,20402	49,79748	50,45089	51,16629	52,12273	53,07917
Room Cooling	0,708106	0,720152	0,699668	0,741135	0,73403	0,76062	0,782553	0,788718	0,793189	0,798168	0,803689	0,811396	0,820067	0,829958	0,840848	0,852772	0,868712	0,884653
Room Heating	32,33683	32,88694	31,95151	33,84518	33,52069	34,73497	35,73657	36,0181	36,22229	36,44968	36,70182	37,05373	37,44973	37,90142	38,39873	38,94323	39,67119	40,39915
cloth	2,413507	2,454564	2,384748	2,526084	2,501866	2,592495	2,667251	2,688263	2,703503	2,720475	2,739294	2,765559	2,795115	2,828827	2,865946	2,906585	2,960917	3,015249
dish	2,135588	2,171918	2,11014	2,235202	2,213772	2,293966	2,360113	2,378706	2,392191	2,407208	2,42386	2,447101	2,473253	2,503084	2,535928	2,571887	2,619963	2,668039
refrig	5,514497	5,608308	5,448787	5,771719	5,716384	5,923459	6,094265	6,142275	6,177095	6,215873	6,258871	6,318884	6,386415	6,463442	6,548251	6,641106	6,765247	6,889388
Small Appliances	9,266403	9,42404	9,155985	9,698632	9,605648	9,953611	10,24063	10,3213	10,37981	10,44497	10,51723	10,61807	10,73155	10,86098	11,00349	11,15952	11,36813	11,57673
total	117,8996	119,9053	116,4947	123,399	122,216	126,6432	130,295	131,3215	132,0659	132,895	133,8143	135,0974	136,5412	138,188	140,0012	141,9865	144,6406	147,2947
Demand PJ	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
lighting	2,883546	2,934585	2,985625	3,030699	3,075773	3,120847	3,165922	3,210996	3,25607	3,301144	3,346218	3,391293	3,436367	3,481441	3,526515	3,57159	3,616664	3,661738
DHW	26,41741	26,885	27,3526	27,76554	28,17848	28,59143	29,00437	29,41732	29,83026	30,24321	30,65615	31,0691	31,48204	31,89498	32,30793	32,72087	33,13382	33,54676
Cooking	54,03561	54,99205	55,94849	56,79315	57,63781	58,48247	59,32713	60,17179	61,01645	61,8611	62,70576	63,55042	64,39508	65,23974	66,0844	66,92906	67,77372	68,61838
Room Cooling	0,900594	0,916534	0,932475	0,946553	0,96063	0,974708	0,988785	1,002863	1,016941	1,031018	1,045096	1,059174	1,073251	1,087329	1,101407	1,115484	1,129562	1,14364
Room Heating	41,1271	41,85506	42,58302	43,2259	43,86878	44,51166	45,15454	45,79741	46,44029	47,08317	47,72605	48,36893	49,01181	49,65469	50,29757	50,94045	51,58333	52,22621
cloth	3,069581	3,123914	3,178246	3,226228	3,27421	3,322192	3,370175	3,418157	3,466139	3,514121	3,562104	3,610086	3,658068	3,70605	3,754032	3,802015	3,849997	3,897979
dish	2,716114	2,76419	2,812266	2,854723	2,89718	2,939637	2,982094	3,024551	3,067008	3,109465	3,151922	3,194379	3,236836	3,279293	3,32175	3,364207	3,406664	3,449121
refrig	7,013528	7,137669	7,26181	7,371442	7,481074	7,590706	7,700338	7,80997	7,919603	8,029235	8,138867	8,248499	8,358131	8,467763	8,577395	8,687028	8,79666	8,906292
Small Appliances	11,78533	11,99393	12,20254	12,38676	12,57098	12,75521	12,93943	13,12365	13,30787	13,4921	13,67632	13,86054	14,04476	14,22899	14,41321	14,59743	14,78165	14,96588
total	149,9488	152,6029	155,2571	157,601	159,9449	162,2888	164,6328	166,9767	169,3206	171,6646	174,0085	176,3524	178,6963	181,0403	183,3842	185,7281	188,0721	190,416

Service Sector

Commerce & other services

Table B-0-2: Commerce & other services subsector demand evolution

Demand PJ	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
lighting	29,9599	30,52547	30,3513	30,81387	30,53857	27,89241	28,6967	28,92277	29,08673	29,26933	29,4718	29,75439	30,07238	30,43508	30,83444	31,27167	31,85623	32,44078
DHW	1,917041	1,95323	1,942086	1,971684	1,954069	1,784749	1,836213	1,850678	1,86117	1,872854	1,885809	1,903891	1,924238	1,947447	1,973	2,000977	2,038381	2,075785
Room Cooling	0,26066	0,265581	0,264066	0,26809	0,265695	0,242672	0,24967	0,251637	0,253063	0,254652	0,256414	0,258872	0,261639	0,264794	0,268269	0,272073	0,277159	0,282245
Room Heating	11,90348	12,12819	12,05899	12,24277	12,1334	11,08204	11,4016	11,49142	11,55656	11,62911	11,70955	11,82183	11,94817	12,09228	12,25095	12,42467	12,65692	12,88917
refrigeration	10,58199	10,78175	10,72023	10,88361	10,78638	9,851741	10,13582	10,21567	10,27358	10,33808	10,40959	10,5094	10,62172	10,74983	10,89088	11,04531	11,25178	11,45825
small Appliances	6,8593	6,988786	6,948911	7,054815	6,991787	6,38595	6,570091	6,62185	6,659389	6,701194	6,74755	6,812248	6,885052	6,968093	7,059524	7,159629	7,293463	7,427296
total	61,73107	62,89638	62,53753	63,49062	62,9234	57,47109	59,12829	59,5941	59,93194	60,30817	60,72535	61,30761	61,96282	62,71016	63,533	64,43391	65,63836	66,84281
FREEZING																		

Demand PJ	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
lighting	33,02533	33,60989	34,19444	34,71068	35,22692	35,74315	36,25939	36,77562	37,29186	37,8081	38,32433	38,84057	39,35681	39,87304	40,38928	40,90551	41,42175	41,93799
DHW	2,113189	2,150592	2,187996	2,221029	2,254061	2,287093	2,320126	2,353158	2,38619	2,419223	2,452255	2,485288	2,51832	2,551352	2,584385	2,617417	2,650449	2,683482
Room Cooling	0,28733	0,292416	0,297502	0,301993	0,306485	0,310976	0,315468	0,319959	0,32445	0,328942	0,333433	0,337925	0,342416	0,346908	0,351399	0,35589	0,360382	0,364873
Room Heating	13,12142	13,35367	13,58592	13,79103	13,99614	14,20125	14,40636	14,61146	14,81657	15,02168	15,22679	15,4319	15,637	15,84211	16,04722	16,25233	16,45743	16,66254
refrigeration	11,66472	11,87118	12,07765	12,25999	12,44233	12,62466	12,807	12,98934	13,17168	13,35401	13,53635	13,71869	13,90102	14,08336	14,2657	14,44804	14,63037	14,81271
small Appliances	7,561129	7,694963	7,828796	7,946988	8,06518	8,183372	8,301564	8,419756	8,537948	8,65614	8,774332	8,892524	9,010716	9,128908	9,2471	9,365292	9,483483	9,601675
total	68,04725	69,2517	70,45615	71,51983	72,58352	73,6472	74,71088	75,77456	76,83825	77,90193	78,96561	80,02929	81,09297	82,15666	83,22034	84,28402	85,3477	86,41139
FREEZING																		

Health Services

Table B-0-3: Health subsector demand evolution

Demand PJ	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
lighting	24,327	24,786	24,644	25,020	24,797	22,648	23,301	23,485	23,618	23,766	23,930	24,160	24,418	24,712	25,037	25,392	25,866	26,341
DHW	6,082	6,196	6,161	6,255	6,199	5,662	5,825	5,871	5,904	5,941	5,983	6,040	6,104	6,178	6,259	6,348	6,467	6,585
Room Cooling	1,651	1,682	1,672	1,698	1,683	1,537	1,581	1,594	1,603	1,613	1,624	1,639	1,657	1,677	1,699	1,723	1,755	1,787
Room Heating	75,384	76,807	76,368	77,532	76,840	70,182	72,205	72,774	73,187	73,646	74,156	74,867	75,667	76,579	77,584	78,684	80,155	81,626
refrigeration	2,027	2,065	2,054	2,085	2,066	1,887	1,942	1,957	1,968	1,980	1,994	2,013	2,035	2,059	2,086	2,116	2,156	2,195
small Appliances	12,163	12,393	12,322	12,510	12,398	11,324	11,650	11,742	11,809	11,883	11,965	12,080	12,209	12,356	12,518	12,696	12,933	13,171
total	123,661	125,995	125,276	127,185	126,049	115,127	118,447	119,380	120,056	120,810	121,646	122,812	124,125	125,622	127,270	129,075	131,488	133,900
Demand PJ	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
lighting	26,816	27,290	27,765	28,184	28,603	29,023	29,442	29,861	30,280	30,699	31,118	31,538	31,957	32,376	32,795	33,214	33,633	34,053
DHW	6,704	6,823	6,941	7,046	7,151	7,256	7,360	7,465	7,570	7,675	7,780	7,884	7,989	8,094	8,199	8,304	8,408	8,513
Room Cooling	1,820	1,852	1,884	1,912	1,941	1,969	1,998	2,026	2,055	2,083	2,112	2,140	2,168	2,197	2,225	2,254	2,282	2,311
Room Heating	83,097	84,568	86,038	87,337	88,636	89,935	91,234	92,533	93,832	95,131	96,430	97,729	99,028	100,327	101,626	102,925	104,223	105,522
refrigeration	2,235	2,274	2,314	2,349	2,384	2,419	2,453	2,488	2,523	2,558	2,593	2,628	2,663	2,698	2,733	2,768	2,803	2,838
small Appliances	13,408	13,645	13,882	14,092	14,302	14,511	14,721	14,930	15,140	15,350	15,559	15,769	15,978	16,188	16,398	16,607	16,817	17,026
total	136,313	138,726	141,139	143,270	145,400	147,531	149,662	151,793	153,923	156,054	158,185	160,316	162,447	164,577	166,708	168,839	170,970	173,100

Education

Table B-0-4. Education subsector demand evolution

Demand PJ	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
lighting	9,416	9,594	9,539	9,684	9,598	8,766	9,019	9,090	9,142	9,199	9,263	9,351	9,451	9,565	9,691	9,828	10,012	10,196
DHW	0,325	0,331	0,329	0,334	0,331	0,302	0,311	0,313	0,315	0,317	0,319	0,322	0,326	0,330	0,334	0,339	0,345	0,352
Cooking	10,263	10,456	10,397	10,555	10,461	9,555	9,830	9,907	9,964	10,026	10,096	10,192	10,301	10,426	10,562	10,712	10,912	11,113
Room Cooling	0,014	0,014	0,014	0,014	0,014	0,013	0,013	0,013	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,015	0,015	0,015
Room Heating	0,635	0,647	0,644	0,654	0,648	0,592	0,609	0,613	0,617	0,621	0,625	0,631	0,638	0,646	0,654	0,663	0,676	0,688
dish	0,152	0,155	0,154	0,157	0,155	0,142	0,146	0,147	0,148	0,149	0,150	0,151	0,153	0,155	0,157	0,159	0,162	0,165
small Appliances	1,299	1,323	1,316	1,336	1,324	1,209	1,244	1,254	1,261	1,269	1,278	1,290	1,304	1,319	1,337	1,356	1,381	1,406
refrigeration	2,462	2,508	2,494	2,532	2,509	2,292	2,358	2,376	2,390	2,405	2,422	2,445	2,471	2,501	2,534	2,569	2,617	2,666
total	19,806	20,180	20,065	20,371	20,189	18,439	18,971	19,120	19,229	19,349	19,483	19,670	19,880	20,120	20,384	20,673	21,060	21,446
Demand PJ	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
lighting	10,379	10,563	10,747	10,909	11,071	11,234	11,396	11,558	11,720	11,883	12,045	12,207	12,369	12,532	12,694	12,856	13,018	13,180
DHW	0,358	0,364	0,371	0,376	0,382	0,387	0,393	0,399	0,404	0,410	0,415	0,421	0,427	0,432	0,438	0,443	0,449	0,454
Cooking	11,313	11,513	11,713	11,890	12,067	12,244	12,421	12,597	12,774	12,951	13,128	13,305	13,482	13,658	13,835	14,012	14,189	14,366
Room Cooling	0,015	0,016	0,016	0,016	0,016	0,017	0,017	0,017	0,017	0,018	0,018	0,018	0,018	0,019	0,019	0,019	0,019	0,019
Room Heating	0,700	0,713	0,725	0,736	0,747	0,758	0,769	0,780	0,791	0,802	0,813	0,824	0,835	0,846	0,857	0,868	0,879	0,890
dish	0,168	0,171	0,174	0,176	0,179	0,182	0,184	0,187	0,189	0,192	0,195	0,197	0,200	0,203	0,205	0,208	0,210	0,213
small Appliances	1,432	1,457	1,482	1,505	1,527	1,549	1,572	1,594	1,617	1,639	1,661	1,684	1,706	1,728	1,751	1,773	1,796	1,818
refrigeration	2,714	2,762	2,810	2,852	2,894	2,937	2,979	3,022	3,064	3,107	3,149	3,191	3,234	3,276	3,319	3,361	3,403	3,446
total	21,832	22,219	22,605	22,947	23,288	23,629	23,970	24,312	24,653	24,994	25,336	25,677	26,018	26,359	26,701	27,042	27,383	27,724

Public

Table B-0-5: Public subsector demand evolution

Demand PJ	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
lighting	59,813	60,942	60,594	61,518	60,968	55,685	57,291	57,742	58,070	58,434	58,839	59,403	60,038	60,762	61,559	62,432	63,599	64,766
DHW	4,047	4,124	4,100	4,163	4,126	3,768	3,877	3,907	3,930	3,954	3,982	4,020	4,063	4,112	4,166	4,225	4,304	4,383
Room Cooling	0,357	0,363	0,361	0,367	0,363	0,332	0,342	0,344	0,346	0,348	0,351	0,354	0,358	0,362	0,367	0,372	0,379	0,386
Room Heating	16,283	16,591	16,496	16,747	16,598	15,159	15,597	15,719	15,809	15,908	16,018	16,171	16,344	16,541	16,758	16,996	17,314	17,631
small Appliances	49,020	49,945	49,660	50,417	49,966	45,637	46,953	47,323	47,591	47,890	48,221	48,683	49,204	49,797	50,451	51,166	52,122	53,079
total	132,668	135,172	134,401	136,449	135,230	123,513	127,074	128,075	128,801	129,610	130,506	131,758	133,166	134,772	136,540	138,477	141,065	143,654
Demand PJ	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
lighting	65,933	67,100	68,267	69,298	70,328	71,359	72,389	73,420	74,451	75,481	76,512	77,543	78,573	79,604	80,635	81,665	82,696	83,726
DHW	4,462	4,541	4,620	4,689	4,759	4,829	4,899	4,968	5,038	5,108	5,178	5,247	5,317	5,387	5,456	5,526	5,596	5,666
Room Cooling	0,393	0,400	0,407	0,413	0,419	0,425	0,432	0,438	0,444	0,450	0,456	0,462	0,468	0,475	0,481	0,487	0,493	0,499
Room Heating	17,949	18,267	18,585	18,865	19,146	19,426	19,707	19,987	20,268	20,549	20,829	21,110	21,390	21,671	21,951	22,232	22,513	22,793
small Appliances	54,035	54,992	55,948	56,793	57,637	58,482	59,327	60,171	61,016	61,861	62,705	63,550	64,395	65,239	66,084	66,929	67,773	68,618
total	146,242	148,831	151,419	153,705	155,991	158,277	160,563	162,849	165,135	167,421	169,707	171,993	174,279	176,565	178,851	181,137	183,423	185,709

Hotels/Restaurants

Table B-0-6: Restaurants/Hotels subsector demand evolution

Demand PJ	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
lighting	0,859	0,875	0,870	0,883	0,875	0,799	0,822	0,829	0,834	0,839	0,845	0,853	0,862	0,872	0,884	0,896	0,913	0,930
DHW	0,211	0,215	0,213	0,217	0,215	0,196	0,202	0,203	0,204	0,206	0,207	0,209	0,211	0,214	0,217	0,220	0,224	0,228
Cooking	1,689	1,721	1,711	1,737	1,721	1,572	1,617	1,630	1,639	1,650	1,661	1,677	1,695	1,715	1,738	1,763	1,796	1,828
Room Cooling	0,030	0,030	0,030	0,030	0,030	0,027	0,028	0,028	0,029	0,029	0,029	0,029	0,030	0,030	0,030	0,031	0,031	0,032
Room Heating	1,348	1,373	1,365	1,386	1,374	1,255	1,291	1,301	1,308	1,317	1,326	1,338	1,353	1,369	1,387	1,407	1,433	1,459
cloth	0,028	0,029	0,029	0,029	0,029	0,026	0,027	0,027	0,027	0,028	0,028	0,028	0,028	0,029	0,029	0,030	0,030	0,031
dish	0,025	0,026	0,025	0,026	0,026	0,023	0,024	0,024	0,024	0,024	0,025	0,025	0,025	0,025	0,026	0,026	0,027	0,027
cooling Appliances	0,405	0,413	0,410	0,417	0,413	0,377	0,388	0,391	0,393	0,396	0,398	0,402	0,407	0,411	0,417	0,423	0,431	0,439
small Appliances	0,109	0,111	0,110	0,112	0,111	0,101	0,104	0,105	0,106	0,106	0,107	0,108	0,109	0,110	0,112	0,113	0,116	0,118
total	4,702	4,791	4,764	4,836	4,793	4,378	4,504	4,539	4,565	4,594	4,626	4,670	4,720	4,777	4,839	4,908	5,000	5,092
FREEZING																		

Demand PJ	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
lighting	0,947	0,963	0,980	0,995	1,010	1,024	1,039	1,054	1,069	1,084	1,098	1,113	1,128	1,143	1,158	1,172	1,187	1,202
DHW	0,232	0,236	0,240	0,244	0,248	0,251	0,255	0,259	0,262	0,266	0,269	0,273	0,277	0,280	0,284	0,288	0,291	0,295
Cooking	1,861	1,894	1,927	1,956	1,986	2,015	2,044	2,073	2,102	2,131	2,160	2,189	2,218	2,247	2,276	2,306	2,335	2,364
Room Cooling	0,033	0,033	0,034	0,034	0,035	0,035	0,036	0,036	0,037	0,037	0,038	0,038	0,039	0,039	0,040	0,040	0,041	0,041
Room Heating	1,486	1,512	1,538	1,561	1,585	1,608	1,631	1,654	1,677	1,701	1,724	1,747	1,770	1,794	1,817	1,840	1,863	1,886
cloth	0,031	0,032	0,032	0,033	0,033	0,034	0,034	0,035	0,035	0,036	0,036	0,037	0,037	0,038	0,038	0,039	0,039	0,040
dish	0,028	0,028	0,029	0,029	0,029	0,030	0,030	0,031	0,031	0,032	0,032	0,032	0,033	0,033	0,034	0,034	0,035	0,035
cooling Appliances	0,446	0,454	0,462	0,469	0,476	0,483	0,490	0,497	0,504	0,511	0,518	0,525	0,532	0,539	0,546	0,553	0,560	0,567
small Appliances	0,120	0,122	0,124	0,126	0,128	0,130	0,132	0,133	0,135	0,137	0,139	0,141	0,143	0,145	0,146	0,148	0,150	0,152
total	5,183	5,275	5,367	5,448	5,529	5,610	5,691	5,772	5,853	5,934	6,015	6,096	6,177	6,258	6,339	6,420	6,501	6,582
FREEZING																		

Sport

Table B-0-7: Sport subsector demand evolution

Demand PJ	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
lighting	10,56674	10,76621	10,70479	10,86793	10,77084	9,837544	10,12121	10,20095	10,25878	10,32318	10,39459	10,49426	10,60641	10,73434	10,87518	11,0294	11,23557	11,44174
DHW	6,544087	6,667622	6,62958	6,730617	6,670486	6,092489	6,268169	6,317549	6,353363	6,393247	6,437472	6,499197	6,568655	6,647881	6,73511	6,830615	6,958298	7,085981
Room Cooling	3,933761	4,00802	3,985152	4,045887	4,009741	3,662297	3,767901	3,797585	3,819113	3,843088	3,869673	3,906777	3,948529	3,996153	4,048588	4,105997	4,18275	4,259502
Room Heating	9,543639	9,723797	9,668318	9,815666	9,727973	8,885045	9,14125	9,213264	9,265494	9,323659	9,388155	9,478173	9,579468	9,695007	9,822219	9,961499	10,14771	10,33392
small Appliances	3,215151	3,275844	3,257154	3,306794	3,277251	2,993278	3,07959	3,103851	3,121447	3,141042	3,16277	3,193096	3,227221	3,266145	3,309002	3,355924	3,418655	3,481387
total	33,80338	34,4415	34,24499	34,76689	34,45629	31,47065	32,37812	32,6332	32,81819	33,02421	33,25266	33,5715	33,93028	34,33952	34,7901	35,28343	35,94298	36,60252
Demand PJ	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
lighting	11,64791	11,85408	12,06025	12,24232	12,4244	12,60647	12,78854	12,97062	13,15269	13,33477	13,51684	13,69892	13,88099	14,06307	14,24514	14,42722	14,60929	14,79136
DHW	7,213664	7,341347	7,469031	7,581791	7,694552	7,807312	7,920073	8,032833	8,145594	8,258354	8,371115	8,483876	8,596636	8,709397	8,822157	8,934918	9,047678	9,160439
Room Cooling	4,336255	4,413007	4,48976	4,557542	4,625324	4,693107	4,760889	4,828671	4,896453	4,964236	5,032018	5,0998	5,167582	5,235365	5,303147	5,370929	5,438712	5,506494
Room Heating	10,52012	10,70633	10,89254	11,05698	11,22143	11,38588	11,55032	11,71477	11,87921	12,04366	12,2081	12,37255	12,53699	12,70144	12,86589	13,03033	13,19478	13,35922
small Appliances	3,544118	3,60685	3,669581	3,724981	3,780381	3,835781	3,891181	3,946581	4,001981	4,057381	4,112781	4,168181	4,223581	4,278981	4,334381	4,389781	4,445181	4,500581
total	37,26207	37,92161	38,58116	39,16362	39,74608	40,32855	40,91101	41,49347	42,07593	42,6584	43,24086	43,82332	44,40579	44,98825	45,57071	46,15317	46,73564	47,3181

Appendix C – Decay of Stock

Table C-0-1: Stock decay by year per lifetime (years)

	Year																							
Lifetime	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
2	1	0,5000	0,0000																					
5	1	0,8000	0,6000	0,4000	0,2000	0,0000																		
8	1	0,8750	0,7500	0,6250	0,5000	0,3750	0,2500	0,1250	0,0000															
10	1	0,9000	0,8000	0,7000	0,6000	0,5000	0,4000	0,3000	0,2000	0,1000	0,0000													
15	1	0,9333	0,8667	0,8000	0,7333	0,6667	0,6000	0,5333	0,4667	0,4000	0,3333	0,2667	0,2000	0,1333	0,0667	0,0000								
20	1	0,9500	0,9000	0,8500	0,8000	0,7500	0,7000	0,6500	0,6000	0,5500	0,5000	0,4500	0,4000	0,3500	0,3000	0,2500	0,2000	0,1500	0,1000	0,0500	0,0000			
22,8	1	0,9561	0,9123	0,8684	0,8246	0,7807	0,7368	0,6930	0,6491	0,6053	0,5614	0,5175	0,4737	0,4298	0,3860	0,3421	0,2982	0,2544	0,2105	0,1667	0,1228	0,0789	0,0351	0

Appendix D – Stock by Sector and Subsector

Residential

Table D-0-1: Residential sector stock [7, 15-19, 22, 27]

	Demand	Stock (% of demand)	PJ - by tech
Lighting	2,350		
Lighting LEDs		0,040	0,094
Lighting Incandescent		0,127	0,298
Lighting Halogens		0,085	0,201
Lighting Fluorescent		0,748	1,758
Cooking	44,042		
Cooking - electrical		0,094	4,125
Cooking LPG		0,000	0,000
Cooking - NG		0,906	39,917
Small Appliances	9,606		
Small Appliances		1,000	9,606
Space Cooling	0,734		
Space Cooling appliances (fans,…)		0,001	0,001
Air conditioner		0,999	0,733
Cloth washing and drying	2,502		
Washing machine & dryer high efficiency		0,800	2,001
Washing machine & dryer low efficiency		0,200	0,500
Dishwashing	2,214		
Dishwasher high efficiency		0,800	1,771
Dishwasher low efficiency		0,200	0,443
Refrigeration	5,716		
Refrigeration Appliances high efficiency		0,800	4,573
Refrigeration Appliances low efficiency		0,200	1,143
DHW	21,532		
DHW Boiler oil		0,180	3,880
DHW Boiler LPG		0,072	1,552
DHW Heater LPG		0,203	4,365
DHW Boiler NG		0,090	1,940

DHW Heater NG		0,090	1,940
DHW Solar thermal		0,095	2,037
DHW Boiler biomass		0,212	4,558
DHW Thermoaccumulators		0,059	1,261
Space Heating	33,521		
Space Heating appliances (small heater …)		0,046	1,543
Air conditioner		0,033	1,122
Space heating Boiler oil		0,259	8,696
Space heating Boiler LPG		0,059	1,964
Space heating Boiler NG		0,059	1,964
Space Heating open fireplace		0,259	8,696
Space Heating close fireplace		0,167	5,610
Space Heating boiler biomass		0,117	3,927

Restaurant/Hotel

Table D-0-2: Restaurant/Hotel subsector stock [7, 15-19, 22, 27]

	Demand	Stock (% of demand)	PJ - by tech
Lighting	0,875		
Lighting LEDs		0,039897	0,0349
Lighting Incandescent		0,126682	0,1109
Lighting Halogens		0,085493	0,0748
Lighting Fluorescent		0,747929	0,6547
DHW	0,215		
DHW Thermoaccumulators		0,48	0,1029
DHW Solar thermal		0,13	0,0277
DHW Boiler oil		0,16	0,0338
DHW Heater LPG		0,03	0,0063
DHW Boiler NG		0,21	0,0440
Cooking	1,721		
Cooking electrical		0,62	1,0696
Cooking LPG		0,21	0,3596
Cooking NG		0,17	0,2921
Space Cooling	0,030		
Space Cooling Air conditioner		0,61	0,0183
Space Cooling Centralized Air conditioner		0,39	0,0117
Space Heating	1,374		
Space Heating Air conditioner		0,02	0,0628
Space Heating Centralized Air conditioner		0,03	0,0402
Space Heating Boiler oil		0,31	0,4234
Space Heating Boiler NG		0,32	0,4427
Dishwashing	0,026		
Dishwasher high efficiency		0,8	0,0204
Dishwasher low efficiency		0,2	0,0051
Small Appliances	0,111		
Small Appliances		1	0,1108
Cloth washing and drying	0,029		
Cloth washing machine & dryer (high efficiency)		0,8	0,0231

Cloth washing machine & dryer (low efficiency)		0,2	0,0058
Refrigeration	0,297266		
Refrigeration Appliances (high efficiency)		0,8	0,2378
Refrigeration Appliances (low efficiency)		0,2	0,0595
Freezing	0,115604		
Freezing Appliances high efficiency		0,8	0,0925
Freezing Appliances low efficiency		0,2	0,0231

Commerce & Other Services

Table D-0-3: Commerce & other services subsector stock [7, 15-19, 22, 27]

	Demand	Stock (% of demand)	PJ - by tech
Lighting	30,538		
Lighting LEDs		0,0398	1,2183
Lighting Incandescent		0,1266	3,8686
Lighting Halogens		0,0854	2,6108
Lighting Fluorescent		0,7479	22,840
DHW	1,9540		
DHW Thermoaccumulators		0,48	0,9370
DHW Solar thermal		0,13	0,2519
DHW Boiler oil		0,09	0,3074
DHW Heater LPG		0,03	0,0569
DHW Boiler NG		0,21	0,4005
Space Cooling	0,2656		
Space Cooling Air conditioner		0,61	0,1620
Space Cooling Centralized Air conditioner		0,39	0,1036
Space Heating	12,1334		
Space Heating Air conditioner		0,26	3,1563
Space Heating Centralized Air conditioner		0,17	2,0180
Space Heating Boiler oil		0,28	3,3385
Space Heating Boiler NG		0,3	3,6204
Small Appliances	6,9917		
Small Appliances		1	6,9917
Refrigeration	7,76619		
Refrigeration Appliances high efficiency		0,8	6,2129
Refrigeration Appliances low efficiency		0,2	1,5532
Freezing	0,02018		
Freezing Appliances high efficiency		0,8	2,4161
Freezing Appliances low efficiency		0,2	0,6040

Education

Table D-0-4: Education subsector stock [7, 15-19, 22, 27]

	Demand	Stock (% of demand)	PJ - by tech
Lighting	9,597		
Lighting LEDs		0,040	0,383
Lighting Incandescent		0,127	1,216
Lighting Halogens		0,085	0,821
Lighting Fluorescent		0,748	7,178
DHW	0,3309		
DHW Thermoaccumulators		0,48	0,159
DHW Solar thermal		0,13	0,043
DHW Boiler oil		0,16	0,052
DHW Heater LPG		0,03	0,010
DHW Boiler NG		0,2	0,068
Cooking	10,460		
Cooking LPG		0,17	2,185
Cooking NG		0,21	1,775
Cooking electrical		0,62	6,5
Space Cooling	0,0141		
Space Cooling Air conditioner		0,610	0,009
Space Cooling Centralized Air conditioner		0,390	0,006
Space Heating	0,6477		
Space Heating Air conditioner		0,15	0,146
Space Heating Centralized Air conditioner		0,09	0,093
Space Heating Boiler oil		0,31	0,200
Space Heating Boiler NG		0,32	0,209
Dishwashing	0,155149		
Dishwasher high efficiency		0,800	0,124
Dishwasher low efficiency		0,200	0,031
Small Appliances	1,323837		
Small Appliances		1,000	1,324

Health Services

Table D-0-5: Health subsector stock [7, 15-19, 22, 27]

	Demand	Stock (% of demand)	PJ - by tech
Lighting	24,797		
Lighting LEDs		0,0398	0,9892
Lighting Incandescent		0,1266	3,1412
Lighting Halogens		0,0854	2,1199
Lighting Fluorescent		0,7479	18,546
DHW	6,199		
DHW Thermoaccumulators		0,48	2,9726
DHW Solar thermal		0,13	0,7993
DHW Boiler oil		0,16	0,9755
DHW Heater LPG		0,03	0,1808
DHW Boiler NG		0,21	1,2708
Space Cooling	1,683		
Space Cooling Air conditioner		0,61	1,0263
Space Cooling Centralized Air conditioner		0,39	0,6562
Space Heating	76,840		
Space Heating Air conditioner		0,23	17,3183
Space Heating Centralized Air conditioner		0,14	11,0723
Space Heating Boiler oil		0,31	23,6836
Space Heating Boiler NG		0,32	24,7652
Small Appliances	12,398		
Small Appliances		1	12,398
Freezing	2,066		
Freezing Appliances high efficiency		0,8	1,6531
Freezing Appliances low efficiency		0,2	0,4132

Public Services

Table D-0-6: Public subsector stock [7, 15-19, 22, 27]

	Demand	Stock (% of demand)	PJ - by tech
Lighting	60,968		
Lighting LEDs		0,0398	2,4324
Lighting Incandescent		0,126	7,7236
Lighting Halogens		0,085	5,2123
Lighting Fluorescent		0,747	45,599
DHW	4,1256		
DHW Thermoaccumulators		0,48	1,9783
DHW Solar thermal		0,13	0,5319
DHW Boiler oil		0,16	0,6492
DHW Boiler LPG		0,03	0,1203
DHW Boiler NG		0,21	0,8457
Space Cooling	0,3634		
Space Cooling Air conditioner		0,39	0,1417
Space Cooling Centralized Air conditioner		0,61	0,2217
Space Heating	16,597		
Space Heating Air conditioner		0,23	3,7408
Space Heating Centralized Air conditioner		0,14	2,3916
Space Heating Boiler oil		0,31	5,1157
Space Heating Boiler NG		0,32	5,3493
Small Appliances	49,9664		
Small Appliances		1	49,9667

Sport

Table D-0-7: Sport subsector stock [7, 15-19, 22, 27]

	Demand	Stock (% of demand)	PJ - by tech
Lighting	10,770		
Lighting LEDs		0,039	0,429
Lighting Incandescent		0,126	1,364
Lighting Halogens		0,085	0,920
Lighting Fluorescent		0,747	8,055
DHW	6,670		
DHW Thermoaccumulators		0,48	3,198
DHW Solar thermal		0,13	0,860
DHW Boiler oil		0,16	1,049
DHW Heater LPG		0,03	0,194
DHW Boiler NG		0,21	1,367
Space Cooling	4,009		
Space Cooling Air conditioner		0,61	2,445
Space Cooling Centralized Air conditioner		0,39	1,563
Space Heating	9,727		
Space Heating Air conditioner		0,23	2,193
Space Heating Centralized Air conditioner		0,14	1,401
Space Heating Boiler oil		0,31	2,998
Space Heating Boiler NG		0,32	3,135
Small Appliances	3,277		
Small Appliances		1	3,277

Appendix E – Model results for no scenario

Table E-0-1: New annual capacity (GW)

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
CENTCOND	11,89	5,14	0,04	0,25	10,77	3,99	12,61	14,24	13,79	15,16	25,49	1,01	1,02	1,21	1,53	13,54	7,37	1,63
DHWTHERMO	28,87	21,3	4,12	19,38	6,96	15,12	12,13	11,42	10,35	10,21	22,63	7,84	9,5	9,71	8,97	38,95	25,1	8,16
FREEZHIGH	0	0	0,01	0,01	0,01	0,12	0,51	0,37	0,26	0,1	0,11	0,02	0,02	0,02	0,02	0,02	0,03	0,04
LIGHTFLUOR	0	113,05	99,42	65,83	68,46	7,99	69,38	57,92	341,75	125,88	121,47	88,29	87,22	32,64	92,84	82,39	369,37	154,85
REFLOW	0	0	0	0	0	0	2,28	2,55	1,63	1,03	0,64	0,65	0,32	0,28	0,39	0,36	0,19	0,19
SMALLAPPL	0,1	6,97	12,04	22,5	5,71	7,21	7,25	5,74	6,05	19,47	11,09	7,86	19,74	19,62	15,18	16,37	14,06	19,23
COOKELC	0	5,54	10,84	19,12	8,31	14,6	13,59	10,46	10,54	11,04	10,17	11,72	11,83	12,06	11,45	12,61	9,41	15,17
AIRCOND	0,15	0,12	0,09	0,22	0,1	0	0,11	0,11	0,21	0	0,37	0,13	0,1	0,24	0,12	0,02	0,14	0,13
CLOTHLOW	0	0	0	0,01	0,34	0,95	1	0,74	0,75	0,73	0,73	0,76	0,76	0,76	0,79	0,76	0,19	0,16
HEATAPPL	0	4,28	0	6,92	0	5,92	6,46	2,64	2,09	2,09	2,64	3,18	1,64	3,73	3,73	167,16	8,65	3,82
DISHHIGH	0	0	0	0	0	0	0	0	0	0	3,27	0,05	0,03	0,04	0,04	0,04	0,08	0,04
SOLTHERMO	19,61	1,14	0,45	1,05	0,33	1,08	0	0	0	0,69	0,81	0,87	0,9	0,96	0,96	20,63	1,71	0,99
	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
CENTCOND	3,12	13,08	6,05	14,77	15,5	16,38	17,13	29,87	1,14	2,48	5,79	3,43	15,16	9,05	3,34	4,7	14,79	7,92
DHWTHERMO	23,13	11,05	18,87	15,77	14,71	13,99	13,49	26,37	11,02	12,98	13,13	12,44	42,41	28,41	11,79	26,42	14,33	22,5
FREEZHIGH	0,04	0,04	0,15	0,53	0,4	0,29	0,14	0,14	0,04	0,04	0,05	0,05	0,05	0,06	0,06	0,07	0,06	0,18
LIGHTFLUOR	145,32	115,08	54,07	99,52	129,73	102,29	387,65	171,6	162,37	131,97	71,05	116,41	148,06	117,79	404,76	188,42	179,34	373,88
REFLOW	0,18	0,19	0,19	2,44	2,72	1,79	1,21	0,8	0,82	0,5	0,44	0,56	0,52	0,36	0,29	0,4	0,36	0,37
SMALLAPPL	29,51	12,59	17,37	13,78	11,65	11,91	25	12,9	12,91	23,21	25,23	19,13	23,1	18,31	22,71	33,14	16,29	17,74
COOKELC	23,07	12,56	18,56	16,72	13,31	13,54	13,86	13,31	14,55	14,98	14,74	14,59	15,44	12,56	17,84	25,91	15,69	21,39
AIRCOND	0,24	0,02	0,4	0,15	0,12	0,27	0,14	0,04	0,17	0,15	0,26	0,05	0,42	0,17	0,14	0,3	0,16	0,07
CLOTHLOW	0,19	0,5	1,14	1,16	0,86	0,91	0,88	0,88	0,91	0,88	0,91	0,95	0,91	0,34	0,28	0,35	0,65	1,3
HEATAPPL	11,29	3,82	9,74	9,74	6,46	5,37	5,92	5,92	6,46	5,46	7,01	7,55	170,44	12,47	61,72	14,56	0	0
DISHHIGH	0,08	0,08	3,31	0,13	0,07	0,08	0,12	0,08	0,16	0,08	0,16	0,12	3,35	0,21	0,11	0,16	0,16	0,12
SOLTHERMO	1,62	0,9	1,62	0,51	0,48	0,51	1,17	1,29	1,38	1,26	1,56	1,47	21,11	2,22	1,5	2,1	1,38	2,13

Table E-0-2: Accumulated annual capacity (GW)

Technology	2015	2020	2030	2040	2050
COMCENTCOND	0	0	12,71	14,96	17,06
COMDHWTHERMO	0	0	2,94	3,52	4,02
COMFREEZHIGH	0	0,11	1,54	1,81	2,07
COMLIGHTFLUOR	0	88,78	223,2	275,79	314,49
COMREFLOW	0	0	7,75	9,11	10,4
COMSMALLAPPL	0	0	10,74	12,63	14,4
EDSPTCENTCOND	0,2	0,37	0,68	0,8	0,91
EDSPTCOOKELEC	0	3,62	12,05	18,9	21,6
EDSPTDHWTHERMO	0,06	0,18	0,4	0,6	0,68
EDSPTDISHHIGH	0	0,02	0,12	0,14	0,16
EDSPTLIGHTFLUOR	0	35,31	70,69	86,68	98,83
EDSPTSMALLAPPL	0	0,31	2,35	2,38	2,73
HEALTHCENTCOND	0	14,69	80,59	97,31	108,08
HEALTHDHWTHERMO	5,12	7,1	9,51	11,34	12,77
HEALTHLIGHTFLUOR	55,05	154,77	182,25	224,04	480,57
HEALTHREFLOW	0	0	2,07	2,42	2,77

HEALTHSMALLAPPL	0	9,77	19,04	22,36	25,54
PUBLICENTCOND	11,69	17,01	17,4	20,27	23,34
PUBLIDHWTHERMO	4,07	6,19	6,33	7,45	8,5
PUBLILIGHTFLUOR	205,66	307,11	440,63	550,39	627,85
PUBLISMALLAPPL	0	28,39	76,78	90,13	102,88
REHOTAIRCOND	0,15	0,68	1,41	1,65	1,89
REHOTCLOTHLOW	0	0,02	0,05	0,05	0,06
REHOTCOOKELEC	0	0	2,64	3,11	3,54
REHOTDHWTHERMO	0	0,15	0,33	0,39	0,44
REHOTDISHHIGH	0	0	0,02	0,02	0,03
REHOTFREEZFHIGH	0	0,03	0,06	0,07	0,08
REHOTLIGHTFLUOR	0,02	3,35	6,48	7,88	9
REHOTREFLOW	0	0	0,3	0,35	0,4
REHOTSMALLAPPL	0	0	0,18	0,2	0,23
RESCLOTHLOW	0	1,27	9,02	10,63	12,13
RESCOOKELEC	0	54,78	159,19	187,18	213,29
RESCOOLSMLAPPL	0	0	3,48	4,09	4,66
RESDHWTHERMO	0	58,46	159,19	187,18	213,29
RESDISHHIGH	0	1,31	4	4,69	5,36
RESHEATAPPL	163,43	180,54	212,48	250,17	319,08
RESLIGHTFLUOR	0	21,66	40,79	49,9	56,9
RESREFHIGH	0	0	3,41	4,01	4,58
RESSMALLAPPL	0,1	11,79	35,01	40,79	46,55
SPORTCENTAIR	0	0	8,39	9,89	12,06
SPORTDHWHEATBIO	3,48	3,53	3,53	0	0
SPORTDHWSOLTHER	50,23	52,16	66,35	78,61	89,39
SPORTDHWTHERMO	19,61	23,66	29,87	35,12	40,07
SPORTLIGHTFLUOR	0	39,81	79,13	97,26	110,9
SPORTSMALLAPPL	0	1,2	5,04	5,92	6,75

Table E-0-3: Annual investment in sectors and subsector (millions of euros)

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Residenti	0,08626	3267,85	464,319	4037,02	881,783	3287,71	3148,72	2151,09	1845,65	1709	3939,83	1604,47	1460,81	1949,81	1855,61	40072	4678,43	1784,29
Services s	145,942	3697,62	124,214	2044,41	3677,14	1414,43	7689,57	15225,2	5402,61	5999,95	9968,43	1704,37	2046,48	2186,08	2566,16	8520,38	5303,51	3102,15
Commerci	0	0,01279	0,28025	0,32124	0,2735	0,0687	1,71248	2,34912	1,93856	493,043	3555,75	64,3419	84,6898	83,2682	89,4416	93,8622	88,0701	84,2847
Education	72,9817	15,3689	10,3909	18,0859	9,11652	14,8366	1,4125	8,2463	15,8364	12,7066	11,8427	34,9152	2,93398	12,354	13,9807	88,3701	23,127	17,424
Health	0,55048	102,942	11,9724	32,0194	3589,78	1314,27	4200,23	4247,28	3878,53	3896,69	4246,49	268,451	285,341	342,229	369,444	784,693	619,342	314,897
Restauran	72,41	57,7316	46,2714	109,929	51,9626	1,45682	58,7394	55,432	104,177	3,06408	179,217	63,5323	49,0929	116,367	59,2093	10,4251	67,8474	66,2258
Sport	0	1670,29	34,4295	1802,17	25,9445	82,0231	3426,26	10911,9	1399,89	1585,61	1974,81	1273,38	1614,86	1623,04	1962,46	3267,15	2539,49	2485,56
Public	0	1851,28	20,8692	81,8856	0,26801	2,35321	1,82595	0,49417	2,71428	9,28039	0,77492	0,22173	10,0307	9,29234	72,1105	4276,35	1965,75	133,853
	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Residenti	5447,8	2207,57	5030,11	4311,89	3391,12	3001,8	2956,05	4631,33	2723,04	2739,64	3069,49	3139,08	41644,7	5926,96	15665,9	6561,74	1667,23	2688,46
Services s	3721,38	6839,42	11076	8670,08	7146,68	9421,67	7795,43	11841,9	6081,93	13351,8	4969,38	4056,53	10674,4	6611,48	4922,66	5178,53	9053,78	5926,48
Commerci	82,516	88,127	84,7325	73,1323	77,7471	74,9425	548,151	3647,79	140,697	156,607	158,799	161,982	169,278	159,917	159,782	155,255	163,288	160,078
Education	25,3796	16,5975	23,1186	5,96287	13,288	19,8534	17,1027	16,9428	38,8721	7,58208	17,3698	18,5321	93,0937	27,9271	22,021	33,0886	18,5003	27,5338
Health	762,469	4101,76	1829,59	4656,38	4603,4	4422,76	4361,98	5555,44	24,5941	593,88	788,109	864,39	1204,32	1070,37	774,484	1214,24	4557,06	2288,03
Restauran	120,163	14,0784	194,776	78,5781	60,7179	133,643	70,989	20,7131	83,3641	73,7229	126,483	26,1304	203,587	82,8852	71,4958	149,754	81,8902	36,2662
Sport	2536,27	2472,16	8829,02	3742,97	2314,34	4659,04	2675,27	2557,44	5614,95	12434,4	3757,67	2803,35	4615,96	3195,38	3648,2	3354,31	3974,9	3188,93
Public	194,693	146,989	114,774	113,765	77,7187	111,993	122,489	44,0888	180,014	86,1524	121,514	182,733	4388,75	2075,21	246,85	272,087	258,538	226,441

Table E-0-4: Primary Energy evolution (PJ)

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2030	2035	2040	2045	2050
BG_CHP	0,74	0,77	0,77	1,62	1,84	0,00	0,00	4,60	4,60	4,60	10,07	16,15	16,15	606,44	686,49	808,42
BG_CHP	0,32	0,33	0,33	0,69	0,79	0,00	0,00	1,97	1,97	1,97	4,32	6,92	6,92	259,90	294,21	346,46
COAL_PP	47,31	11,86	11,77	11,20	9,72	0,00	0,00	0,00	2,04	4,70	4,73	0,00	0,00	0,00	0,00	0,00
Geo_PP	0,79	1,42	1,42	1,42	1,42	1,42	1,42	1,42	1,42	1,42	1,42	2,43	2,43	7,25	7,25	7,25
Hydro_Lar	82,17	82,17	82,17	82,17	85,96	85,47	85,96	85,47	85,96	85,47	85,96	85,96	85,96	85,96	85,96	85,96
Hydro_Sm	6,06	6,06	6,06	9,77	9,77	9,77	9,77	9,77	9,77	9,77	9,77	9,77	9,77	9,77	6,06	6,06
NG_CHP	2,65	5,32	5,34	5,37	5,39	0,00	0,00	1,66	2,47	2,40	2,32	0,00	0,00	0,00	0,00	0,00
NG_CHP	1,14	2,28	2,29	2,30	2,31	0,00	0,00	0,71	1,06	1,03	0,99	0,00	0,00	0,00	0,00	0,00
NG_PP	250,65	291,61	289,41	300,41	296,52	173,82	262,35	270,66	280,90	290,23	296,77	11,95	33,84	51,23	52,24	41,52
PV_Large_	33,24	33,64	34,05	34,45	34,72	36,48	36,48	36,48	36,48	36,48	36,48	36,48	36,48	36,48	36,48	36,48
PV_Small_	18,24	18,64	18,85	19,05	19,29	20,08	20,27	20,27	20,27	20,27	20,27	20,27	20,27	20,27	20,27	20,27
Solar_Ther	0,46	0,59	0,73	0,87	1,01	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14	0,94	0,58
WD_CHP	536,92	559,63	559,12	572,46	571,32	567,86	571,69	574,67	576,73	578,59	580,98	475,06	478,19	13,87	1,84	0,92
WD_CHP	230,11	239,84	239,62	245,34	244,85	243,37	245,01	246,29	247,17	247,97	248,99	203,60	204,94	5,95	0,79	0,39
WD_PP	1,00	1,00	1,00	1,00	0,41	0,00	0,00	0,00	0,00	0,00	1,25	0,00	0,00	0,00	0,00	0,00
Wind_PP	50,56	50,88	51,21	51,53	51,85	52,17	52,17	52,17	52,17	52,17	52,17	56,18	56,18	56,18	60,19	60,19
Wind_Sma	0,00	0,00	0,00	0,00	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03

Appendix F - Model results for the PNEC30 scenario

Table F-0-1: New annual capacity (GW)

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
COOKELEC	0,00	5,54	10,84	19,12	8,31	14,60	13,59	10,46	10,54	11,04	10,17	11,72	11,83	12,06	11,45	12,61	9,41	15,17
CLOTHHIGH	0,00	0,00	0,00	0,00	0,24	0,68	0,71	0,53	0,53	0,52	0,52	0,54	0,54	0,54	0,56	0,54	0,13	0,11
DISHHIGH	0,00	0,14	0,35	0,30	0,05	0,47	0,31	0,28	0,22	0,28	0,23	0,30	0,26	0,27	0,26	0,30	0,22	0,42
FREEZHIGH	0,00	0,00	0,01	0,01	0,01	0,12	0,51	0,37	0,26	0,10	0,11	0,02	0,02	0,02	0,02	0,02	0,03	0,04
HEATPUMP	0,00	4,28	0,00	6,92	0,00	5,92	6,46	2,71	2,22	2,09	12,33	3,46	1,86	4,06	4,20	182,53	9,15	4,30
LIGHTFLUOR	0,02	113,05	99,42	59,64	881,14	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
LIGHTLED	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	351,41	9,49	8,96	9,48	10,63	11,15
REFHIGH	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,49	0,88	0,57	0,34	0,35	0,18	0,67	0,21	3,45	0,14	0,13
THERMO	0,06	22,23	4,12	20,38	6,96	15,12	14,15	17,49	10,74	10,70	13,76	8,38	10,29	10,48	9,93	39,81	26,24	9,41
SMALLAPPL	0,00	5,15	10,39	19,00	4,32	4,20	4,57	3,80	5,11	16,57	5,82	5,87	18,46	17,26	12,80	13,49	11,82	16,88
	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
COOKELEC	23,07	12,56	18,56	16,72	13,31	13,54	13,86	13,31	14,55	14,98	14,74	14,59	15,44	12,56	17,84	25,91	15,69	21,39
CLOTHHIGH	0,13	0,35	0,81	0,82	0,61	0,64	0,63	0,63	0,65	0,63	0,65	0,67	0,65	0,24	0,20	0,24	0,46	0,92
DISHHIGH	0,38	0,12	0,55	0,37	0,36	0,28	0,35	0,29	0,38	0,32	0,33	0,33	0,36	0,30	0,49	0,44	0,19	0,62
FREEZHIGH	0,04	0,04	0,15	0,53	0,40	0,29	0,14	0,14	0,04	0,04	0,05	0,05	0,05	0,06	0,06	0,07	0,06	0,18
HEATPUMP	11,78	4,37	10,12	10,30	6,83	6,02	6,34	15,96	7,32	6,06	9,39	8,32	186,07	13,25	62,45	15,28	0,81	0,74
LIGHTFLUOR	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
LIGHTLED	9,36	10,33	5,61	11,97	9,33	8,76	6,79	6,53	6,64	6,58	6,61	6,61	7,92	6,03	6,23	6,55	6,53	439,56
REFHIGH	0,13	0,14	0,10	0,15	0,58	1,02	0,69	0,46	0,47	0,32	0,77	0,30	3,60	0,19	0,16	0,22	0,19	0,20
THERMO	24,27	12,19	70,26	17,63	15,67	16,05	14,33	17,67	13,83	19,91	14,34	13,77	43,94	29,70	13,62	27,81	16,23	24,03
SMALLAPPL	25,17	10,45	10,43	10,41	9,13	10,35	21,42	10,28	10,27	21,35	22,22	16,12	16,52	15,29	19,75	28,16	13,56	13,43

Table F-0-2: Accumulated annual capacity (GW)

	2015	2020	2025	2030	2050
COMDHWTHERMO	0,00	0,00	0,71	2,94	4,02
COMHEATPUMP	0,00	0,00	6,45	7,76	10,42
COMLIGHTFLUOR	0,00	267,46	238,15	0,00	0,00
COMLIGHTLED	0,00	0,00	0,00	81,16	114,36
COMREFHIGH	0,00	0,00	1,82	4,17	5,60
COMSMALLAPPL	0,00	0,00	5,12	10,74	14,40
EDSPTCENTCOND	0,46	0,46	0,46	0,00	0,00
EDSPTCOOKELEC	0,00	3,62	7,05	12,05	21,60
EDSPTDISHHIGH	0,00	0,02	0,11	0,12	0,16
EDSPTHEATPUMP	0,00	0,00	0,02	0,41	0,56
EDSPTLIGHTLED	0,00	0,00	0,00	25,70	35,94
EDSPTSMALLAPPL	0,00	0,31	1,12	2,35	2,73
HEALTHAIRCOND	0,00	0,00	0,00	0,00	0,00
HEALTHCENTCOND	63,26	63,26	63,26	0,00	0,00
HEALTHDHWTHERMO	5,12	7,10	7,97	9,51	12,77
HEALTHHEATPUMP	0,00	0,00	7,75	49,19	65,98
HEALTHLIGHTFLUOR	55,05	315,85	169,72	0,00	0,00
HEALTHLIGHTLED	0,00	0,00	0,00	66,27	174,75
HEALTHSMALLAPPL	0,00	9,77	13,85	19,04	25,54
PUBLICENTCOND	17,01	17,01	17,01	0,00	0,00
PUBLIDHWSOLTHER	0,00	0,00	0,00	0,00	0,00
PUBLIDHWTHERMO	4,07	6,19	6,19	6,33	8,50
PUBLIHEATPUMP	0,00	0,00	0,00	10,62	14,25
PUBLILIGHTFLUOR	205,66	670,72	400,13	0,00	0,00
PUBLISMALLAPPL	0,00	28,39	42,29	76,78	102,88

REHOTAIRCOND	0,15	0,79	0,64	0,00	0,00
REHOTCLOTHHIGH	0,00	0,01	0,03	0,03	0,04
REHOTDHWTHERMO	0,00	0,15	0,31	0,33	0,44
REHOTDISHHIGH	0,00	0,00	0,02	0,02	0,03
REHOTFREEZFHIGH	0,00	0,03	0,06	0,06	0,08
REHOTHEATPUMP	0,00	0,00	0,43	0,88	1,18
REHOTLIGHTFLUOR	0,02	7,98	6,49	0,00	0,00
REHOTREFHIGH	0,00	0,00	0,07	0,16	0,21
REHOTSMALLAPPL	0,00	0,00	0,07	0,18	0,23
RESCOOKELEC	0,00	54,78	105,87	159,19	213,29
RESDHWTHERMO	0,00	58,46	112,31	149,04	199,68
RESDISHHIGH	0,00	1,31	2,61	4,00	5,36
RESHEATAPPL	163,43	180,54	196,46	212,48	319,08
RESHEATFIREOP	0,00	0,00	0,00	0,00	0,00
RESHEATPUMP	0,00	0,00	1,65	1,75	2,35
RESLIGHTFLUOR	0,00	49,29	43,57	0,00	0,00
RESLIGHTLED	0,00	0,00	0,00	14,83	20,69
RESSMALLAPPL	0,10	11,79	23,11	35,01	46,55
SPORTCENTAIR	5,73	5,73	5,73	0,00	0,00
SPORTHEATPUMP	0,00	0,00	1,34	5,12	7,32
SPORTLIGHTFLUOR	0,00	102,69	82,71	0,00	0,00
SPORTLIGHTLED	0,00	0,00	0,00	28,78	40,33
SPORTSMALLAPPL	0,00	1,20	3,14	5,04	6,75

Table F-0-3: Annual investment in sectors and subsector (millions of euros)

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Residential	3808	3268	464	4037	882	3288	3149	2151	1846	1709	4704	1616	1716	1964	1870	40087	4704	1800
Services	2779	2	0	2	0	0	3	10	1	1	23	2	9	3	4	78	5	4
Commercial	472	0	0	0	2	0	0	2	3	23	8755	110	1504	182	197	1381	246	239
Education	156	1	1	9	2	1	1	0	7	1	28	85	429	27	40	425	26	25
Health	595	103	12	32	12	0	1	8	20	21	10486	631	1763	839	894	53545	1382	765
Public	597	155	17	9	4	2	2	0	0	9	0	0	2577	97	255	14591	514	384
Restaurant/l	72	58	46	110	105	1	5	95	180	3	313	110	125	204	196	18	26	21
Sport	885	1679	34	1802	27	82	3450	10392	676	896	3053	1314	2133	1683	2023	8052	2634	2579
	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Residential	5473	2233	4583	4330	3403	3006	2980	5868	2754	2759	3098	3157	41204	5962	15685	6604	1695	2953
Services	5	5	90	6	3	6	4	27	7	15	8	6	81	7	7	7	8	14
Commercial	235	245	237	208	217	208	178	9003	316	358	359	368	1557	406	406	397	414	1751
Education	34	25	29	19	10	38	19	47	101	20	37	51	447	25	25	48	25	459
Health	1860	1280	1296	1132	911	1370	1176	13713	45	1440	1916	2124	54534	2481	1882	2941	2388	4919
Public	328	439	266	405	228	330	320	142	482	236	322	475	14826	730	592	500	660	3145
Restaurant/l	31	22	28	23	113	207	21	331	137	103	221	222	43	43	38	56	38	88
Sport	2629	2556	88290	3894	1922	4012	2062	3715	5748	12530	5166	2812	9300	3203	3657	3363	3983	3675

Table F-0-4: Primary Energy evolution (PJ)

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
BG_PP	0,00	0,00	0,00	0,45	0,00	0,00	0,00	0,00	0,00	0,00	0,29	0,00	0,00	0,00	0,00	0,00	0,00	13,82
BG_CHP	0,74	0,77	0,77	9,31	9,53	0,00	3,41	23,82	23,82	23,82	23,82	23,82	4,76	4,76	4,76	4,76	616,83	808,42
BG_CHP	0,32	0,33	0,33	3,99	4,08	0,00	1,46	10,21	10,21	10,21	10,21	10,21	2,04	2,04	2,04	2,04	264,35	346,46
COAL_PI	47,31	11,86	11,77	11,62	10,14	0,00	0,00	0,00	2,03	4,69	4,73	1,94	0,00	0,00	0,00	0,00	0,00	0,00
Geo_PP	0,79	1,42	1,42	1,42	1,42	1,42	1,42	1,42	1,42	1,42	1,42	1,42	1,42	1,42	1,42	2,43	7,25	7,25
Hydro_La	82,17	82,17	82,17	82,17	85,96	85,47	85,96	85,47	85,96	85,47	85,96	85,47	85,96	85,47	85,96	85,96	85,96	85,96
Hydro_Sr	6,06	6,06	6,06	6,06	6,06	6,06	6,06	6,06	6,06	6,06	6,06	6,06	6,06	6,06	6,06	6,06	6,06	6,06
NG_PP	250,65	298,83	297,45	313,93	308,48	194,12	279,25	271,73	281,97	291,30	299,16	288,26	25,43	27,92	30,44	27,39	51,44	46,90
PV_Large	33,24	33,64	34,05	34,45	34,72	36,48	36,48	36,48	36,48	36,48	36,48	36,48	36,48	36,48	36,48	36,48	36,48	36,48
PV_Smal	18,24	18,64	18,85	19,05	19,29	20,08	20,27	20,27	20,27	20,27	20,27	20,27	20,27	20,27	20,27	20,27	20,27	20,27
Solar_Th	0,46	0,59	0,73	0,87	1,01	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14	1,14	0,58
WD_CHP	536,92	552,40	551,08	557,12	554,49	551,82	555,67	558,65	560,72	562,57	563,50	565,74	462,94	469,86	477,39	474,72	6,99	0,92
WD_CHP	230,11	236,74	236,18	238,76	237,64	236,49	238,14	239,42	240,31	241,10	241,50	242,46	198,40	201,37	204,59	203,45	2,99	0,39
WD_PP	1,00	1,00	1,00	1,00	0,41	0,00	0,00	0,00	0,00	0,00	1,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Wind_PP	50,56	50,88	51,21	51,53	51,85	52,17	52,17	52,17	52,17	52,17	52,17	52,17	52,17	52,17	52,17	56,18	56,18	60,19
Wind_Sm	0,00	0,00	0,00	0,00	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
WindOff_	0,00	0,00	0,00	0,00	0,00	0,24	0,24	0,24	0,24	0,24	0,24	0,24	0,24	0,24	0,24	0,24	0,24	0,24

Appendix G – Model results for the RNC2050 scenario

Table G-0-1: New annual capacity (GW)

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
CENTCOND	16,77	0,26	0,04	0,25	10,77	3,99	12,61	14,24	13,79	15,16	25,49	1,01	1,02	1,21	1,53	18,42	2,49	1,63
DHWTHERMO	31,75	18,43	4,12	19,38	6,96	15,12	12,13	11,42	10,35	10,21	22,63	7,84	9,50	9,71	8,97	41,82	22,23	8,16
FREEZHIGH	0,00	0,00	0,01	0,01	0,01	0,12	0,51	0,37	0,26	0,10	0,11	0,02	0,02	0,02	0,02	0,02	0,03	0,04
LIGHTFLUOR	0,00	43,83	21,80	37,61	21,35	9,75	27,82	22,48	597,59	49,28	28,09	47,08	31,57	20,58	39,36	35,32	615,20	65,45
REFLOW	0,00	0,00	0,00	0,00	0,00	0,00	2,28	2,55	1,63	1,03	0,64	0,65	0,32	0,28	0,39	0,36	0,19	0,19
SMALLAPPL	70,42	3,70	9,83	7,24	3,89	4,43	5,30	5,51	5,74	9,25	7,51	8,12	9,32	9,79	10,36	81,85	10,71	16,98
COOKELC	0,00	5,54	10,84	19,12	8,31	14,60	13,59	10,46	10,54	11,04	10,17	11,72	11,83	12,06	11,45	12,61	9,41	15,17
CLOTHLOW	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,02	0,02	0,02	0,10	0,00	0,00	0,02	0,00	0,00	0,00
HEATAPPL	0,00	0,14	0,35	0,30	0,05	0,47	0,31	0,28	0,22	0,27	0,23	0,30	0,26	0,27	0,26	0,30	0,22	0,42
DISHHIGH	0,00	0,14	0,35	0,30	0,07	0,47	0,31	0,37	0,22	0,29	0,23	0,30	0,26	0,27	0,26	0,30	0,22	0,43
SOLTHERMO	50,23	0,93	0,00	1,01	0,00	0,00	2,01	6,08	0,39	0,49	0,69	0,69	0,89	0,88	1,08	0,98	1,37	1,37
	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
CENTCOND	3,12	13,08	6,05	14,77	15,50	16,38	17,13	29,87	1,14	2,48	5,79	3,43	20,03	4,17	3,34	4,70	14,79	7,92
DHWTHERMO	23,13	11,05	18,87	15,77	14,71	13,99	13,49	26,37	11,02	12,98	13,13	12,44	45,28	25,54	11,79	26,42	14,33	22,50
FREEZHIGH	0,04	0,04	0,15	0,53	0,40	0,29	0,14	0,14	0,04	0,04	0,05	0,05	0,05	0,06	0,06	0,07	0,06	0,18
LIGHTFLUOR	45,37	64,10	24,57	45,86	63,25	56,72	630,87	79,53	59,73	78,16	38,67	59,54	79,32	68,14	645,02	93,58	73,87	317,50
REFLOW	0,18	0,19	0,19	2,44	2,72	1,79	1,21	0,80	0,82	0,50	0,44	0,56	0,52	0,36	0,29	0,40	0,36	0,37
SMALLAPPL	14,07	10,64	11,32	11,73	11,40	11,54	14,69	12,53	13,12	12,77	15,31	14,27	85,32	14,86	20,43	17,64	14,31	14,91
COOKELC	23,07	12,56	18,56	16,72	13,31	13,54	13,86	13,31	14,55	14,98	14,74	14,59	15,44	12,56	17,84	25,91	15,69	21,39
CLOTHLOW	0,00	0,00	0,02	0,00	0,01	0,02	0,02	0,02	0,12	0,00	0,00	0,02	0,00	0,00	0,02	0,00	0,00	0,02
HEATAPPL	0,37	0,12	0,55	0,37	0,36	0,28	0,33	0,29	0,37	0,32	0,33	0,32	0,36	0,29	0,49	0,44	0,19	0,61
DISHHIGH	0,38	0,13	0,56	0,37	0,45	0,28	0,35	0,30	0,38	0,33	0,33	0,33	0,36	0,30	0,49	0,44	0,21	0,62
SOLTHERMO	1,38	1,37	51,51	2,10	1,08	2,18	1,08	0,98	3,18	7,16	1,57	1,57	1,77	1,77	2,06	1,86	2,26	1,77

Table G-0-2: Accumulated annual capacity (GW)

	2015	2020	2030	2040	2050
COMCENTCOND	0,00	0,00	12,71	14,96	17,06
COMDHWTHERMO	0,00	0,00	2,94	3,52	4,02
COMFREEZHIGH	0,00	0,11	1,54	1,81	2,07
COMLIGHTFLUOR	0,00	88,78	223,20	275,79	314,49
COMREFLOW	0,00	0,00	7,75	9,11	10,40
COMSMALLAPPL	0,00	0,00	10,74	12,63	14,40
EDSPTCENTCOND	0,20	0,37	0,68	0,80	0,91
EDSPTCOOKELEC	0,00	3,62	12,05	18,90	21,60
EDSPTDHWTHERMO	0,06	0,18	0,40	0,60	0,68
EDSPTDISHHIGH	0,00	0,02	0,12	0,14	0,16
EDSPTLIGHTFLUOR	0,00	35,31	70,69	86,68	98,83
EDSPTSMALLAPPL	0,00	0,31	2,35	2,38	2,73
HEALTHCENTCOND	0,00	14,69	80,59	97,31	108,08
HEALTHDHWTHERMO	6,12	7,10	9,51	11,34	12,77
HEALTHLIGHTFLUOR	0,00	174,57	189,68	224,04	480,57
HEALTHREFLOW	0,00	0,00	2,07	2,42	2,77
HEALTHSMALLAPPL	0,00	9,77	19,04	22,36	25,54
PUBLICENTCOND	16,56	17,01	17,40	20,27	23,34
PUBLIDHWTHERMO	5,94	6,19	6,33	7,45	8,50

PUBLILIGHTFLUOR	0,00	451,60	467,87	550,39	627,85
PUBLISMALLAPPL	0,00	73,05	76,78	90,13	102,88
REHOTAIRCOND	0,15	0,68	1,41	1,65	1,89
REHOTCLOTHLOW	0,00	0,02	0,05	0,05	0,06
REHOTCOOKELEC	0,00	0,00	2,64	3,11	3,54
REHOTDHWTHERMO	0,00	0,15	0,33	0,39	0,44
REHOTDISHHIGH	0,00	0,00	0,02	0,02	0,03
REHOTFREEZFHIGH	0,00	0,03	0,06	0,07	0,08
REHOTLIGHTFLUOR	0,02	3,35	6,48	7,88	9,00
REHOTREFLOW	0,00	0,00	0,30	0,35	0,40
REHOTSMALLAPPL	0,00	0,00	0,18	0,20	0,23
RESCLOTHLOW	0,00	1,27	9,02	10,63	12,13
RESCOOKELEC	0,00	54,78	159,19	187,18	213,29
RESCOOLSMLAPPL	0,00	0,00	3,48	4,09	4,66
RESDHWTHERMO	0,00	58,46	159,19	187,18	213,29
RESDISHHIGH	0,00	1,31	4,00	4,69	5,36
RESHEATAPPL	0,00	180,54	212,48	250,17	319,08
RESLIGHTFLUOR	0,00	21,66	40,79	49,90	56,90
RESREFHIGH	0,00	0,00	3,41	4,01	4,58
RESSMALLAPPL	0,10	11,79	35,01	40,79	46,55
SPORTCENTAIR	0,00	0,00	8,39	9,89	12,06
SPORTDHWHEATBIO	3,48	3,53	3,53	0,00	0,00
SPORTDHWSOLTHER	50,23	52,16	66,35	78,61	89,39
SPORTDHWTHERMO	19,61	23,66	29,87	35,12	40,07
SPORTLIGHTFLUOR	0,00	39,81	79,13	97,26	110,90
SPORTSMALLAPPL	0,00	1,20	5,04	5,92	6,75

Table G-0-3: Annual investment in sectors and subsector (millions of euros)

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Residential	3808	3268	464	4037	882	3288	3149	2151	1846	1709	3940	1604	1461	1950	1856	40072	4678	1784
Services	11056	1863	122	2031	3675	1412	7700	15212	5405	5990	9967	1704	2037	2178	2562	10415	3464	3099
Commercial & c	0	0	0	0	0	0	2	2	2	493	3556	64	85	83	89	94	88	84
Education	73	15	10	18	9	15	1	8	16	13	12	35	3	12	14	88	23	17
Health	461	27	18	27	3588	1314	4200	4247	3880	3896	4246	268	285	342	369	860	545	321
Public	1061	84	12	74	0	0	0	0	4	0	0	0	0	1	68	6096	200	125
Restaurant/hote	72	58	46	110	52	1	58	55	104	3	179	63	49	116	59	10	68	66
Sport	9389	1679	34	1802	26	82	3439	10899	1400	1586	1975	1273	1615	1623	1962	3267	2539	2486
	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Residential	5448	2208	5030	4312	3391	3002	2956	4631	2723	2740	3069	3139	41645	5927	15666	6562	1667	2688
Services	3708	6838	90534	8668	7146	9421	7789	11841	6094	13329	4961	4052	12569	4769	4924	5165	9051	5924
Commercial & c	83	88	85	73	78	75	548	3648	141	157	159	162	169	160	160	155	163	160
Education	25	17	23	6	13	20	17	17	39	8	17	19	93	28	22	33	19	28
Health	757	4100	1830	4656	4603	4423	4363	5555	24	594	788	864	1279	995	782	1209	4555	2288
Public	186	147	112	112	77	111	115	43	180	76	113	178	6208	308	240	263	258	224
Restaurant/hote	120	14	194	78	60	133	70	20	83	73	126	26	203	83	71	150	81	35
Sport	2536	2472	88290	3743	2314	4659	2675	2557	5628	12422	3758	2803	4616	3195	3648	3354	3975	3189

Table G-0-4: Primary Energy evolution (PJ)

	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
BG_CHP	0,74	0,77	0,77	1,62	0,92	0,00	4,60	293,27	336,23	1283,17	1407,58	1687,71
BG_CHP	0,32	0,33	0,33	0,69	0,39	0,00	1,97	125,69	144,10	549,93	603,25	723,31
BG_PP	0,00	0,00	0,00	0,45	0,00	0,00	0,00	0,00	0,00	0,00	0,45	5,21
Geo_PP	0,79	1,42	1,42	1,42	1,42	1,42	1,42	2,43	2,43	7,25	7,25	7,25
Hydro_Larg	82,17	82,17	82,17	82,17	85,96	85,47	85,96	85,96	85,96	85,96	85,96	85,96
Hydro_Sma	6,06	6,06	6,06	9,77	9,77	9,77	9,77	9,77	9,77	9,77	6,06	6,06
NG_CHP	2,65	5,32	5,34	5,37	5,30	0,00	2,32	0,00	0,00	0,00	0,00	0,00
NG_CHP	1,14	2,28	2,29	2,30	2,27	0,00	0,99	0,00	0,00	0,00	0,00	0,00
NG_PP	267,37	307,12	303,93	314,66	308,07	180,56	297,85	85,28	2,10	7,43	6,48	0,00
PV_Large_I	33,24	33,64	34,05	34,45	34,72	36,48	36,48	36,48	36,48	36,48	36,48	36,48
PV_Small_I	18,24	18,64	18,85	19,05	19,29	20,08	20,27	20,27	20,27	20,27	20,27	20,27
Solar_Ther	0,46	0,59	0,73	0,87	1,01	1,14	1,14	1,14	1,14	1,14	1,14	1,14
WD_CHP	602,16	620,45	619,13	628,74	627,41	624,77	637,63	647,89	658,41	10,54	1,84	0,92
WD_CHP	258,07	265,91	265,34	269,46	268,89	267,76	273,27	277,67	282,18	4,52	0,79	0,39
WD_PP	1,00	1,00	0,62	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Wind_PP	50,56	50,88	51,21	51,53	51,85	52,17	52,17	56,18	56,18	56,18	60,19	60,19
Wind_Smal	0,00	0,00	0,00	0,00	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
WindOff_P	0,00	0,00	0,00	0,00	0,00	0,24	0,24	0,24	0,24	0,24	0,24	0,24