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"Optimal deployment of heat and CHP technologies for the decarbonisation of the heating sector in the urban context"

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ABSTRACT

Today more than half of the human population live in an urban area, thus meeting the urban energy demand in a low carbon way covers a very central role along the pathways of the sustainable development.
A long-term energy system model is proposed to understand how a representative town sited in North Italy can achieve the 2030 and 2050 greenhouse gasses emission targets.
The developed model relies on the evaluation of the energy demand for the urban area, concerning the domestic sector, service sector, as well the supply sector, starting from the reference year, considered the 2015, up to the 2050.
The whole procedure begins from the definition of a suitable methodology for the energy demand characterization, and continues passing through the implementation of a model using the TIMES model generator platform.
The model is used to generate scenarios to explore different situations related to the greenhouse gasses emissions for the year 2050.
Two main scenarios are analysed, the first called “SCEN60” in which the target is a reduction of the 60% in the emission with respect to the 1990, the second called “SCEN80” in which this target is set to the 80%.
Since a lot of possibilities are in principle suitable for the achievement of these targets, find the optimal one, intended as economic optimal, is the main challenge related to this thesis.
Once that the optimal configuration for both scenarios is characterized, the cost for the CO2 abatement is evaluated in order to assign a monetary price to the sustainable pathway toward a less emitting energy system.
The main results of this analysis show that the CO2 emission targets can be met by the system through the massive use of high efficiency technologies, such as Heat pumps and micro CHP for the heating sector.
About the electricity production, the main results suggest that the import of electricity at high renewable share is the best option in order to satisfy the increasing demand, due to the higher level of electrification, but at the same time respect the emission targets.

SUMMARY

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1 INTRODUCTION

1.1 MAJOR EUROPEAN TRENDS IN UN URBAN AREAS

Nowadays urbanized areas hold a very high percentage of the human population, especially in Europe.
In fact, more than 75% of the population in the European Union live in an urbanized area.
This percentage, already very high, is doomed to increase during the next years and according to the projections of the (United Nation, 2014) in 2050 more than 80% of the total European population will live in urbanized areas.

Considering the environmental framework, human settlements accounts for approximately 76% of the total global energy consumption and to the 71% of the corresponding CO_2 emissions (World Energy Council, 2013).
In this context, investigating the possible evolution of consumptions patterns has become of great importance, especially for what concern environmental impact, and sustainable development.
Concerning the urban context, one of the highest impact on the CO_2 emissions is given by the heating sector.
Since this sector is one of the most important final use, especially for the North Europe states, as well the others, analysing it can be of a great interest for the decarbonisation process.
Related to the heating sector, in fact, the policy makers have to face with long term decisions, especially for what concern the infrastructures (e.g. DH).
Against this background European Nations are leading a process of sustainable development that is translated in long term energy planning.

1.2 LONG TERM CAPACITY PLANNING

In 2014 European leaders adopted the “2030 climate and Energy framework” (European Commision, 2014) in which they set targets for the year 2030, in particular:

- At least 40 % cuts in the greenhouse gas emission (from 1990 level);
- At least 27 % share for renewable energy;
- At least 27 % improvement in energy efficiency.

This framework, based on the “2020 climate and energy package” is in line with the long term prospective set out in the “Roadmap for moving to a competitive low carbon economy in 2050”.
The latter is an ongoing energy plan that sets ambitious targets for the year 2050:
European commission is looking at cost-efficient ways to make the European economy more climate friendly and less energy consuming.
The targets of the roadmap suggest a reduction at least of 80% of the greenhouse gas emission with respect to the year 1990.
These targets, already righteous, have to face the several necessities that will come up in the next years:
One of them is represented by the energy consumption growth.
According to the U.S. Energy Information Administration the energy consumption projection to 2040 points out a very sensible increase on the use of every resource with the only exception of the coal.
This trend is reported in the Figure 1

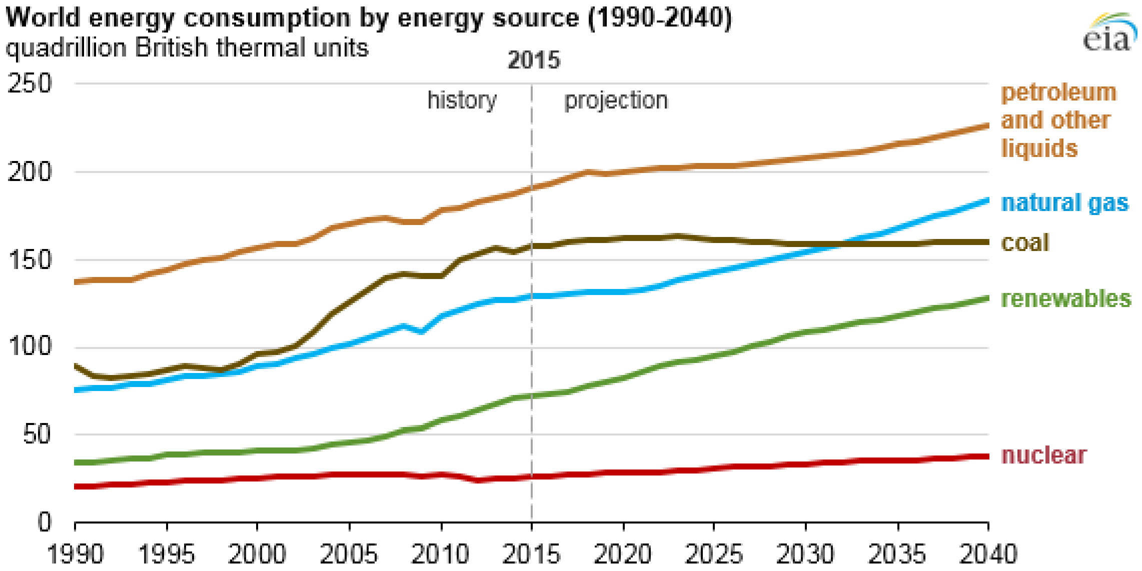

Figure 1- World Energy consumption

In this framework, in the last years, many models were developed in order to plan the energy pathway in different Regions.
One of the most widespread is the TIMES model generator.
The reason for this success is the versatility of this kind of integrated models through which is possible to define cost optimal transition to more sustainable energy consumption.

In literature there are many studies conducted on a wide range of aspects related to long term capacity planning using TIMES.
For example (Lind & Espegren, 2017) analysed the possibility of decarbonisation in the city of Oslo through an optimisation of the energy system.
(Di Leo, Pietrapertosa, Loperte, Salvia, & Cosmi, 2015) investigated the possible evolution of energy sector in the Italian region Basilicata; (Yang, Yeh, Zakerinia, Ramea, & McCollum, 2015) produced a study in which the achievement of the GHGs emission for California was the main target.
This kind of models can be applied for studying the future role of the new or existing technologies and commodities as well, for example (Forsell et al., 2013) evaluated the future use of biomass in Sweden an France by the representation of a sensible variation in the supply and cost of this source in these Nations.
A new work proposed by (McDowall, Solano Rodriguez, Usubiaga, & Acosta Fernández, 2018) analysed the role of the indirect emissions from equipment and infrastructures in the pathways to the European decarbonisation.
Another aspect related to the sustainable development was studied by (García-Gusano, Espegren, Lind, & Kirkengen, 2016) that focused their work on the role of the social discount rate.
A different point of view was adopted by (Vaillancourt, Labriet, Loulou, & Waaub, 2008) that proposed a large scale model, applied to 15 regions across the Word, analysing the opportunity given by the Nuclear as part of decarbonisation
Regarding urbanisation, (Sandvall, Ahlgren, & Ekvall, 2017) studied the possibility of construction of new low-energy buildings areas in Sweden and in particular the best option, on the environmental point of view, for the supply of heating.
Still about the urbanisation framework (Shi, Chen, & Yin, 2016) proposed a model in which the decarbonisation in the building sector in China was the main topic.
(Rosenberg, Lind, & Espegren, 2013) proposed a model for Norway with the focus on the evolution of the energy demand and the role of the production by renewable energy sources.

1.3 MOTIVATION

How it is possible to notice from the literature, urban applications are one of the most increasing in interest nowadays regarding the energy planning.
Following these studies already conducted, this work aims at developing a model representative of a small city sited in the North Italy, in order to figure out which can be the most interesting pathway in order to achieve the environmental goals set by legislation.
The approach used is similar to the one adopted by the authors above mentioned, in fact even in this case there's the use of an integrated model, that as first define the consumption of the investigated area, and then find the most convenient strategy in order to gain the requested energetic performance.

The use of a representative town can be considered an innovation, aiming at the definition of a model that, by adjusting the proper settings, can be adapted to multiple realities.
Of course this type of approach has as strong point the flexibility and scalability, but on the other side, a lot of attention have to be payed to the selection, collection and elaboration of input data.
In fact, being a representative place, no historical data can be used, so average value referred to the whole Nation have to be properly selected.

1.4 CASE STUDY

The model will be applied to a case study, as already mentioned in the previous paragraph, representative a small town of the North Italy.
In order generate a representative town, average parameters for populations and densities are used.
The population is considered to be composed by 50,000 people with a density equal to 2400 people/km^2.
These data will be used in the next sections of the work in order to properly define the energy usage.

1.5 THESIS OUTLINE

The presented thesis is developed in the next Chapters according to the following structure:

- Chapter 2 Methodology:
  In this section the methodology for estimating the energy demand is explained and validated.

- Chapter 3 TIMES model:
  In this chapter the explanation as well the implementation of the case study is presented.

- Chapter 4 Results:
  In the fourth Chapter the key results of the runs are presented.

- Chapter 5 Discussion:
  In this Chapter comments on the results as well the main implications are reported.

- Chapter 6 Conclusion:
  Once that the key results and the main implications are presented, a brief conclusion is proposed.

- APPENDIX A:
  In this first appendix some complementary information related to the methodology are located.

- APPENDIX B:
  In this second appendix some additional information about the model implementation are introduced.

2 METHODOLOGY

This Chapter is devoted to the explanation of the methodology adopted in order to build the consumption of thermal and electric energy for the case study.
First of all the time discretization adopted is presented, then the step by step construction of the two models are presented in separate sections.

In order to develop a suitable demand curve that is able to reflect the energy requirement for the analysed area, different approaches are used both for thermal and electric demands.
The flow chart in the Figure 2 shows the schematic of the proposed methodology for generating respectively the electric and thermal demand.
As it can be seen, while for the thermal demand a statistical model is build up, taking in consideration national statistical data, on the other hand, for the electric one, experimental measurements conducted by (Andrea & Danese, 2004), are used as basis in order to develop further considerations.

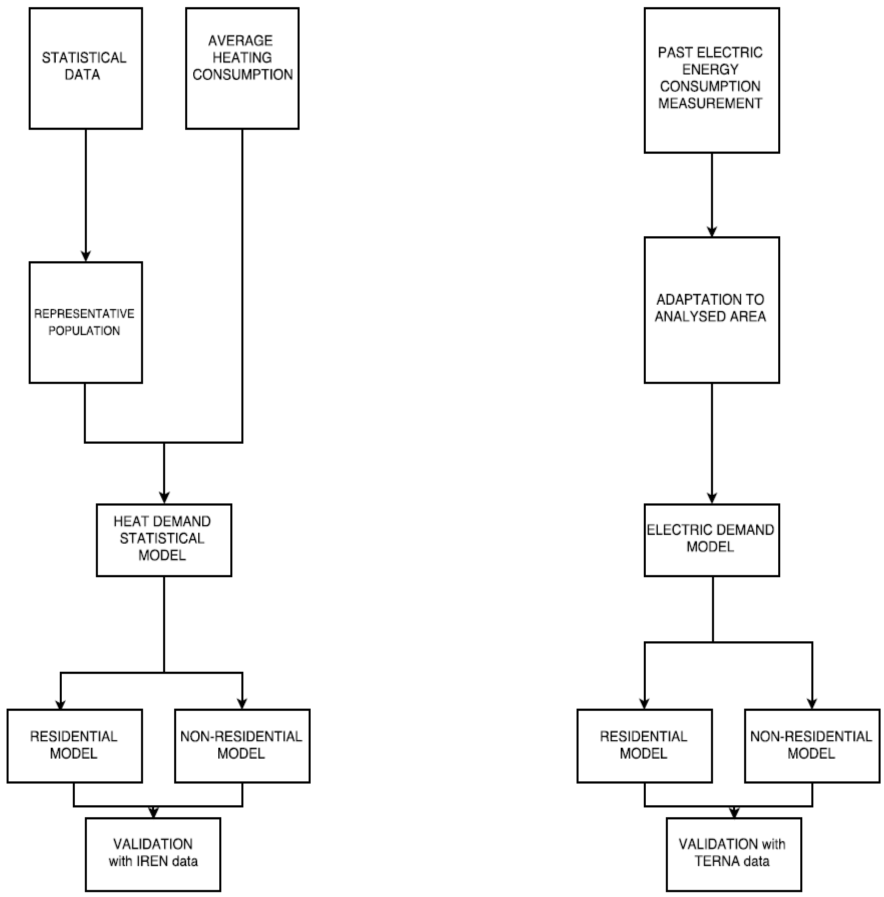

Figure 2 - Model approach for thermal energy demand (left side) and electric energy demand (right side)

2.1 TIME DISCRETIZATION

First of all a suitable time discretization is needed for the generation of the model.
Suitable time discretisation means time steps that are able to reflect the real behaviour of the demand, but at the same time are compact in order to make easier the interpretation and organisation of data.

To do this, time steps equal to 1 hour are chosen for the daytime, and one day for each season is selected as representative.
Linking together this information, 24 time steps constitute each reference day and considering 4 reference days per year, there will be 96 time steps for each year of the analysis.
The analysis cover a time span of 35 years, from 2015 to 2050.

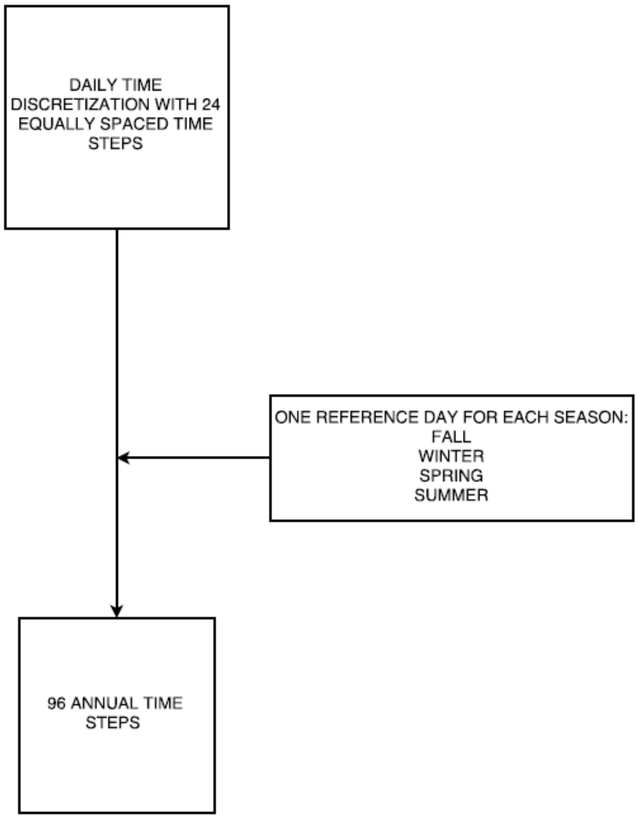

Figure 3 – Time discretization

Concerning the reference day it's useful to point out that it is not a real day, but it is obtained by average values of the consumption in the considered season.
Furthermore, no distinction between weekdays and weekend days is considered.
In fact, this approach aims to the distribution of the total demand according to seasonal curves, so not distinguish between weekdays and weekend days do not leads to the global balance.

2.2 ESTIMATION OF THE THERMAL DEMAND

This section is divided into two parts, the first related to the energy demand for space heating, the second is devoted to the request for hot water.

2.2.1 Space heating

The aim of this section is to obtain seasonal demand curves for the space heating for the analysed area.
These curves are obtained through the definition of the population and their habits, as well the climatic data.

These information linked together are summarised in three coefficients used to properly define the daily schedule of thermal consumption for the two heated seasons (fall and winter).

First of all a suitable representative population need to be defined in order to construct the fundament of the model.
The first step is to define the population living in the area and this is obtained through statistical data, taken from ISTAT database (ISTAT, 2016).
The aim of this first step is to define the composition of households, in order to model the demand along the days.
The population is divided into the following classes:

- Single inhabitant working 8 hours per day (SF);
- Single inhabitant working 4 hours per day (SP);
- Single inhabitant who doesn't work (SD);
- Family with at least one son with age lower than 3 (FMN);
- Family with at least one son with age higher than 3, both parent work 8 hours per day (FMF);
- Family with at least one son with age higher than 3, with at least one parent who doesn't work (FMD);
- Family without sons that work for 8 hours per day (NF);
- Family without sons with at least one of them that doesn't work (FD);
- Family without sons that work for 4 hours per day (FP);
- Single inhabitant retired (PS);
- Couple of retired (CP).

In order to obtain the distribution percentage of these population classes the ISTAT database is used, with the aim of sample a percentage that represent the social background in Italy.

NATIONAL ISTAT DATA (ISTAT, 2016)	
Unemployment percentage	0.11
Part-time percentage	0.2
Inhabitant (millions)	59.38
Families (millions)	24.61
Families without sons (millions)	6.66
Families with sons (millions)	10.27
Single person families (millions)	7.66
m^2/person	40.7
births per year	534,000
Retired percentage	0.27

Table 1 – National Data about Population

Starting from the data in the **Errore. L'origine riferimento non è stata trovata.** it is possible to obtain ome other useful information.
In fact, with the previous statistical data the total population is defined, so with appropriate ratio it is possible to obtain the result that are shown in Table 2, regarding the percentage of the singles and the type of families with sons.

Single percentage	0.13
families without sons percentage	0.11
families with at least one son percentage	0.49
families with at least one baby percentage (age < 3 years)	0.09

Table 2 – Families type (%)

In order to obtain the last class shown in Table 2 it is necessary to consider the total number of "sons", where "sons" means an inhabitant that still lives in family, and the number of babies through the data about birds per year.
This consideration is shown in Table 3.

Families type	Units	Number of people	Number of sons
Single	7,667,305	7,667,305	0
Family without sons	6,665,800	13,331,600	0
Family with 1 son	4,892,316	14,676,948	4,892,316
Family with 2 sons	3,977,401	15,909,604	7,954,802
Family with 3 sons	1,060,350	5,301,750	3,181,050
Family with at least 4 sons	348,594	2,493,492	2,091,564

Table 3 – Sons per family

Having the births per years it is possible to obtain the number of babies in the reference year, and then the percentage of "sons" who are babies.
Furthermore Table 3 is useful also for another purpose:
While it is easier to find the number of sons per woman in the already available data, for this model it's necessary to account them only for the families which actually have at least one.
So dividing the number of sons by the number of families which have at least one, it's possible to obtain the average number of sons per family, that's equal to 1.76, higher, as expected, of the average number of sons per woman, that's equal to 1.34 (ISTAT, 2016).

Now that all the family classes are properly defined, it is possible to define the occupation hours.
These represent the hours along the day in which the members of the selected family type are at home.
Table 4 presents these occupation hours that are defined according to the data already introduced about the working life for the selected family type.

Type	Inhabitants	Hours not at home		Percentage
SF	1	08:00	17:00	0.07
SP	1	08:00	13:00	0.02

SD	1	N	N	0.01
FMN	3.76	N	N	0.03
FMF	3.76	08:00	13:00	0.29
FMD	3.76	N	N	0.04
NF	2	08:00	17:00	0.06
FD	2	N	N	0.01
FP	2	08:00	13:00	0.02
PS	1	N	N	0.13
CP	2	N	N	0.33

Table 4 – Occupancy hours at home

Once collected all the needed data about the population of the considered region, it's possible to start elaborating climatic data of the reference days.
In order to proceed, the external temperature is considered the same as in Turin, exploiting data from ARPA PIEMONTE archive (ARPA PIEMONTE, 2010).
In this archive is possible to find the experimental measures of the external temperature along the year with a time resolution of one hour for the year 2010.
After that, these data are organised for obtaining the external average temperature during the four seasons.
Outside temperatures used for the calculations, and the differences from the internal set point are shown in the Appendix A, Table 46.
These data are obtained through a systematic average along the different hours for every day belonging to the considered season, i.e., the average external temperature at 00:00 for the fall reference day it's obtained by the average of the external temperature at the 00:00 for all the days of October and November, so using the formulation of Equation 1:

$$T_{reference,given\ hour} = \frac{\sum_{i=1}^{n} T_{external,given\ hour}}{\#\ Days\ of\ the\ season} \qquad (1)$$

In which:
i = i-th day of the month;
n= number of days in the season.

Since in the modelled area there are not only households but also non residential (commercial and public) buildings, a "Black Box" approach is used in order to model the region.
While the domestic demand is generated considering several significant aspects that can be addressed to the behaviour of the population, everything that is not domestic is accounted into a single demand that is obtained by a comparison between calculated data only for the domestic and real data provided by the local DH utility (IREN).

Starting with the domestic sector, a suitable number of coefficients are needed, in order to model the thermal requirement for the investigated sector.
In fact, since the model aims to the generation of seasonal curves, a certain number of coefficient must be introduced in order to give the right shape to these curves.
These coefficients are mainly three, each one of them linked to a key driver for the thermal consumption.
The first, named α takes into account the occupancy hours at home.
The second, β, considers the regulation of the space heating according to the different hours of the day.
The third, σ, is evaluated considering the temperature difference between the ambient air and the reference set point.

The first aspect considered is how much people are at home each hour of the day:
Table 5 shows this consideration.

Hour	SF	SP	SD	FMN	FMF	FMD	NF	FD	FP	PS	CP	TOT
0	1	1	1	3.76	3.76	3.76	2	2	2	1	2	23.28
1	1	1	1	3.76	3.76	3.76	2	2	2	1	2	23.28
2	1	1	1	3.76	3.76	3.76	2	2	2	1	2	23.28
3	1	1	1	3.76	3.76	3.76	2	2	2	1	2	23.28
4	1	1	1	3.76	3.76	3.76	2	2	2	1	2	23.28
5	1	1	1	3.76	3.76	3.76	2	2	2	1	2	23.28
6	1	1	1	3.76	3.76	3.76	2	2	2	1	2	23.28
7	1	1	1	3.76	3.76	3.76	2	2	2	1	2	23.28
8	0	0	1	2.76	0	1	0	1	0	1	2	8.76
9	0	0	1	2.76	0	1	0	1	0	1	2	8.76
10	0	0	1	2.76	0	1	0	1	0	1	2	8.76
11	0	0	1	2.76	0	1	0	1	0	1	2	8.76
12	0	0	1	2.76	0	1	0	1	0	1	2	8.76
13	0	1	1	2.76	1.76	2.76	0	1	2	1	2	15.28
14	0	1	1	2.76	1.76	2.76	0	1	2	1	2	15.28
15	0	1	1	2.76	1.76	2.76	0	1	2	1	2	15.28
16	0	1	1	2.76	1.76	2.76	0	1	2	1	2	15.28
17	1	1	1	2.76	1.76	2.76	0	1	2	1	2	16.28
18	1	1	1	3.76	3.76	3.76	2	2	2	1	2	23.28
19	1	1	1	3.76	3.76	3.76	2	2	2	1	2	23.28
20	1	1	1	3.76	3.76	3.76	2	2	2	1	2	23.28
21	1	1	1	3.76	3.76	3.76	2	2	2	1	2	23.28
22	1	1	1	3.76	3.76	3.76	2	2	2	1	2	23.28
23	1	1	1	3.76	3.76	3.76	2	2	2	1	2	23.28

Table 5 – Hours at home per class of family

For every hour of the day, the number of people for each class of families is considered, if they are at home or if they are not, according to the estimated data about the working life.
For example, from 01:00 to 02:00 everybody is considered to stay at home, instead from 11:00 to 12:00 most of the people are working.
So the "TOT" column in Table 5 is obtained summing each row, and it shows the minimum value for the hours in which most of the people are at work, from the 08:00 to the 13:00.
Exploiting this analysis is possible to determine the first coefficient, α, that is obtained by the ratio between the TOT value at a given hour and the maximum daily value for a class, according to the formulation expressed in the Equation 2:

$$\alpha_i = \frac{\sum Classes_i}{\sum Classes_{i_{MAX}}} \qquad (2)$$

Where
α_i= α coefficient for the i-th time step;
$\sum Classes_i$= summation of the number of people at home for the i-th time step for each class;
$\sum Classes_{i_{MAX}}$= Maximum value of the summation of number of people at home for the i-th time step for each class during the reference day.
Values of α along the day are shown in the Appendix A, Table 47.

It's well known that during the heated seasons there is a maximum number of hours in which heating systems can be switched on.
This number of hours is selected according to the climatic class of the city, according the DPR 412/93.

This subdivision in climatic classes is based on the parameter named Heating Degree Days (HDD), that takes into account the difference between the external temperature and the comfort set point, set at 20 °C.
For a generic city belonging to the E class, such as Turin, this number it's equal to 14.
In order to take into account this regulation a second coefficient, β, is defined.
It's useful to point out that, while the first coefficient, α, is not affected by the season, the second instead it is, indeed since the outside temperature changes considerably according to the season, as well the regulation changes accordingly.
This coefficient is modelled in order to represent in which hours of the day the heating system are normally switched on (hours with values higher than 0.4), and hours in which they are normally switched off (hours with values lower than 0.4). In Table 48, Appendix A the β coefficient is presented both for winter and fall.
Strictly speaking, this coefficient has to be 0 during the hour outside the normal operation, but looking at the measured consumption along the days, it is not 0 in these moments, so lower value are used instead of 0 (0.4), that will give 0 demand instead of the real one.
Furthermore, since heat storage is not explicitly implemented within the model, even the percentage normally accounted for the storage is considered as consumption in that moment.

As already said, one of the elements to take into account is the external temperature.
Considering hour by hour the difference between the external temperature and the internal set point, fixed to the comfort temperature equal to 20 °C, it is possible to obtain the third coefficient, named σ.
This coefficient gives a contribution related to the temperature difference between the ambient air and the internal set point to the global coefficient, that is used to shape the demand curves.
In Table 49, Appendix A the σ coefficients both for fall and winter are reported.
This coefficient is obtained through the formulation in Equation 3:

$$\sigma_i = \frac{(T_{ext,i} - T_{s.p.})}{(T_{ext,i} - T_{s.p.})_{MAX}} \qquad (3)$$

In which:
σ_i= σ coefficient in the i-th time step;
$T_{ext,i}$= external temperature at the i-th time step [°C];
$T_{s.p.}$= 20 [°C];
$(T_{ext,i} - T_{s.p.})_{MAX}$= maximum difference during the reference day.

Since all the needed coefficients are defined it is possible to determine the Global coefficient, that contains all the previous ones.
This coefficient is calculated through the product of the previous coefficients for each time step.
Results of global coefficient both for winter and fall are shown in Table 6.

Hour	Global Coef. (Winter)	Global Coef. (Fall)
0	0.20	0.14
1	0.20	0.14
2	0.20	0.15
3	0.20	0.15
4	0.20	0.20
5	0.40	0.40
6	1.00	0.80
7	0.99	0.77
8	0.36	0.32
9	0.32	0.28
10	0.32	0.25
11	0.31	0.22
12	0.29	0.20
13	0.39	0.26
14	0.40	0.26

15	0.52	0.36
16	0.55	0.43
17	0.49	0.42
18	0.71	0.49
19	0.73	0.52
20	0.64	0.49
21	0.65	0.45
22	0.28	0.23
23	0.19	0.14

Table 6 – Global Coefficient

The comparison between winter and fall global coefficient is presented in the Figure 4.
As expected, the hourly global coefficients for the winter are always higher to the ones for the fall.
This reflects the higher thermal consumption in the winter season with the respect to the fall.

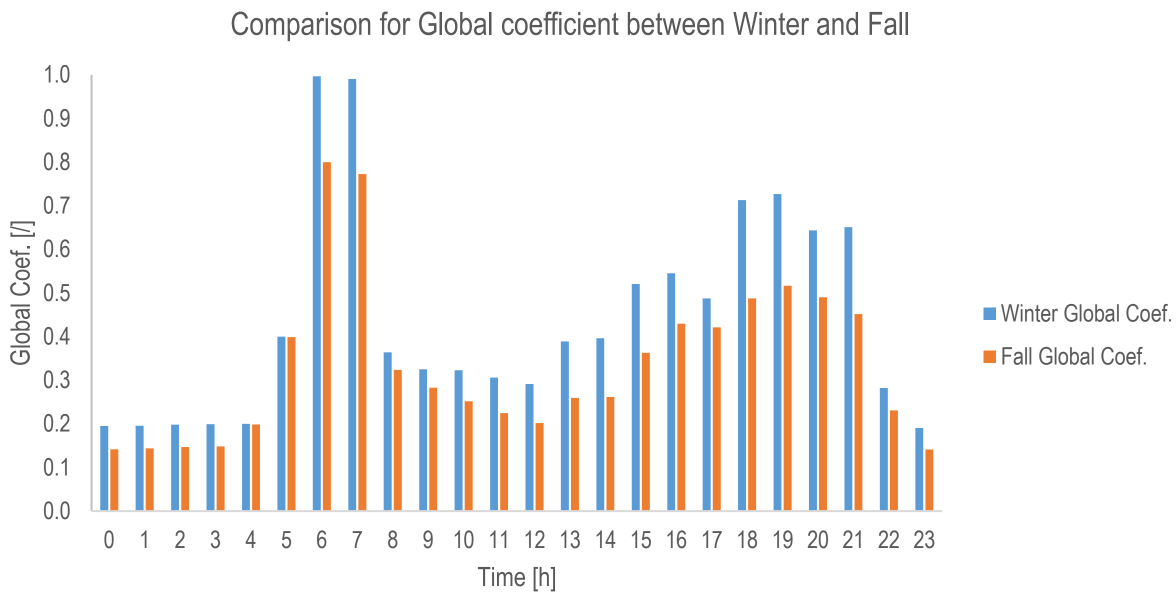

Figure 4 – Winter and Fall Global coeffients

Since all the coefficients needed for the calculation are obtained, it is possible to determine the demand curve for domestic space heating.
This calculation is conducted for each time step of each reference day belonging to heating seasons, i.e., fall and winter.
The starting point is the data about the annual consumption for domestic heating, considered equal to 170 kWh/m^2 (Fedrizzi & Dipasquale, 2015);
after this, it is requested to determine how much of it is used in autumn days, and how much of it is used in winter days.
To approximate this number, the heating degree days (HDD) are considered.
They are calculated considering the external temperature, as the summation of the difference between the internal set point and the external temperature along the reference day:

$$\text{HDDref} = \sum_{i=1}^{24}(T_{s.p} - T_{ext}) \qquad (4)$$

HDD_{fall} = 246 [°C];

HDD_{winter}=446 [°C].

Thanks to these results the proportion of heating uses in the two seasons is built:

$E_{DH,Fall}$=60.4 $\frac{kWh}{m^2}$
$E_{DH,Winter}$=109.6 $\frac{kWh}{m^2}$;

At this point it is possible to proceed to the calculation regarding the domestic heating along the reference days.
Results are shown in the Table 7.

Hour	$P_{DH,Fall}$ [MW]	$P_{DH,Winter}$ [MW]
0	33.15	46.42
1	33.65	46.54
2	34.29	47.19
3	34.63	47.37
4	46.39	47.58
5	93.30	95.12
6	187.05	237.22
7	180.67	235.71
8	75.69	86.65
9	66.13	77.32
10	58.86	76.79
11	52.51	72.82
12	47.20	69.34
13	60.70	92.55
14	61.19	94.32
15	84.89	123.91
16	100.48	129.76
17	98.52	116.05
18	114.01	169.66
19	120.80	172.90
20	114.61	153.16
21	105.59	154.86
22	53.95	67.17
23	33.07	45.33
TOTAL [MWh/d]	1891.35	2505.75

Table 7 – Domestic Heating calculation

Now, that the domestic demand is generated, it is necessary to estimate the space heating demand of not private houses in the region.
As already said, a black box approach is used.
This choice is given by the fact that commercial sector more than the public one, is very diversified, so, especially for a fictitious region, can be very hard to handle all the different activities that can be present.
Furthermore, in the commercial sector, the consumption of the various type of activities can vary a lot between them, so a simple approach is used.
In this kind of approach again a reference data is used, the annual consumption of energy needed for offices heating (Fedrizzi & Dipasquale, 2015).
This consumption, equal to 160 kWh/m^2/y is the starting point for the following considerations.
First of all it's necessary to define in which hours of the day this consumption is located.
To do this, as first guess, the hours between the 08:00 and the 18:00 are selected, because it is the time frame during the day in which the activities and offices are normally operating.
In order to give a shape to this second part of the demand, the percentage of worker is considered.
In fact, the consumption of heating for the non-residential sector is related to the working hours that's the key driver.
In Table 50, Appendix A, the hourly coefficient related to the working hours during the day is presented.
This coefficient is calculated considering the percentage of working population for each time step.
Since the hourly subdivision is defined, the last free parameter is the number of square meters of non-domestic buildings that are present in the region, that are needed in order to pass from a specific consumption (kWh/m^2) to the effective one (kWh).
Despite the region is not real, so a representative value can be suitable, further considerations are conducted in order to obtain the most appropriate curve.
These considerations are developed in the following paragraph of validation.

2.2.1.1 Validation

In order to validate what done so far, a comparison between calculated value and IREN data is performed.
As reference supply curve, profile data from the IREN company for January is selected for winter, instead a curve for October is chosen as reference for the fall.
These two curves are selected in order to represent the two different consumption for winter and fall:
In fact, given the difference in the external temperature between these two seasons, the months of October and January are selected as representative.
Values, with a time resolution of one hour, are calculated as percentage and a comparison between the calculated and measured curves is performed.

Measured data by IREN are presented in the Figure 5 and Figure 6.
These curves are obtained by the hourly average consumption in the selected month.

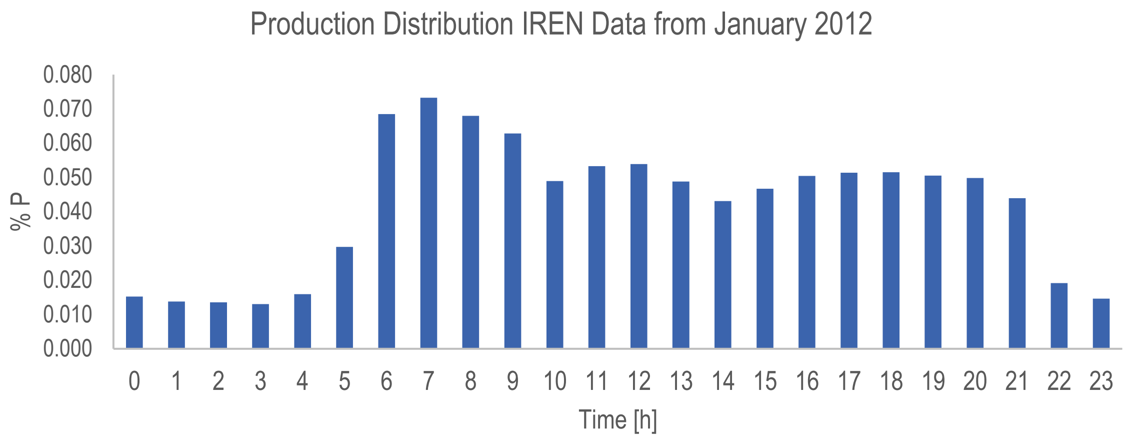

Figure 5 – Average Production distribution from IREN company January 2012

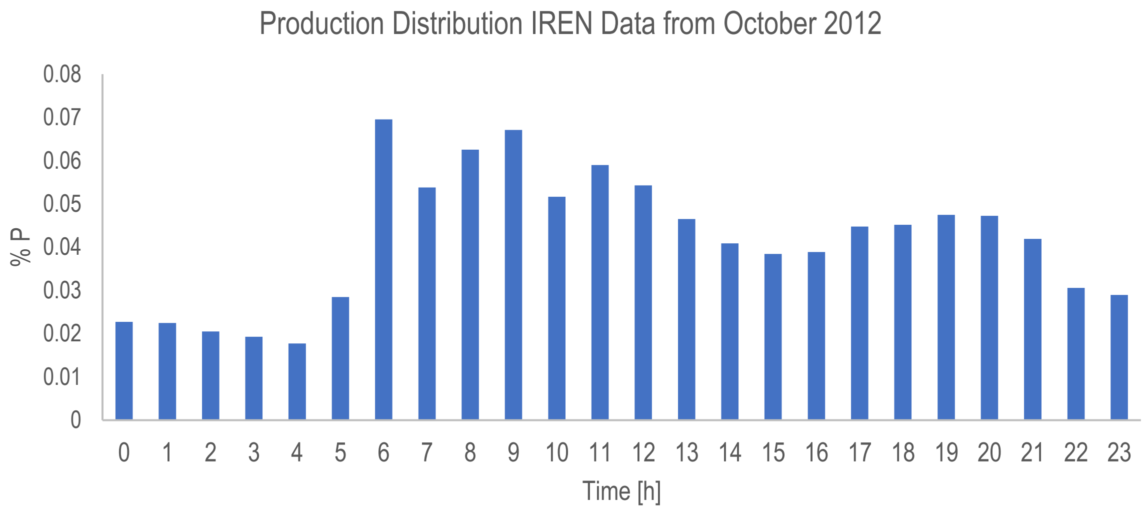

Figure 6 – Average Production distribution from IREN company October 2012

About the calculated curve, the summation between residential and non-residential is performed, obtaining the total demand.
Total demand both for fall and winter is presented in Table 8.

Hour	P Winter [MW]	%P	P Fall [MW]	% P
0	46	0.01	33	0.01
1	47	0.01	34	0.01
2	47	0.02	34	0.01
3	47	0.02	35	0.01
4	48	0.02	46	0.02
5	95	0.03	93	0.04
6	237	0.08	187	0.08
7	236	0.08	181	0.08
8	175	0.06	142	0.06
9	166	0.05	133	0.06
10	165	0.05	126	0.05

11	161	0.05	119	0.05
12	158	0.05	114	0.05
13	130	0.04	89	0.04
14	132	0.04	90	0.04
15	162	0.05	113	0.05
16	167	0.05	129	0.05
17	154	0.05	127	0.05
18	170	0.05	114	0.05
19	173	0.06	121	0.05
20	153	0.05	115	0.05
21	155	0.05	106	0.04
22	67	0.02	54	0.02
23	45	0.01	33	0.01
TOT [MWh/d]	3136		2367	

Table 8 – Total demand Winter and Fall

In order to validate the proposed model, a deviation analysis is performed.
For each time step, the percentage of energy predicted by the model is compared to the one that is reported in the IREN datasheet.
This analysis aims to identify the distribution of the demand, if it is located where it is supposed to be and to refine some aspects of the model:
Indeed, in the previous paragraph, the square meters for non-residential buildings was still a free parameter.
Now, through iterative calculation of the deviations, it is possible to fix this free parameter.
By some iterations, starting from a guess value of 30 m^2/person, the analysis shows that the most indicated value is 18 m^2/person.
These results of the deviation analysis are collected in the Appendix A, Table 51, and Table 52.

Deviations for the hourly consumption distribution are calculated both in absolute and relative values according to equation 5 and 6, where P_i identify the hourly consumption percentage.

$$\delta_{abs} = \%P_{i,cal} - \%P_{i,measured} \qquad (5)$$

$$\delta_{rel} = \frac{(\%P_{i,cal} - \%P_{i,measured})}{\%P_{i,cal}} \qquad (6)$$

.

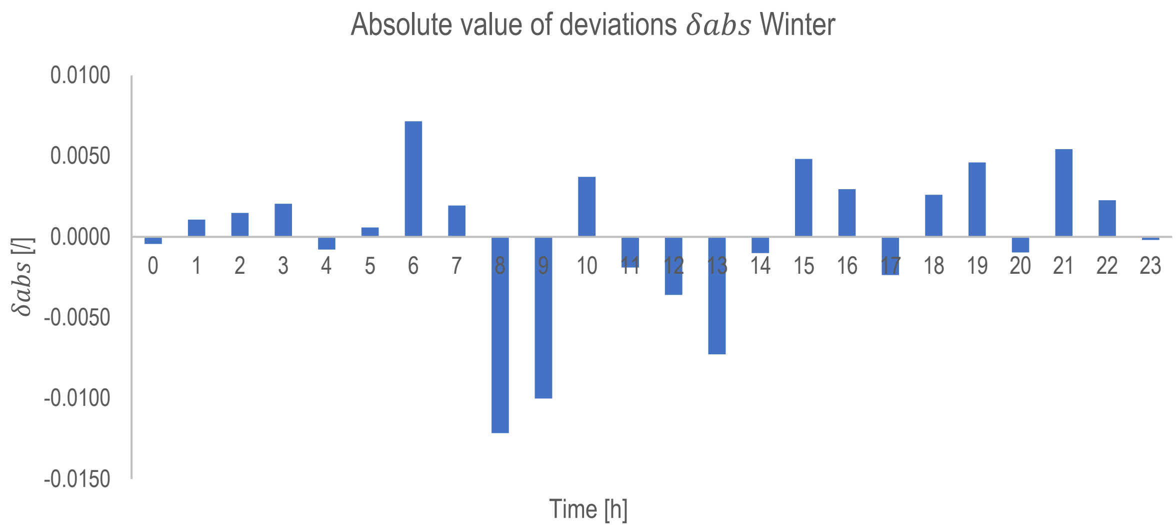

Figure 7 – Deviations for Winter absolute values

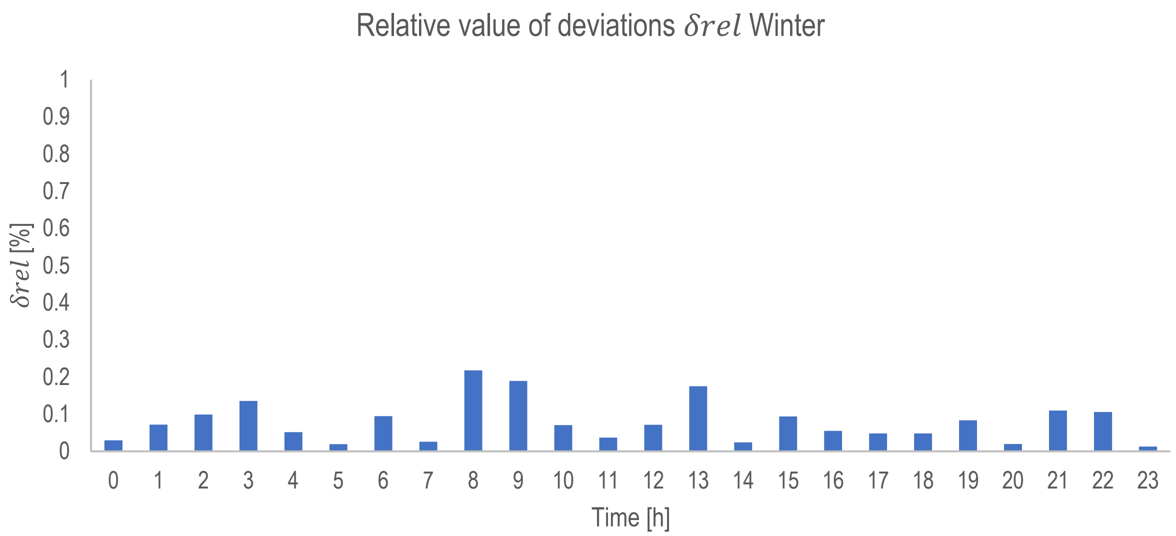

Figure 8 – Deviations for Winter relative values

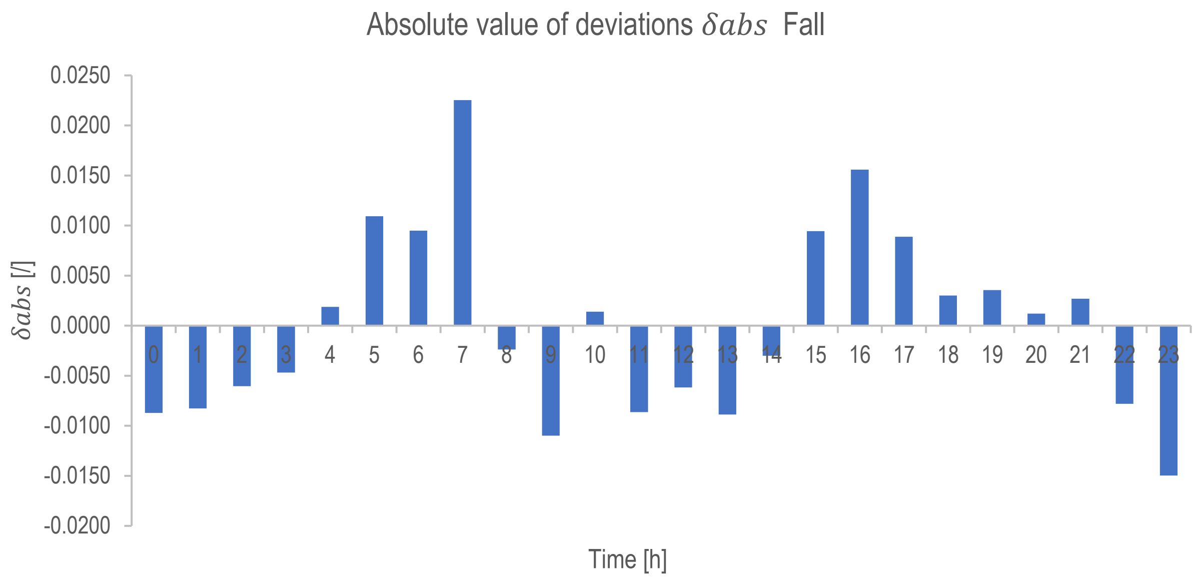

Figure 9 – Deviations for Fall absolute values

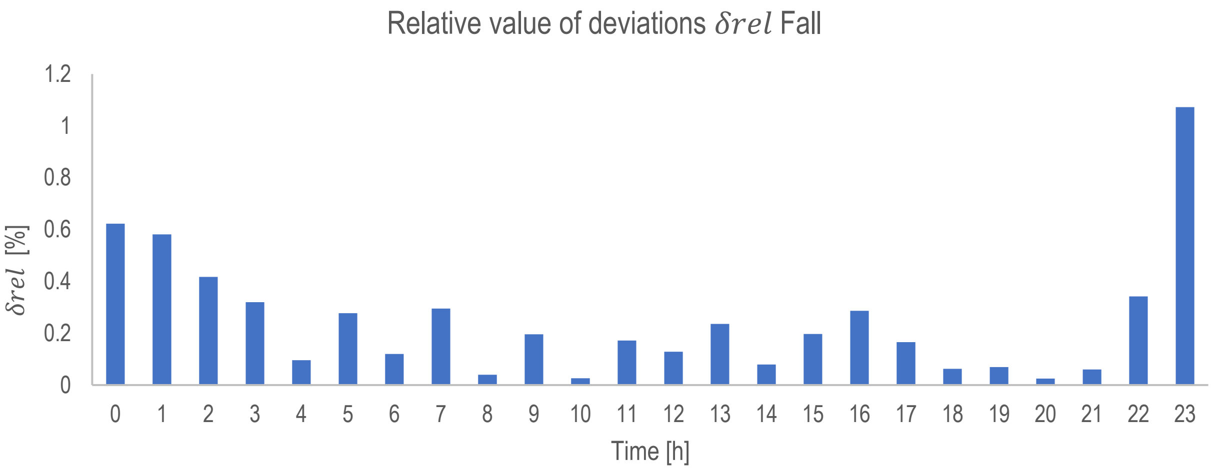

Figure 10 – Deviations for Fall relative values

In order to make this validation more clear, a comparison between the total demand curve and the measured one is presented, both for winter and fall, in the Figure 11 and in Figure 12.
Looking at the Figure 11 and Figure 12 is possible to notice the strong points as well the weak points of the proposed consumption model.
About the winter behaviour, it is possible to see that the global trend of the measured curve is strongly traced by the constructed curve:
Indeed, what comes out from the deviation analysis is a good approximation of the real demand, except for few points during the day.
These points are located during the first half of the day, roughly until the 13:00.
This can be interpreted through α_i.
Indeed, it considers who is actually at home during the time step considered, and this implies that the regulation of the domestic heating must be precise.
Since α_i does not take into account who is not at home but does not switch off the heating system, this can be a factor that leads to the underestimation.

For what concern the fall demand, also in this case the general trend is respected;
In this case the deviation analysis shows slightly higher differences between the measured demand and the calculated one.
Also in this case some differences between the 04:00 and the 21:00 can be imputable to the α_i coefficients, but in this second comparison some differences in the night and the in the early morning are present, that can't be explained by the parameters taken into account for the model.
These differences can be a starting point in order to develop future works that aim to the improvement of the proposed model.

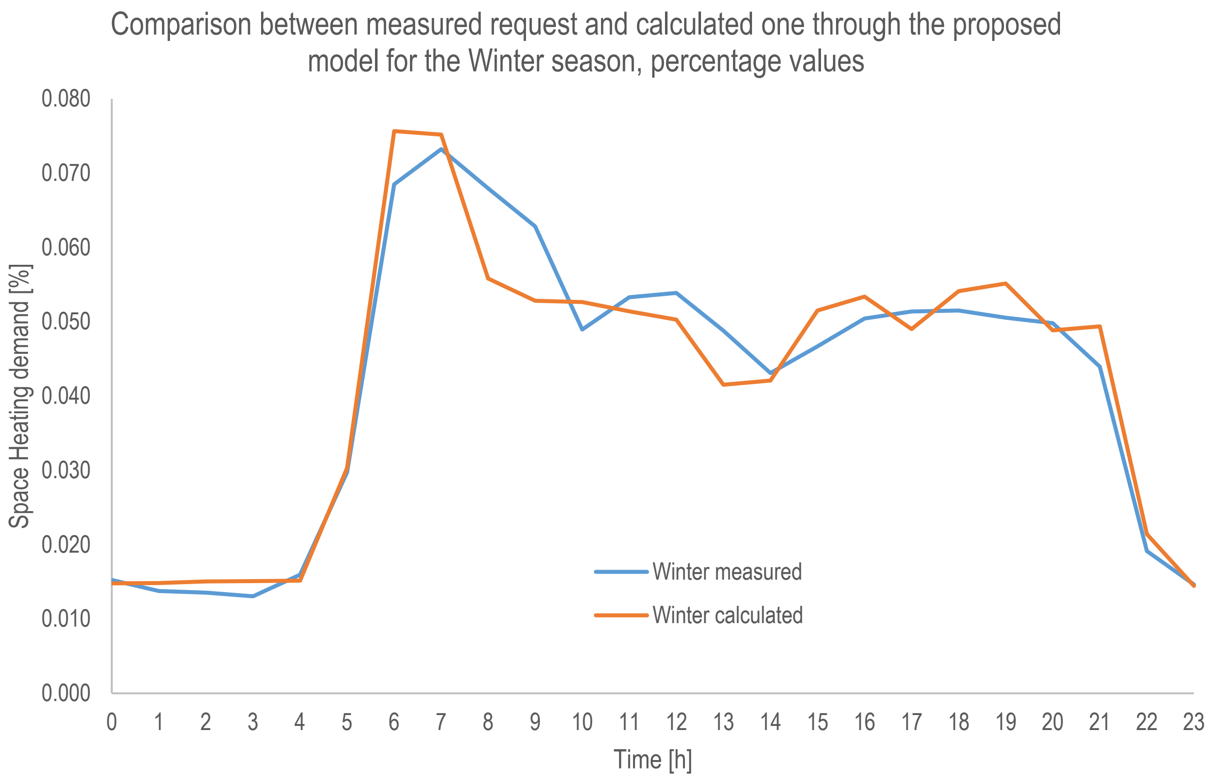

Figure 11 – Model Comparison Winter

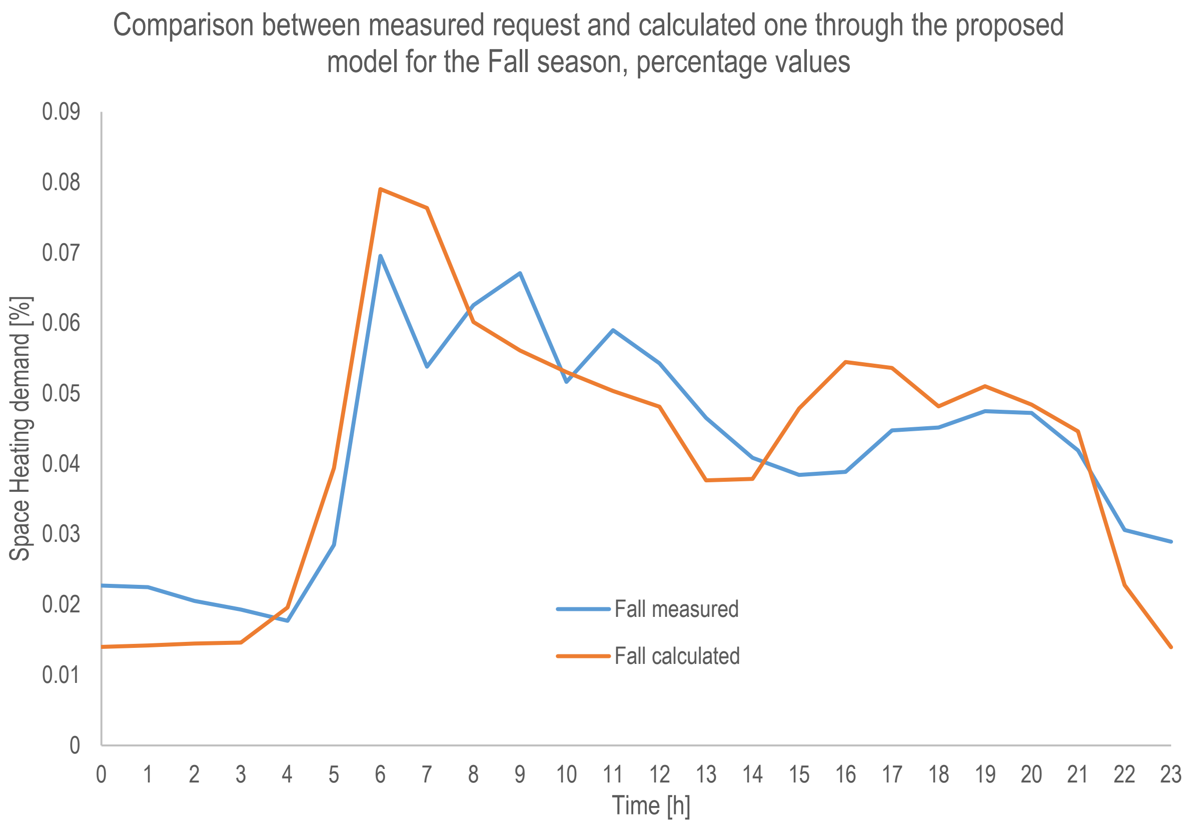

Figure 12 – Model Comparison Fall

2.2.2 Domestic Hot Water

Once the demand for space heating has been characterised, it's necessary to move to the one related to domestic hot water.
In order to model the curve for the reference days of the year a simple approach is used.
This calculation is performed using the equation 7:

$$E_{DHW} = C_p * V * \rho * \Delta T \qquad (7)$$

In which:

E_{DHW}= Daily energy consumption $[\frac{J}{P*d}]$;
C_p= Thermal Capacity of the water=4186 $[\frac{J}{kg*K}]$;
V= Volume of domestic hot water used from a single person= 50 $\frac{l}{P*d}$;
ρ= Water density = 1000 $\frac{kg}{m^3}$;
ΔT= T_{set_point} - T_{ground_water} [°C];
T_{set_point}= Fixed temperature for the domestic usage = 48 °C
T_{ground_water}=Temperature of the ground water, according to the season [°C].

Values for the ground water temperature are taken from (Fischer, Wolf, Scherer, & Wille-Haussmann, 2016) , and are reported in the Table 9.

Season	T_{ground_water} [°C]
Summer	12
Fall	12
Winter	8
Spring	8

Table 9 – Ground Water temperature

In order to shape the demand curve, as for the thermal one, a consumption coefficient is introduced.
It is calculated as already shown for the thermal demand in the paragraph devoted to the thermal demand.
At this stage, since the consumption coefficient as well all the elements of the equation 7 are provided, it is possible to calculate the consumption for the domestic hot water.
Results according to the different reference days are reported in Table 10.

Hour	P_{DHW} Fall [MW]	P_{DHW} Winter [MW]	P_{DHW} Summer [MW]	P_{DHW} Spring [MW]
0	1.70	1.89	1.70	1.89
1	1.70	1.89	1.70	1.89
2	1.72	1.92	1.72	1.92
3	1.73	1.92	1.73	1.92
4	1.74	1.93	1.74	1.93
5	1.74	1.93	1.74	1.93
6	11.56	12.85	11.56	12.85
7	11.49	12.76	11.49	12.76
8	4.22	4.69	4.22	4.69
9	3.77	4.19	3.77	4.19
10	3.74	4.16	3.74	4.16
11	3.55	3.94	3.55	3.94
12	3.38	3.75	3.38	3.75
13	5.64	6.26	5.64	6.26
14	5.75	6.38	5.75	6.38
15	6.04	6.71	6.04	6.71
16	6.32	7.03	6.32	7.03
17	5.66	6.28	5.66	6.28
18	8.27	9.19	8.27	9.19
19	8.43	9.36	8.43	9.36
20	1.60	1.78	1.60	1.78
21	1.62	1.80	1.62	1.80
22	1.64	1.82	1.64	1.82
23	1.66	1.84	1.66	1.84
TOT [MWh/d]	104.65	116.28	104.65	116.28

Table 10 – DHW demand according to different seasons

2.2.3 Total Thermal Energy Demand

What argued until now it's the methodology used in order to build up the thermal demand both for space heating and domestic hot water.

The first one calculated both for residential and non-residential, the second only for the residential sector. Table 11 shows the numerical results.

Thermal Energy Demand [GWh]	Fall	Winter	Spring	Summer
Residential heating	123	223	N/A	N/A
Non-residential heating	31	56	N/A	N/A
Domestic hot water	9	10	10	9
Total	163	289	10	9

Table 11 – Thermal Balance

As expected the highest demand is located in the winter days, instead dramatically lower demands are present for spring and summer which aren't heated seasons.
These results can be rearranged whit a different prospective in order to take additional information about the specific demands.
In fact, looking at the specific values is useful in order to check if they are close, or not, with the typical values.
Specific consumptions are collected in the Table 12.

	Fall	Winter	Spring	Summer
Residential heating [kWh/m^2]	60	110	N/A	N/A
Non-residential heating [kWh/m^2]	56	103	N/A	N/A
Domestic hot water [kWh/person/day]	2.1	2.3	2.3	2.1

Table 12 – Specific Consumption

Considering the table 12, since the specific heating was the starting point of the model, it is respected also in the final results, in which the residential heating accounts 170 kWh/m^2, instead the non-residential 160 kWh/m^2.
Concerning the domestic hot water, a specific consumption of 2.1 kWh/p/day in fall and summer and 2.3 kWh/p/day for winter and spring is obtained.
In order to evaluate the quality of these results, (Fuentes, Arce, & Salom, 2018) is taken as reference.
In this work the specific energy consumptions for domestic hot water for some European states is presented.
Since in this list there is not the Italy, the State with the closest consumption considered in this thesis is selected.
The state selected is the Switzerland with a consumption of 55 l/p/day and an average consumption of 2.8 kWh/p/day.
In general, among the mainly European Nation presented in the cited work, the specific consumption vary in the range between 1.56 - 3.34 kWh/p/day, so the values obtained are validated.

2.3 ELECTRIC ENERGY CONSUMPTION

In order to determine the electric energy consumption a different approach with respect to the thermal one is used.
While, for the latter a statistical approach was adopted, as shown in the previous paragraphs, for the electric energy a previous study, conducted by (Andrea & Danese, 2004) is used as basis.
The only feature that this two type of approaches share is the subdivision in residential and non-residential.

Since a suitable model for the electric energy consumption for the residential sector is needed, the study conducted by (Andrea & Danese, 2004) is used as starting point.
This study shows, according to the different seasons, the energy consumption determined by the common devices present in the habitations.
The devices considered are:

- Fridge/Freezer;
- Lightning;
- Washing machine;
- Dishwasher;
- Personal Computers;
- Audio-visual devices (TV, stereo, etc).

Since the data provided by the campaign are presented in energy consumption over habitations, it is necessary to determine the number of houses in the region, given the number of inhabitants.
This is done through statistical data, considering again the percentage for each class of inhabitants, thus calculating the number of houses.
The results are collected in the Appendix A, Table 53.
At this point, having the average consumption per house, and the number of houses in the region it is possible to calculate the total annual consumption for the residential sector.
Results are presented in the Table 13.

	Average annual consumption		Daily average consumption
	[kWh/y/house]	[GWh/y]	[MWh/d]
Fridge/Freezer	637	16	45
Lightning	375	10	26
Washing machine	224	6	16
Dish Washer	184,5	5	13
Audio-visual device	355	9	25
Persona Computer	132	3	9

Table 13 – Electric Energy consumption for domestic devices

Since the time discretization must be consistent to the one used for the thermal case, it is necessary to rearrange the data in order to obtain a daily profile with time steps of 1 hour.
To do this, data from the campaign are organized in a suitable form, in order to carry out the request curves to be used in the model.
In order to give the requested shape to the daily curves the graphs proposed in the study are taken as model; for each time step the percentage of the total energy is used as reference in order to build up the curves.
Results according to the difference facilities can be found as follows.
It's important to point out, that, while, for the lightning the season is actually a parameter that strongly affect the consumption, instead for the other devices it is not, so the others are considered constant during the year.

Fridge/Freezer

Hour	Usage percentage	Hour	Usage percentage
0	0.042	12	0.042
1	0.042	13	0.042
2	0.042	14	0.042
3	0.042	15	0.042

4	0.042	16	0.042
5	0.042	17	0.042
6	0.042	18	0.042
7	0.042	19	0.042
8	0.042	20	0.042
9	0.042	21	0.042
10	0.042	22	0.042
11	0.042	23	0.042

Table 14 – Fridge Freezer usage percentage

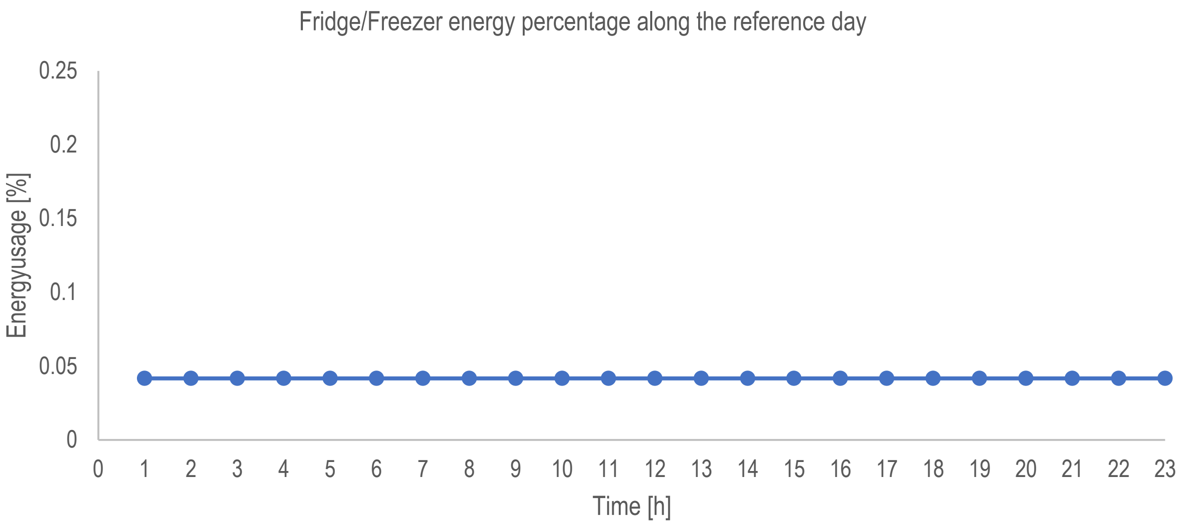

Figure 13 – Fridge Freezer energy consumption

Lightning

Hour	Winter Usage percentage	Fall and Spring Usage percentage	Summer Usage percentage
0	0.03	0.07	0.08
1	0.03	0.05	0.06
2	0.02	0.04	0.04
3	0.01	0.03	0.03
4	0.01	0.01	0.02
5	0.01	0.01	0.01
6	0.01	0.01	0.02
7	0.03	0.02	0.02
8	0.02	0.03	0.02
9	0.04	0.03	0.02
10	0.03	0.03	0.02
11	0.03	0.04	0.03
12	0.03	0.03	0.04
13	0.04	0.03	0.04
14	0.04	0.04	0.02
15	0.04	0.03	0.02

16	0.04	0.03	0.03
17	0.06	0.03	0.03
18	0.09	0.04	0.04
19	0.08	0.06	0.05
20	0.09	0.07	0.06
21	0.09	0.09	0.09
22	0.08	0.09	0.10
23	0.05	0.07	0.09

Table 15 – Lightning usage percentage

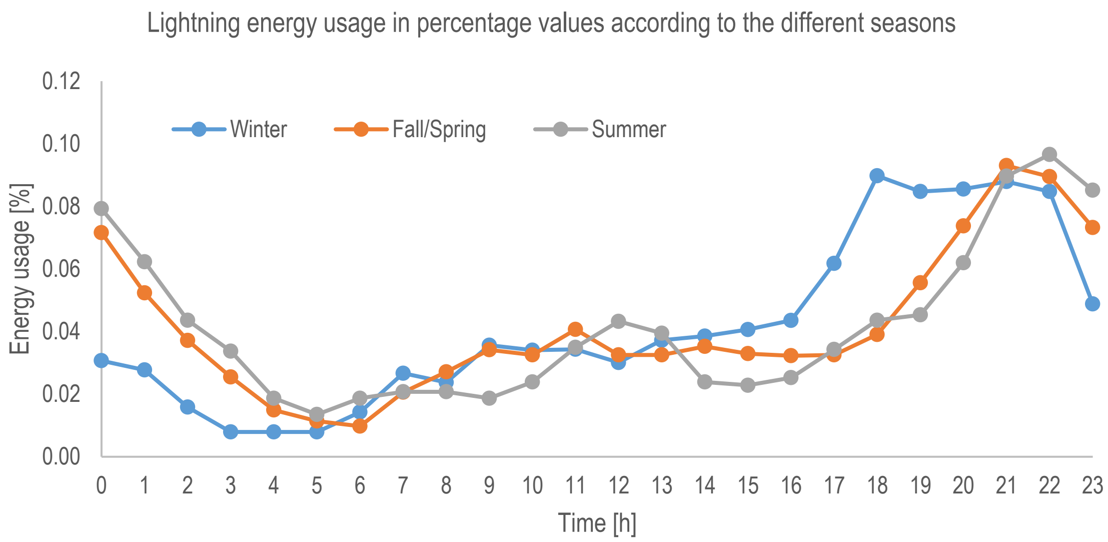

Figure 14 – Energy consumption for Lightning according to the seasons

Washing machine

Hour	Usage percentage	Hour	Usage percentage
0	0.003	12	0.088
1	0.003	13	0.066
2	0.000	14	0.049
3	0.000	15	0.063
4	0.000	16	0.050
5	0.004	17	0.042
6	0.007	18	0.053
7	0.031	19	0.049
8	0.075	20	0.038
9	0.111	21	0.028
10	0.103	22	0.025
11	0.098	23	0.014

Table 16 – Washing machine usage percentage

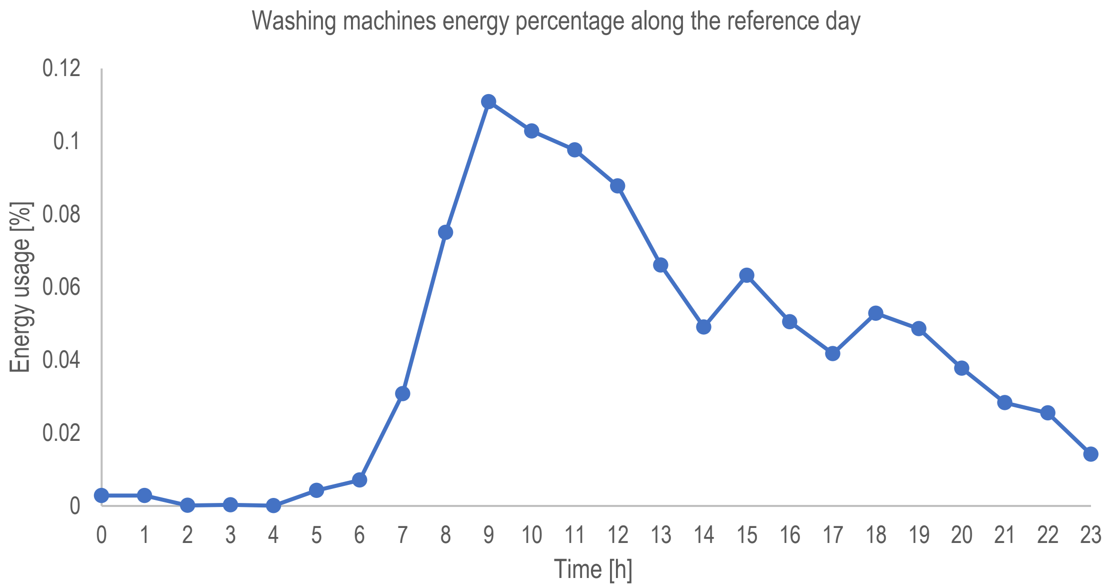

Figure 15 – Washing machine energy usage

Dish washer

Hour	Usage percentage	Hour	Usage percentage
0	0.0300	12	0.0236
1	0.0129	13	0.0400
2	0.0047	14	0.1085
3	0.0001	15	0.1122
4	0.0001	16	0.0772
5	0.0001	17	0.0293
6	0.0071	18	0.0156
7	0.0222	19	0.0150
8	0.0376	20	0.0670
9	0.0464	21	0.1258
10	0.0486	22	0.1052
11	0.0304	23	0.0406

Table 17 – Dish washer usage percentage

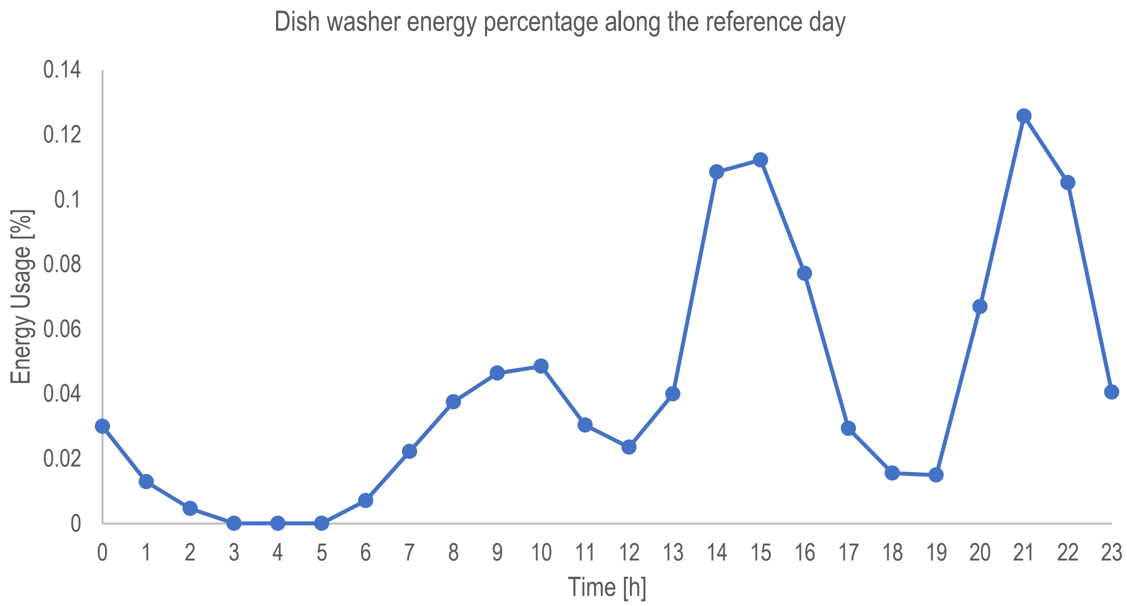

Figure 16 – Dish washer energy usage

Audio-visual device

Hour	Usage percentage	Hour	Usage percentage
0	0.04	12	0.04
1	0.03	13	0.05
2	0.03	14	0.05
3	0.02	15	0.05
4	0.02	16	0.04
5	0.02	17	0.04
6	0.03	18	0.04
7	0.03	19	0.06
8	0.03	20	0.07
9	0.03	21	0.07
10	0.03	22	0.07
11	0.03	23	0.07

Table 18 – Audio-visual device usage percentage

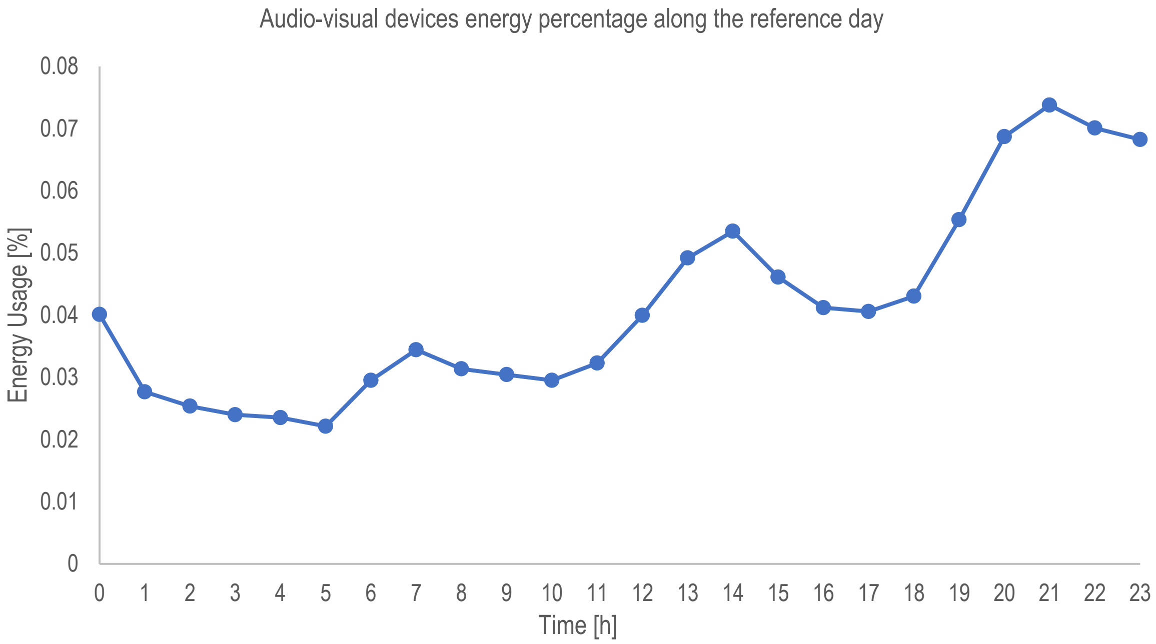

Figure 17 – Audio-visual energy usage

Personal Computers

Hour	Usage percentage	Hour	Usage percentage
0	0.03	12	0.05
1	0.03	13	0.05
2	0.02	14	0.05
3	0.01	15	0.06
4	0.01	16	0.06
5	0.01	17	0.06
6	0.02	18	0.07
7	0.02	19	0.07
8	0.02	20	0.06
9	0.03	21	0.06
10	0.04	22	0.06
11	0.05	23	0.05

Table 19 – Personal Computers usage percentage

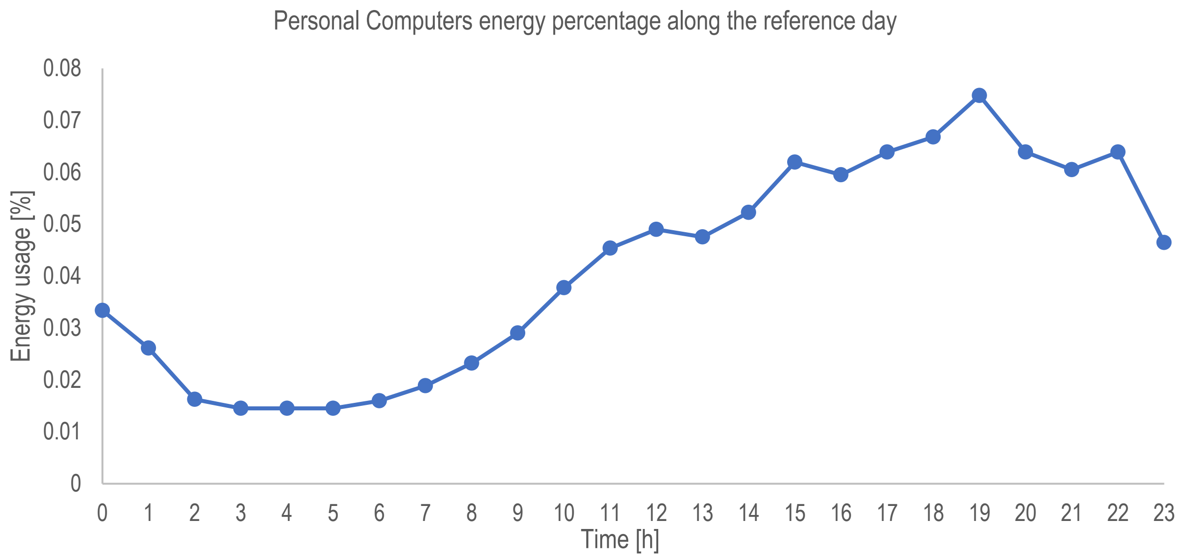

Figure 18 – Personal Computers energy usage

Since all the demand curves for the domestic devices are provided, it is possible to determine the daily energy consumption according to the seasons.
In fact, now it is possible to spread the daily average consumption for each facility in the different time step, thanks to the usage percentage shown above.
Results according to the different reference day are shown the following figures and tables.

Power Consumption [MW] Winter Reference day

Hour	Fridge/Freezer	Lightning	Washing Machine	Dish Washer	Audio-Visual device	PCs	TOTAL
0	1.87	0.81	0.04	0.39	1.00	0.31	4.42
1	1.87	0.73	0.04	0.17	0.69	0.24	3.74
2	1.87	0.42	0.00	0.06	0.63	0.15	3.13
3	1.87	0.21	0.00	0.00	0.60	0.13	2.81
4	1.87	0.21	0.00	0.00	0.59	0.13	2.80
5	1.87	0.21	0.07	0.00	0.55	0.13	2.83
6	1.87	0.38	0.11	0.09	0.74	0.15	3.33
7	1.87	0.70	0.48	0.29	0.86	0.18	4.38
8	1.87	0.63	1.18	0.49	0.78	0.22	5.16
9	1.87	0.94	1.75	0.60	0.76	0.27	6.18
10	1.87	0.90	1.62	0.63	0.74	0.35	6.10
11	1.87	0.90	1.54	0.39	0.81	0.42	5.93
12	1.87	0.79	1.38	0.31	1.00	0.45	5.80
13	1.87	0.98	1.04	0.52	1.23	0.44	6.08
14	1.87	1.02	0.77	1.41	1.34	0.49	6.88
15	1.87	1.07	1.00	1.46	1.15	0.57	7.12
16	1.87	1.15	0.80	1.00	1.03	0.55	6.39
17	1.87	1.63	0.66	0.38	1.01	0.59	6.14
18	1.87	2.37	0.83	0.20	1.07	0.62	6.96
19	1.87	2.23	0.77	0.19	1.38	0.69	7.14
20	1.87	2.26	0.59	0.87	1.72	0.59	7.89
21	1.87	2.32	0.45	1.63	1.84	0.56	8.66
22	1.87	2.23	0.40	1.36	1.75	0.59	8.21
23	1.87	1.29	0.22	0.53	1.70	0.43	6.04

Table 20 – Power Consumption Winter

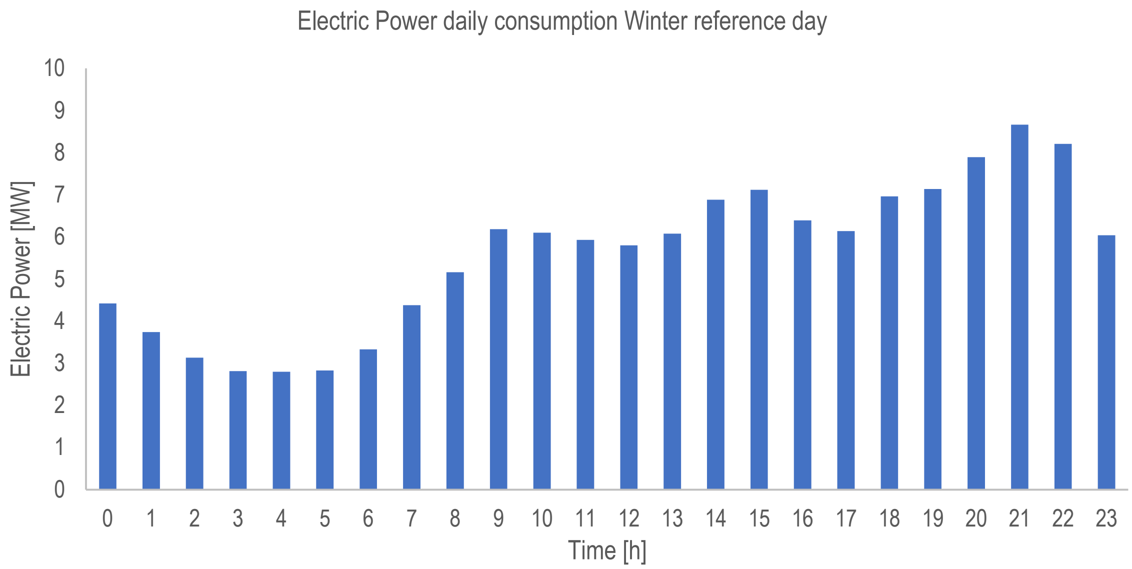

Figure 19 – Power Consumption Winter

			Power Consumption [MW] Spring/Fall Reference day				
Hour	Fridge/Freezer	Lightning	Washing Machine	Dish Washer	Audio-Visual device	PCs	TOTAL
0	1.87	1.89	0.04	0.39	1.00	0.31	5.50
1	1.87	1.38	0.04	0.17	0.69	0.24	4.39
2	1.87	0.98	0.00	0.06	0.63	0.15	3.69
3	1.87	0.67	0.00	0.00	0.60	0.13	3.28
4	1.87	0.39	0.00	0.00	0.59	0.13	2.98
5	1.87	0.30	0.07	0.00	0.55	0.13	2.92
6	1.87	0.26	0.11	0.09	0.74	0.15	3.21
7	1.87	0.54	0.48	0.29	0.86	0.18	4.22
8	1.87	0.72	1.18	0.49	0.78	0.22	5.25
9	1.87	0.90	1.75	0.60	0.76	0.27	6.15
10	1.87	0.86	1.62	0.63	0.74	0.35	6.06
11	1.87	1.07	1.54	0.39	0.81	0.42	6.10
12	1.87	0.86	1.38	0.31	1.00	0.45	5.86
13	1.87	0.86	1.04	0.52	1.23	0.44	5.95
14	1.87	0.93	0.77	1.41	1.34	0.49	6.80
15	1.87	0.87	1.00	1.46	1.15	0.57	6.91
16	1.87	0.85	0.80	1.00	1.03	0.55	6.09
17	1.87	0.86	0.66	0.38	1.01	0.59	5.37
18	1.87	1.03	0.83	0.20	1.07	0.62	5.62
19	1.87	1.47	0.77	0.19	1.38	0.69	6.37
20	1.87	1.95	0.59	0.87	1.72	0.59	7.58
21	1.87	2.45	0.45	1.63	1.84	0.56	8.80
22	1.87	2.36	0.40	1.36	1.75	0.59	8.33
23	1.87	1.93	0.22	0.53	1.70	0.43	6.68

Table 21 – Power Consumption Spring/Fall

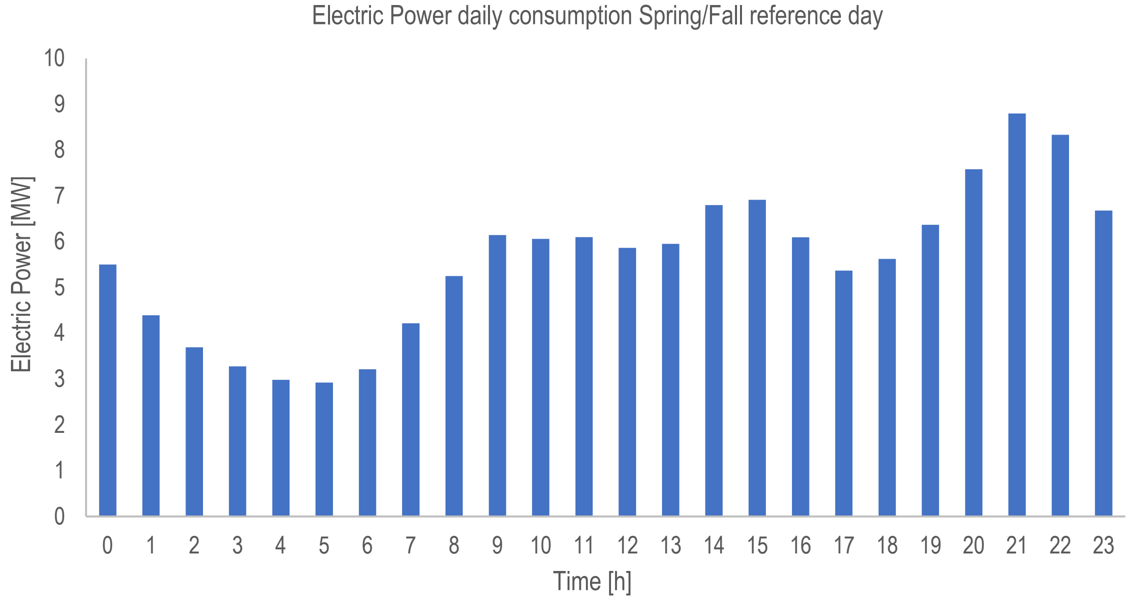

Figure 20 - Power Consumption Spring/Fall

Power Consumption [MW] Summer Reference day							
Hour	Fridge/Freezer	Lightning	Washing Machine	Dish Washer	Audio-Visual device	PCs	TOTAL
0	1.87	2.09	0.04	0.39	1.00	0.31	5.70
1	1.87	1.64	0.04	0.17	0.69	0.24	4.65
2	1.87	1.15	0.00	0.06	0.63	0.15	3.86
3	1.87	0.89	0.00	0.00	0.60	0.13	3.50
4	1.87	0.49	0.00	0.00	0.59	0.13	3.08
5	1.87	0.36	0.07	0.00	0.55	0.13	2.98
6	1.87	0.49	0.11	0.09	0.74	0.15	3.45
7	1.87	0.55	0.48	0.29	0.86	0.18	4.22
8	1.87	0.55	1.18	0.49	0.78	0.22	5.08
9	1.87	0.49	1.75	0.60	0.76	0.27	5.74
10	1.87	0.63	1.62	0.63	0.74	0.35	5.83
11	1.87	0.92	1.54	0.39	0.81	0.42	5.95
12	1.87	1.14	1.38	0.31	1.00	0.45	6.15
13	1.87	1.04	1.04	0.52	1.23	0.44	6.14
14	1.87	0.63	0.77	1.41	1.34	0.49	6.50
15	1.87	0.60	1.00	1.46	1.15	0.57	6.65
16	1.87	0.67	0.80	1.00	1.03	0.55	5.91
17	1.87	0.90	0.66	0.38	1.01	0.59	5.41
18	1.87	1.15	0.83	0.20	1.07	0.62	5.74
19	1.87	1.20	0.77	0.19	1.38	0.69	6.10
20	1.87	1.63	0.59	0.87	1.72	0.59	7.27
21	1.87	2.36	0.45	1.63	1.84	0.56	8.71
22	1.87	2.55	0.40	1.36	1.75	0.59	8.52
23	1.87	2.24	0.22	0.53	1.70	0.43	7.00

Table 22 – Power Consumption Summer

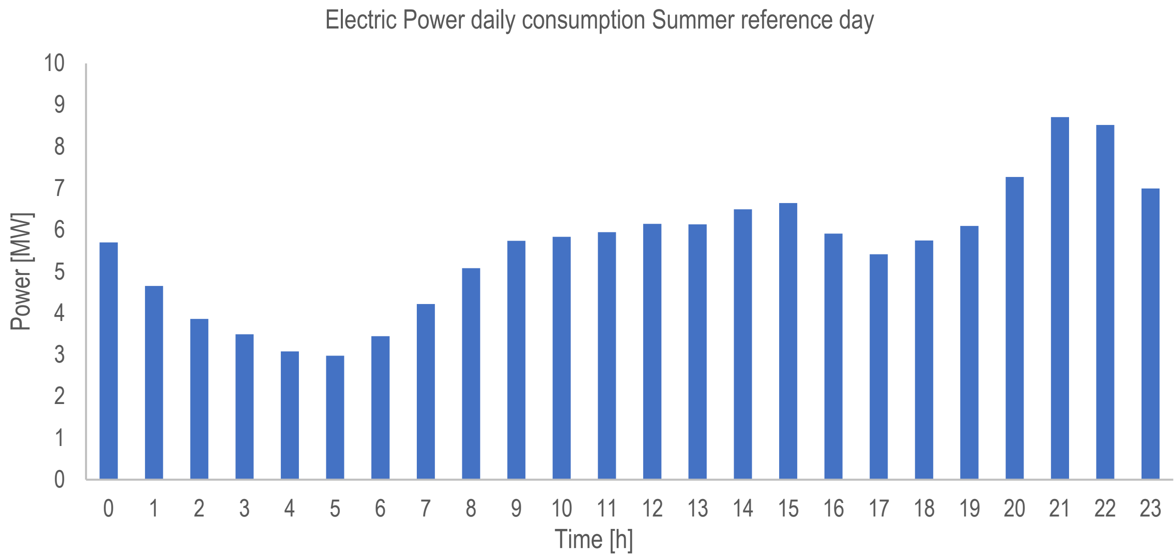

Figure 21 - Power Consumption Summer

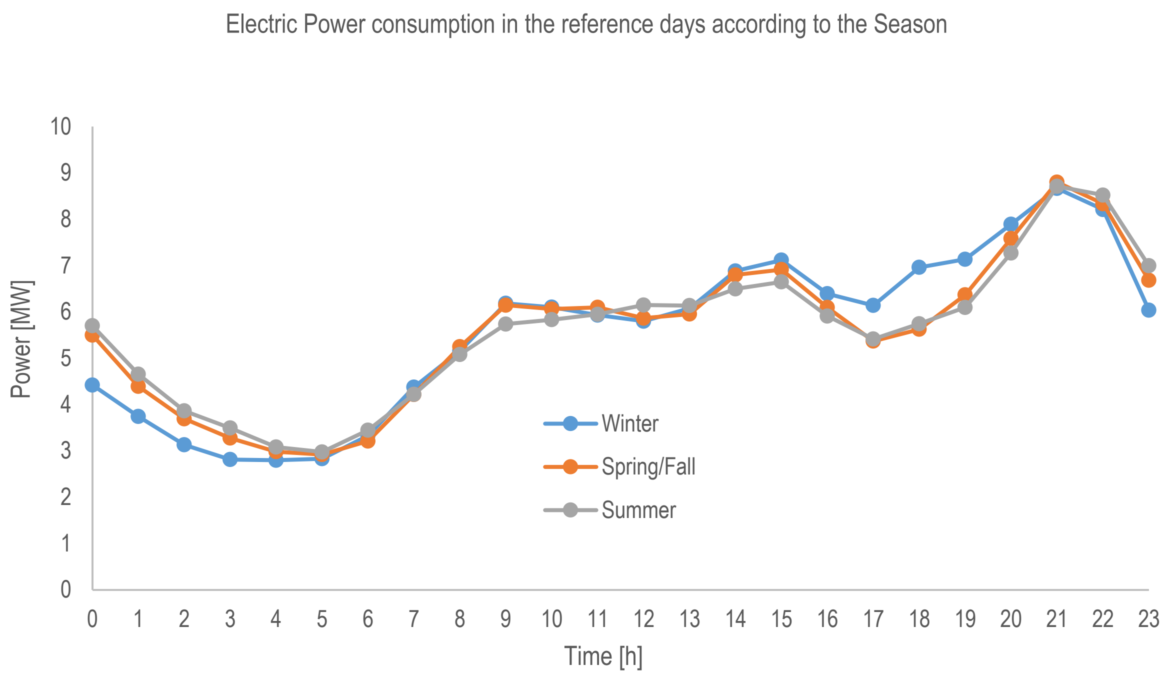

Figure 22 – Electric Power Consumption comparison between Seasons

With the procedure argued so far, it is possible to determine the electric power consumption for the residential sector with the required time steps of 1 hour.
How it is possible to notice from the Figure 22 there is not a very big difference between spring/fall and summer.
Instead there is a remarkable difference for the winter.
This is due to the electric consumption for Lightning that is higher in winter with respect to the other seasons.

Now that the residential consumption is defined, in order to conclude this part of the model, it is necessary to determine the total electric power consumption of the region, which include also the non-residential sector.

As in the case of the thermal model, even in this part a black box approach is used, considering all the activities that are not residential in this big sector, named non-residential.
It is necessary to point out that the non-residential doesn't contain in it the Industrial sector, that given the nature of the region, is not considered in this model.
As for the non-residential sector a starting point is needed in order to develop the model, and in this case data from TERNA are used for this purpose:
In fact, from the annual report of the TERNA company (Sull & Elettricaitalia, 2015) comes out that the tertiary sector, that fits well in the "non-residential" of the model, accounts a consumption equal to 1.5 the residential one.
At this point, in order to obtain a reasonable estimation of the non-residential sector, just a simple a multiplication of the residential sector consumption times the coefficient above is not suitable.
In fact, proceeding in this way, there will be an estimation that is continuous along all the day, that not reflect the real consumption of the tertiary sector, that is present mostly only during the working hours.

To do this, as first step, an hourly coefficient is defined, in order to determine in which time steps of the day the non-residential sector is present.
A reasonable choice is to set this coefficient equal to 1 from the hours between the 08:00 and the 21:00, and 0.2 in the remaining hours, in order to take into account all the business that work in the night and in the early morning.
Given this coefficient, an iterative calculation through Excel is performed, in order to determine the values of the ratio Non-residential/residential consumption according to the different season.
Results about the calculation performed are collected in the following tables.

	Winter Reference Day		$\frac{Non-Res.}{Res.}$ =2.14
Hour	Residential Consumption [MW]	Non-Res. Coefficient	Non-Res. Consumption [MW]
0	4.42	0.2	1.90
1	3.74	0.2	1.60
2	3.13	0.2	1.34
3	2.81	0.2	1.21
4	2.80	0.2	1.20
5	2.83	0.2	1.21
6	3.33	0.2	1.43
7	4.38	0.2	1.88
8	5.16	1	11.06
9	6.18	1	13.26
10	6.10	1	13.08
11	5.93	1	12.71
12	5.80	1	12.44
13	6.08	1	13.03
14	6.88	1	14.76
15	7.12	1	15.26
16	6.39	1	13.70

17	6.14	1	13.16
18	6.96	1	14.92
19	7.14	1	15.30
20	7.89	1	16.92
21	8.66	0.2	3.72
22	8.21	0.2	3.52
23	6.04	0.2	2.59

Table 23 – Non-Residential calculation Winter

	Spring Reference Day		$\frac{Non-Res.}{Res.}$ =2.21
Hour	Residential Consumption [MW]	Non-Res. Coefficient	Non-Res. Consumption [MW]
0	5.50	0.2	2.43
1	4.39	0.2	1.94
2	3.69	0.2	1.63
3	3.28	0.2	1.45
4	2.98	0.2	1.32
5	2.92	0.2	1.29
6	3.21	0.2	1.42
7	4.22	0.2	1.86
8	5.25	1	11.60
9	6.15	1	13.58
10	6.06	1	13.40
11	6.10	1	13.48
12	5.86	1	12.97
13	5.95	1	13.16
14	6.80	1	15.03
15	6.91	1	15.28
16	6.09	1	13.47
17	5.37	1	11.87
18	5.62	1	12.43
19	6.37	1	14.08
20	7.58	1	16.76
21	8.80	0.2	3.89
22	8.33	0.2	3.69
23	6.68	0.2	2.95

Table 24 – Non-Residential calculation Spring

	Fall Reference Day		$\frac{Non-Res.}{Res.}$ =2.21
Hour	Residential Consumption [MW]	Non-Res. Coefficient	Non-Res. Consumption [MW]
0	5.50	0.2	2.43
1	4.39	0.2	1.94

2	3.69	0.2	1.63
3	3.28	0.2	1.45
4	2.98	0.2	1.32
5	2.92	0.2	1.29
6	3.21	0.2	1.42
7	4.22	0.2	1.87
8	5.25	1	11.61
9	6.15	1	13.60
10	6.06	1	13.41
11	6.10	1	13.49
12	5.86	1	12.98
13	5.95	1	13.17
14	6.80	1	15.04
15	6.91	1	15.30
16	6.09	1	13.49
17	5.37	1	11.88
18	5.62	1	12.45
19	6.37	1	14.09
20	7.58	1	16.78
21	8.80	0.2	3.89
22	8.33	0.2	3.69
23	6.68	0.2	2.96

Table 25 – Non-Residential calculation Fall

Hour	Summer Reference Day Residential Consumption [MW]	Non-Res. Coefficient	$\frac{Non-Res.}{Res.}$ =2.25 Non-Res. Consumption [MW]
0	5.70	0.2	2.56
1	4.65	0.2	2.09
2	3.86	0.2	1.74
3	3.50	0.2	1.57
4	3.08	0.2	1.38
5	2.98	0.2	1.34
6	3.45	0.2	1.55
7	4.22	0.2	1.90
8	5.08	1	11.41
9	5.74	1	12.88
10	5.83	1	13.10
11	5.95	1	13.36
12	6.15	1	13.80
13	6.14	1	13.78
14	6.50	1	14.59
15	6.65	1	14.93
16	5.91	1	13.27
17	5.41	1	12.16
18	5.74	1	12.90
19	6.10	1	13.69
20	7.27	1	16.33

21	8.71	0.2	3.91
22	8.52	0.2	3.83
23	7.00	0.2	3.14

Table 26 – Non-Residential calculation Summer

2.3.1 Validation

Now, that the global electric consumption is defined, both for residential and non-residential sector, as in the thermal case a validation is proposed.
This validation is carried out making a comparison between the calculated data and the national data, taken from the TERNA data bank (TERNA, 2015).
It is important to point out, that while in the thermal case the overlap between the calculated curve and the measured was possible, in this case, since the Industrial sector is not considered, a complete overlap is not achievable, especially in the early morning and in the night, in which the industrial contribution is bigger with respect to the others.
Also in this case, the comparison is performed between the percentage value with respect to the total daily energy consumption.
Results according to the different seasons are shown in the following tables and figures.

Hour	Fall Reference Day Power calc. [MW]	Percentage consumption	Percentage from TERNA	δ_{abs} Calc.-Meas.
0	7.93	0.02	0.04	-0.012
1	6.34	0.02	0.03	-0.014
2	5.33	0.02	0.03	-0.015
3	4.73	0.01	0.03	-0.016
4	4.30	0.01	0.03	-0.017
5	4.22	0.01	0.03	-0.017
6	4.63	0.01	0.03	-0.018
7	6.08	0.02	0.04	-0.019
8	16.86	0.05	0.04	0.007
9	19.74	0.06	0.05	0.011
10	19.47	0.06	0.05	0.009
11	19.59	0.06	0.05	0.009
12	18.84	0.06	0.05	0.007
13	19.13	0.06	0.05	0.010
14	21.84	0.07	0.05	0.019
15	22.21	0.07	0.05	0.019
16	19.58	0.06	0.05	0.011
17	17.25	0.05	0.05	0.004
18	18.07	0.05	0.05	0.008
19	20.46	0.06	0.05	0.015
20	24.36	0.07	0.05	0.023
21	12.69	0.04	0.05	-0.009
22	12.02	0.04	0.04	-0.007
23	9.64	0.03	0.04	-0.010

Table 27 – Comparison Fall reference Day

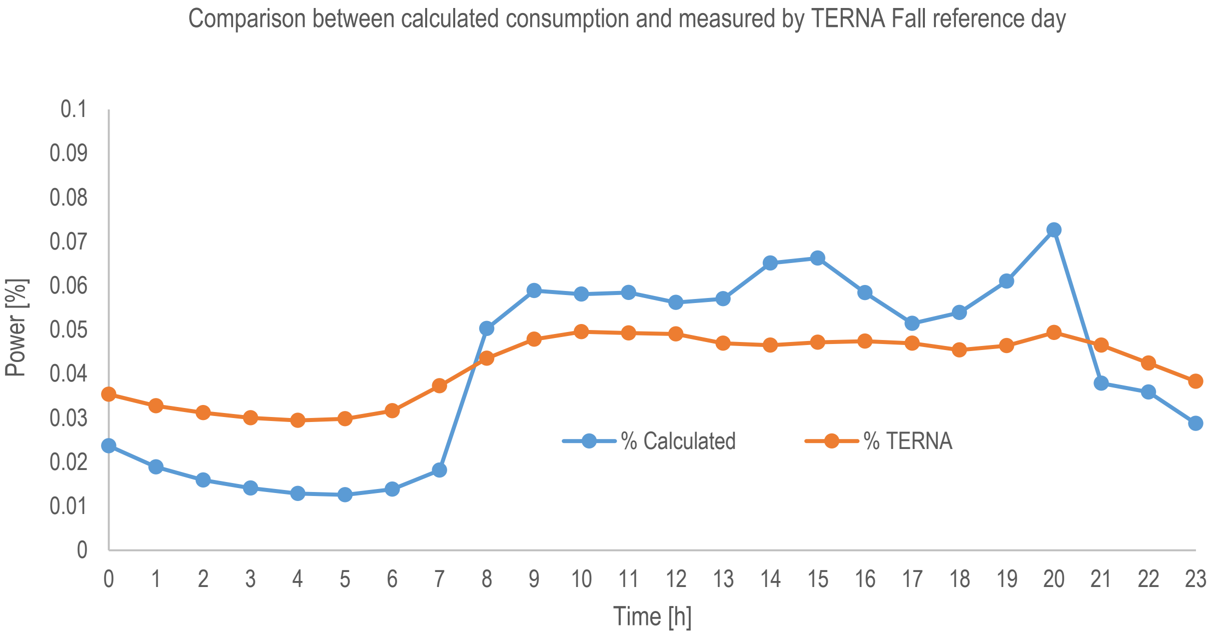

Figure 23 – Comparison Fall reference day

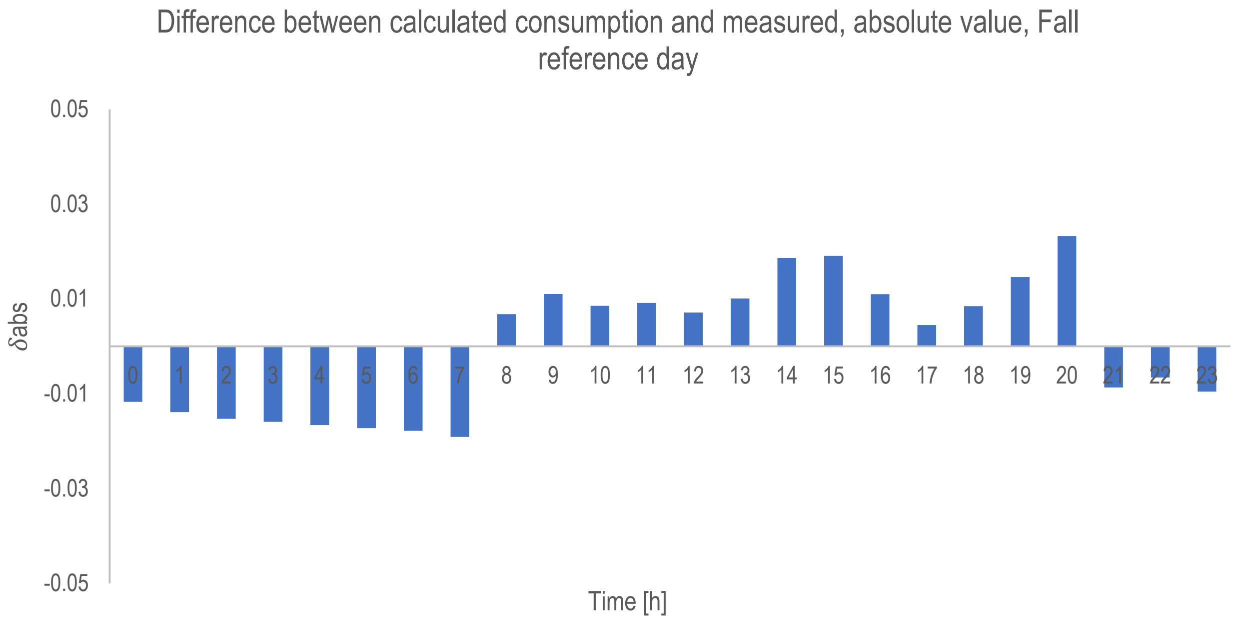

Figure 24 – Deviations absolute values Fall referecene day

Hour	Winter Reference Day Power calc. [MW]	Percentage consumption	Percentage from TERNA	δ_{abs} Calc.-Meas.
0	6.32	0.02	0.03	0.015
1	5.35	0.02	0.03	0.015
2	4.47	0.01	0.03	0.015
3	4.02	0.01	0.03	0.016
4	4.00	0.01	0.03	0.015
5	4.04	0.01	0.03	0.016
6	4.76	0.01	0.03	0.015

7	6.25	0.02	0.04	0.017
8	16.22	0.05	0.04	-0.005
9	19.44	0.06	0.05	-0.009
10	19.18	0.06	0.05	-0.007
11	18.65	0.06	0.05	-0.006
12	18.24	0.05	0.05	-0.004
13	19.10	0.06	0.05	-0.009
14	21.64	0.06	0.05	-0.017
15	22.37	0.07	0.05	-0.019
16	20.10	0.06	0.05	-0.012
17	19.30	0.06	0.05	-0.009
18	21.89	0.07	0.05	-0.015
19	22.43	0.07	0.05	-0.017
20	24.81	0.07	0.05	-0.025
21	12.38	0.04	0.05	0.009
22	11.73	0.03	0.04	0.007
23	8.63	0.03	0.04	0.012

Table 28 – Comparison Winter reference day

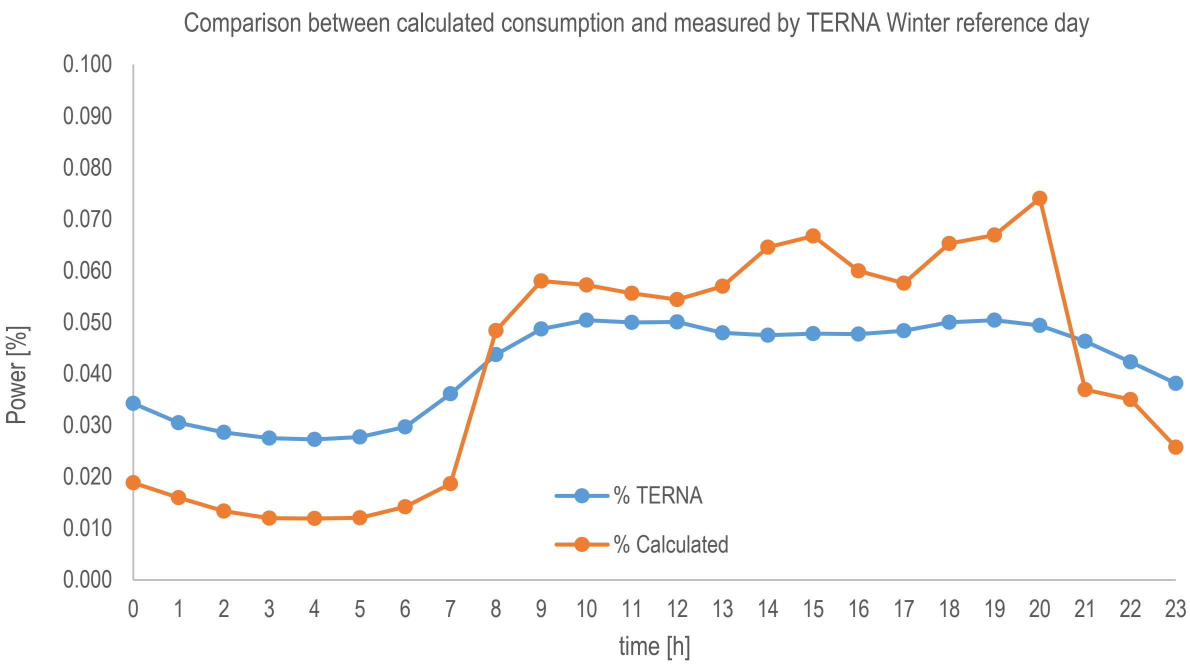

Figure 25 – Comparison Winter reference day

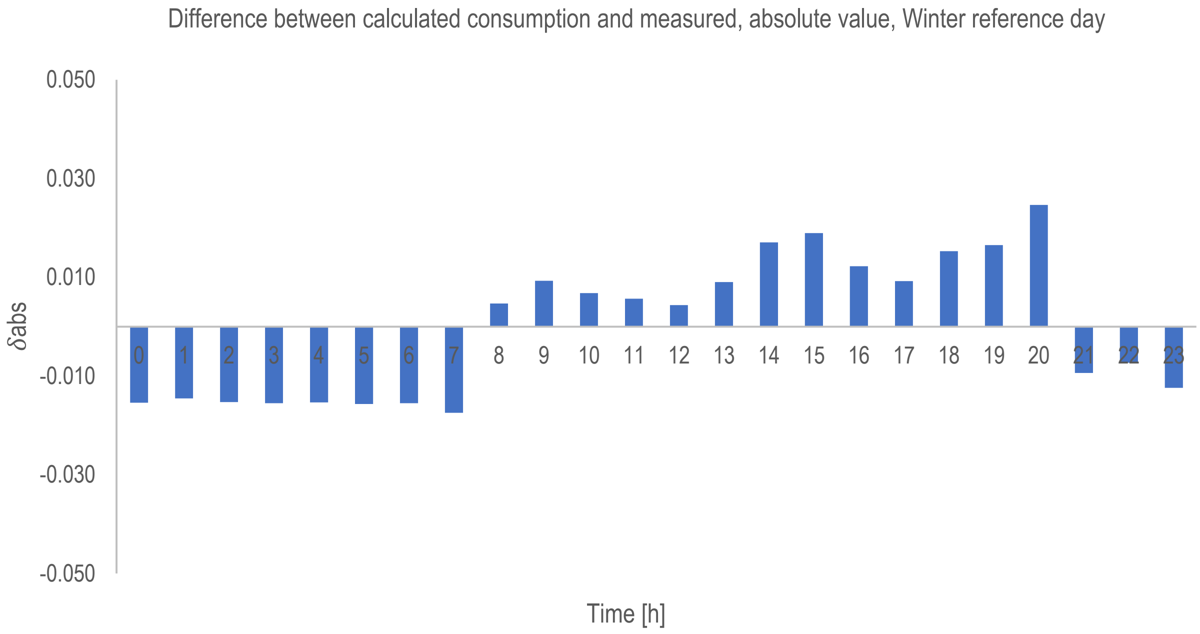

Figure 26 – Deviations absolute values Winter reference day

Hour	Power calc. [MW]	Percentage consumption	Percentage from TERNA	δ_{abs} Calc.-Meas.
		Spring Reference Day		
0	7.93	0.02	0.04	-0.014
1	6.33	0.02	0.03	-0.010
2	5.33	0.02	0.03	-0.011
3	4.73	0.01	0.03	-0.012
4	4.30	0.01	0.03	-0.013
5	4.21	0.01	0.03	-0.014
6	4.63	0.01	0.03	-0.016
7	6.08	0.02	0.04	-0.018
8	16.85	0.05	0.04	0.008
9	19.73	0.06	0.05	0.011
10	19.46	0.06	0.05	0.008
11	19.58	0.06	0.05	0.008
12	18.83	0.06	0.05	0.006
13	19.11	0.06	0.05	0.010
14	21.82	0.07	0.05	0.018
15	22.20	0.07	0.05	0.018
16	19.57	0.06	0.05	0.010
17	17.24	0.05	0.05	0.003
18	18.06	0.05	0.05	0.007
19	20.44	0.06	0.05	0.015
20	24.35	0.07	0.05	0.025
21	12.69	0.04	0.05	-0.012
22	12.02	0.04	0.05	-0.011
23	9.63	0.03	0.04	-0.014

Table 29 – Comparison Spring reference day

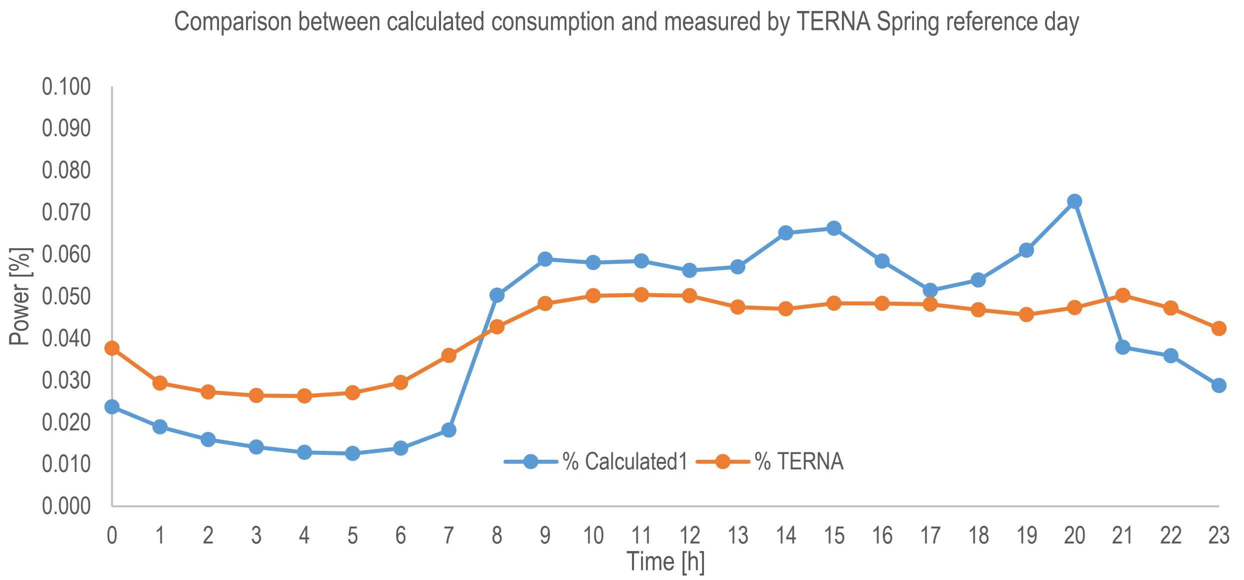

Figure 27 – Comparison Spring reference day

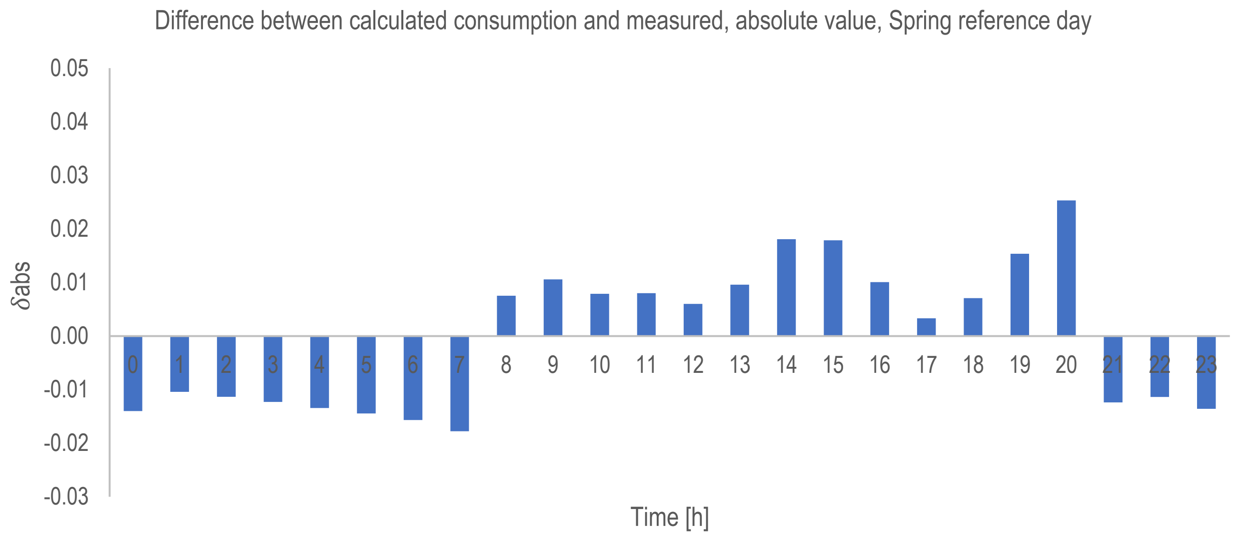

Figure 28 – Deviations absolute values Spring reference day

	Summer Reference Day			
Hour	Power calc. [MW]	Percentage consumption	Percentage from TERNA	δ_{abs} Calc.-Meas
0	8.26	0.02	0.04	-0.013
1	6.74	0.02	0.03	-0.012
2	5.60	0.02	0.03	-0.012
3	5.06	0.02	0.03	-0.014
4	4.47	0.01	0.03	-0.015
5	4.31	0.01	0.03	-0.015
6	5.00	0.01	0.03	-0.015
7	6.12	0.02	0.03	-0.016
8	16.49	0.05	0.04	0.009

9	18.62	0.06	0.05	0.009
10	18.93	0.06	0.05	0.007
11	19.30	0.06	0.05	0.007
12	19.95	0.06	0.05	0.009
13	19.91	0.06	0.05	0.009
14	21.09	0.06	0.05	0.011
15	21.57	0.06	0.05	0.013
16	19.18	0.06	0.05	0.007
17	17.57	0.05	0.05	0.004
18	18.65	0.06	0.05	0.009
19	19.79	0.06	0.05	0.014
20	23.60	0.07	0.04	0.026
21	12.62	0.04	0.04	-0.006
22	12.35	0.04	0.04	-0.006
23	10.14	0.03	0.04	-0.010

Table 30 – Comparison Summer reference day

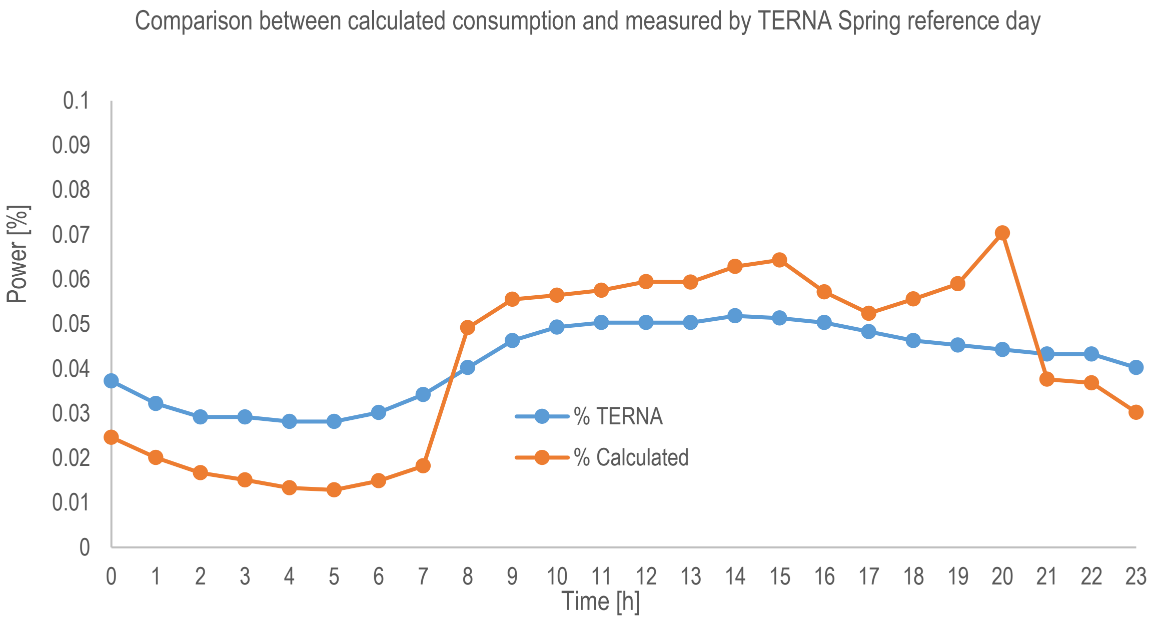

Figure 29 – Comparison Summer reference day

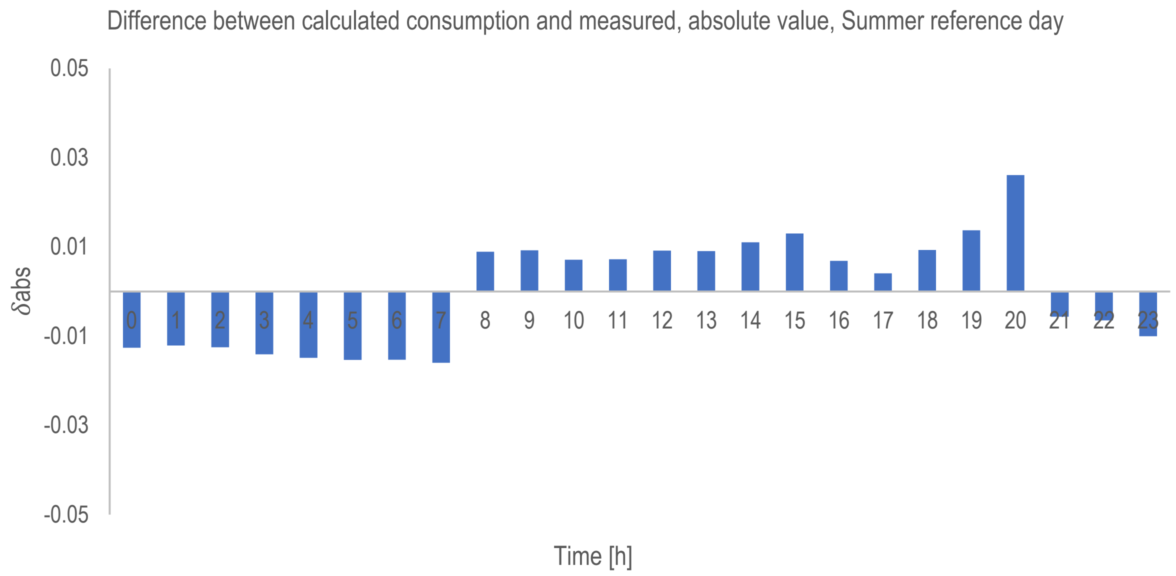

Figure 30 – Deviation absolute value Summer reference day

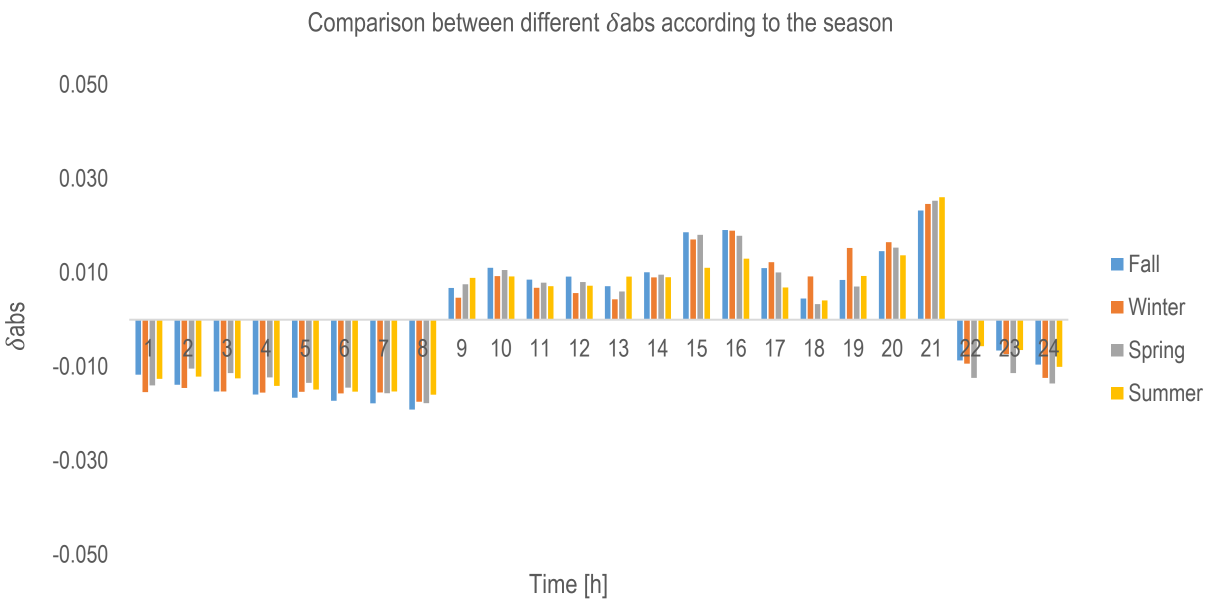

Figure 31 – Deviations Comparison

How it is possible to notice from the previous chart, the general trend of the deviations between the calculated consumption and the real one is the same for each season:
In fact, as expected, the calculated curves are lower than the real ones the morning, before the 09:00 and in the night, after the 22:00.
Since the deviation are calculated as difference between the energy consumption, in percentage value with respect to the daily total one, these deviations show relative modest values, with the highest value for the 21:00 around the 2,8%.

3 DESCRIPTION OF THE INTEGRATED MODEL

Since the consumption model is already defined it is possible to proceed to the construction of the TIMES model.
This third Chapter is devoted to the explanation of the main features related to the process of construction of the model.
As first, the TIMES environment is described, then the reference energy system at the base year, as well all the new technologies and model constraints are explained.

3.1 TIMES DESCRIPTION

"TIMES (an acronym for The Integrated MARKAL-EFOM System) is an economic model generator for local, national, multi-regional, or global energy systems, which provides a technology-rich basis for representing energy dynamics over a multi-period time horizon. It is usually applied to the analysis of the entire energy sector, but may also be applied to study single sectors such as the electricity and district heat sector. Estimates of end-use energy service demands (e.g., car road travel; residential lighting; steam heat requirements in the paper industry; etc.) are provided by the user for each region to drive the reference scenario. In addition, the user provides estimates of the existing stocks of energy related equipment in all sectors, and the characteristics of available future technologies, as well as present and future sources of primary energy supply and their potentials.
Using these as inputs, the TIMES model aims to supply energy services at minimum global cost (more accurately at minimum loss of total surplus) by simultaneously making decisions on equipment investment and operation; primary energy supply; and energy trade for each region. For example, if there is an increase in residential lighting energy service relative to the reference scenario (perhaps due to a decline in the cost of residential lighting, or due to a different assumption on GDP growth), either existing generation equipment must be used more intensively or new – possibly more efficient – equipment must be installed. The choice by the model of the generation equipment (type and fuel) is based on the analysis of the characteristics of alternative generation technologies, on the economics of the energy supply, and on environmental criteria. TIMES is thus a vertically integrated model of the entire extended energy system […]".

This brief description of TIMES, extracted from (Loulou & Goldstein, 2005), explain the main role of the TIMES code and why it is used in the present work.
In fact, through the use of this platform it is possible to study the behaviour of the analysed region, as part of the energy system, i.e. consumption, technological mix, emission and costs.

3.2 VEDA

VEDA Front End (FE) and VEDA Back End (BE) are tools that allow the designer to work on the code not directly but through the use of Microsoft EXCEL worksheet.
The Front End is used in order to build the model with the use of EXCEL, instead the Back End is used to extract the data regarding the simulations by the construction of customized tables.

3.3 MODEL CONSTRUCTION

The procedure used in order to build the model is articulated into three steps:

- Definition of the Base Year
- SubRes Implementation

- Definition of the technical and environmental constraints

The next paragraphs are devoted to the explanation of these features.

3.3.1 Time discretization

The time discretization already explained in the previous Chapter is implemented inside the code.
As already mentioned, this discretization is used in order to have a good time resolution for the model that at the same time won't penalize the availability of the results.
A reference day for each season during the year is selected, having 4 reference days each year, with a time resolution of 1 hour.
Stated that, along the year 96 time steps are present, with the assumption that all the days of a season are the same as the reference one.
The simulation covers a period that goes from the base year, considered as 2015, until the 2050, year in which specified environmental constraints must be met.

3.3.2 Demand characterization

The demand characterization, already discussed in the previous chapter, is now applied inside the TIME model.
This is obtained by the use of the function "commodity fraction" that permits to split the demand among to the hours of the reference days of the year.

3.3.3 Reference energy system

Once that the time discretization and the demand are implemented it is necessary to define all the technologies that compose the reference energy system (RES).
Some assumptions are made in order to have the starting point, since the analysed area is a representative one, no effective data are available.
As already explained, the final consumption is characterized by electrical energy, space heating and hot water.
For each type of final use at least one technology is required in order to satisfy the demand.
The following paragraphs cover each of them separately.
It's also important to point out regard the RES that no extraction of natural resources is assumed in the analysed region, with only exception of solar irradiance.

3.3.3.1 Electric Energy

In order to satisfy the electric energy demand two type of energy carriers are implemented within the model.
A centralized CHP is defined, which also provides heating (paragraph 3.3.3.2), as well the possibility to import electricity.
The centralized CHP is sized in order to guarantee the total electric energy supply for the first year of analysis.
The technical aspects of the plants are reported in the Table 31.

	P_{el} [MWel]	P_{th} [MWth]	UF [%]	η_{el}	η_{th}	CEH
BP	28	58	0.65	0.3	0.55	-0.18
COND	38	0		0.4	0	

Table 31 – CHP technical specifications

The centralized CHP is defined as variable, in order to guarantee the right mix between heat and electricity according to the selected season.
To do this, the two fringe conditions are defined, the Back Pressure (BP) and the Condensing (COND).
BP condition corresponds to the lowest generation of electricity and the maximum of heat, instead the COND one represents the full generation of electricity.
In order to permit the code to select one point between this two another parameter is used, the CEH, that represents the slope of the line passing through the BP and COND modes (the characteristic behaviour of the centralized Plant is assumed as linear by the code).

For what concern the possibility of import of electricity this is defined as an import with the price taken as the average PUN for the year 2017.
Data about cost related to the import of electricity are summarised in Table 32.

User	Cost [€/MWh]	Reference
System	54.84	(GME, 2017)
Final User	148	(AEEGSI, 2017)

Table 32 – Electricity Cost

In the previous Table there are two costs:
The first, already discussed, is the one considered for the import of electricity at the system level.
The second one expresses the total cost of the electricity for the final user, charged with taxes and system charges.
This value is taken from Autorità Energia Elettrica il Gas e il Sistema Idridico (AEEGSI), as average value referred to the 2017.
For the electric energy sector another features is implemented in the code, the possibility of Export.
This kind of mechanism allows the system to produce a surplus of electric energy with the possibility of export at the price equal to the PUN.

3.3.3.2 Space Heating

For the space heating two technologies are defined;
A district heating network (DHN) linked with the centralized CHP plant, and gas boilers.
To the reference year the share of these two technologies is assumed as 13% of the consumption provided by the district heating network, and the remaining 87% from the gas boilers.
So in this first definition of the share the DHN is an early stage and the possibility to develop is processed by the code.
The technological aspects of these two system are presented in the Table 33.

	P [MWth]	UF [%]	η_{th}
Gas Boilers	160	0.25	0.98
Distric heating grid	60	0.25	0.86

Table 33 – Space Heating technologies

In Table 33 it is possible to find also the utilisation factor (UF) of these technologies that is a parameter used for all the technologies present in this analysis.
This factor represents the hour of the year in which a technology is used and it is expressed in percentage value.
For the space heating it is calculated making the ratio between the hours of the year in which the heating system are normally switched on and the total hours.

The same approach used in the previous paragraph for the import of electricity is now applied to the natural gas.
Even in this case, two prices are selected, the first representing the cost for the import at system level, the second, charged with taxes and system cost, represent the price for the final consumption.
Details about these costs are reported in Table 34.

User	Cost [€/Sm^3]	Reference
System	0.215	(GME, 2017)
Final User	0.41	(AEEGSI, 2017)

Table 34 – Natural Gas Cost

The first cost is taken from data of GME (Gestore dei Mercati Energetici) as an average value for the "Mercato del giorno Prima" in the 2017.
The second one, instead, is taken from the authority AEEGSI, as average value for the 2017.

3.3.3.3 Hot water

About the consumption of hot water, even in this case two base technologies are defined, electric boilers and gas boilers.
The starting share between them is supposed at 50%.
Technical specification of these two technologies is reported in Table 35.

	P [MWth]	UF [%]	η_{th}
Electric Boilers	3.83	0.6	0.75
Gas Boilers	3.83	0.6	0.90

Table 35 – DHW technologies

3.3.3.4 RES-Base year

Since the technologies implemented at the base year of the analysis are already explained it's possible to characterize the RES having the starting point for the analysis.

Table 36 shows the technologies at the base year with all the data needed.
Figure 32 shows a simple scheme for the technological share.

		P [MWel]	P [MWth]	UF [%]	η_{el}	η_{th}	INV COST [M€/MW]	VAROM [€/MWhprod/y]	FIXOM [€/MW/y]	Lifetime [y]	References
CHP Plant	BP	28	58.13	0.65	0.3	0.55	1	5.2	11000	25	(Adminstration, 2013)
	COND	38.44	0		0.4	0		5.2			
Electric boilers		N/A	3.83	0.6	N/A	0.75	0.426	N/R	49000	25	(Fleiter et al., 2016)
Gas boilers DHW		N/A	3.83	0.6	N/A	0.90-0.98	0.36	N/R	30000	25	(Brunner & Rodrigo, 2017)
Gas boiler heating		N/A	160	0.2471	N/A	0.90	0.36	N/R	30000	25	(Brunner & Rodrigo, 2017)
District heating grid		N/A	58.13	0.2471	N/A	0.86	0.56	N/R	N/R	30	(Fleiter et al., 2016)

Table 36 – Technologies Base year

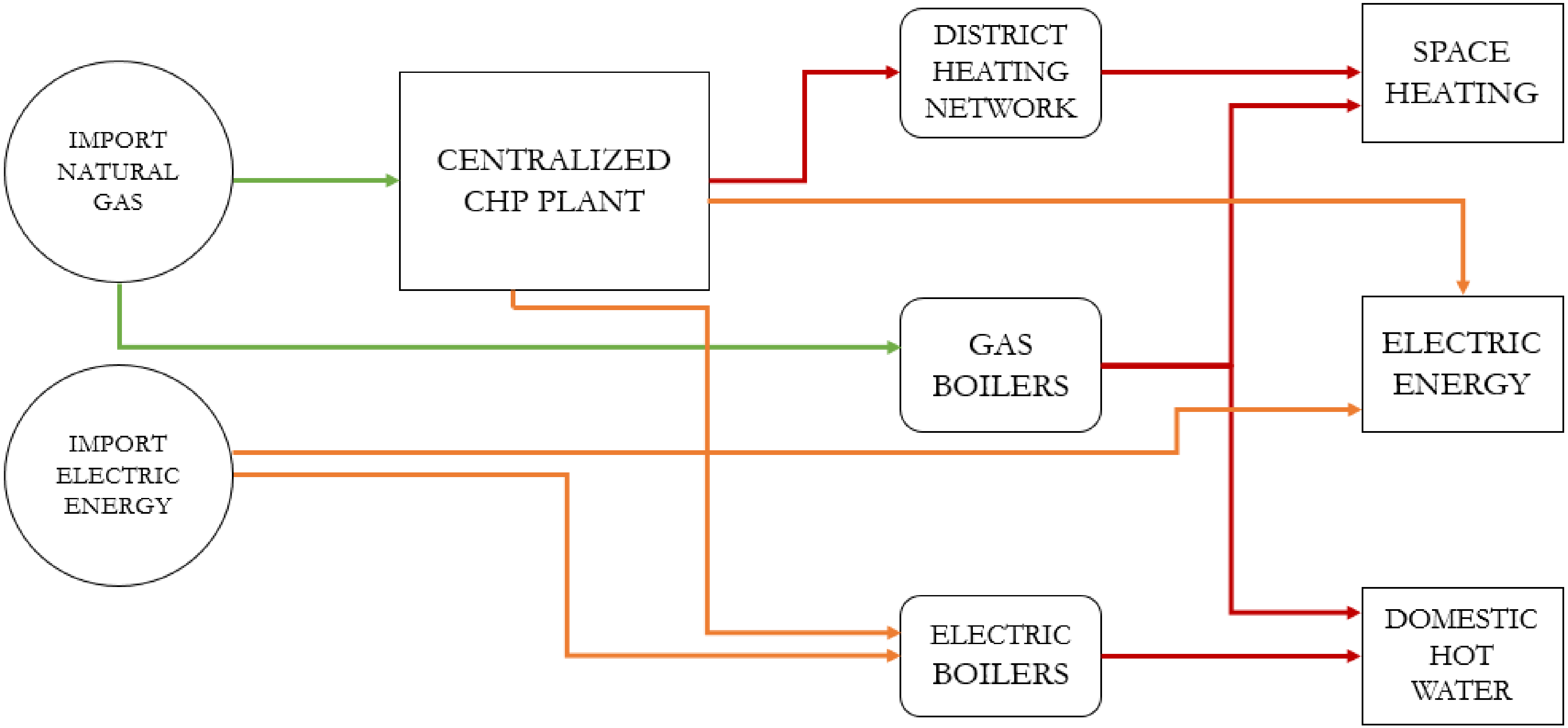

Figure 32 – RES Base year

3.4 BASE YEAR IMPLEMENTATION

After that the technologies, as well the demands, are defined it's necessary to implement them in the model, by the means of VEDA front End (FE).
In the Figure 33 the VEDA FE navigator is presented.

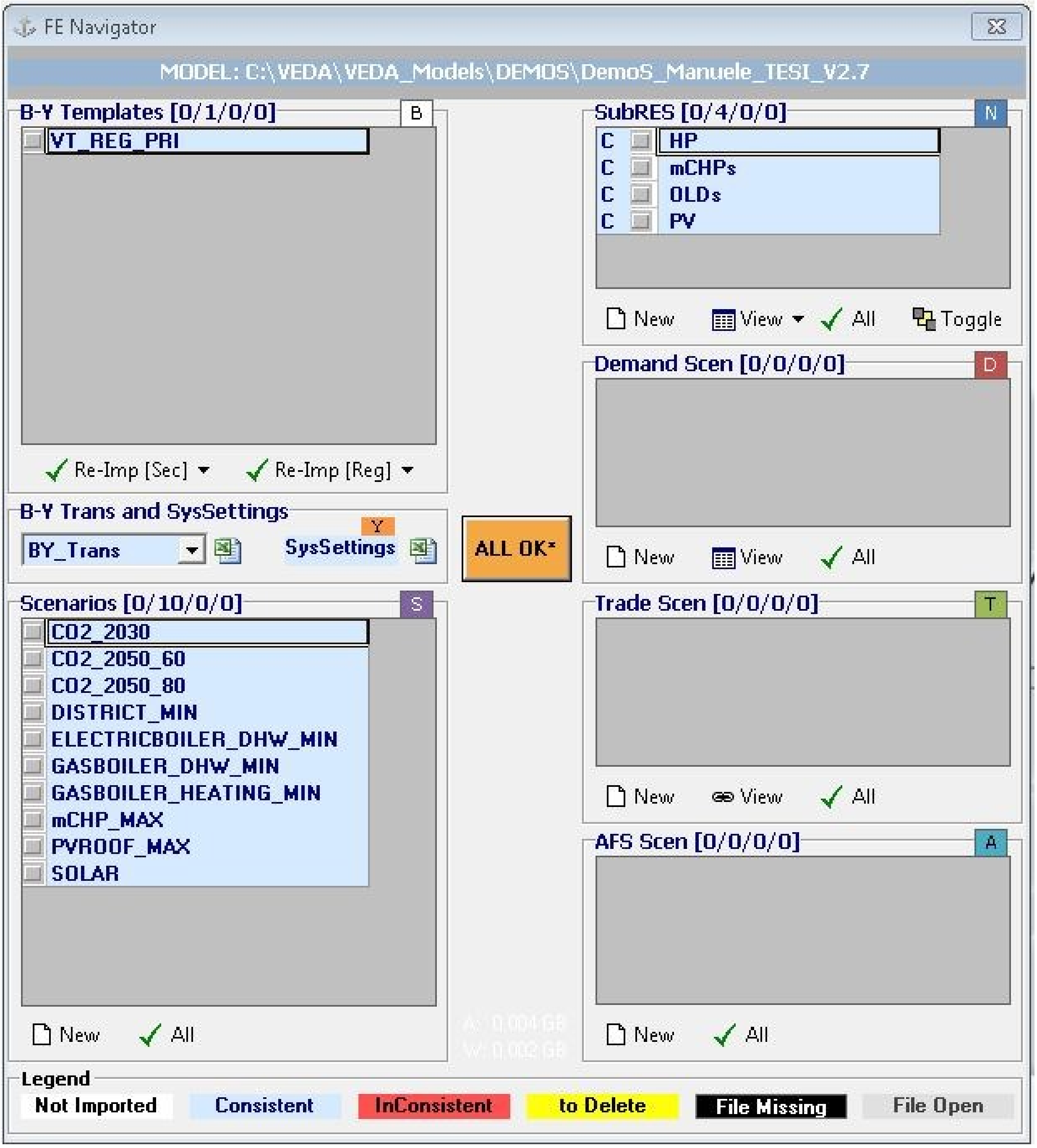

Figure 33 – VEDA FE Navigator

For the explanation of the various sections that compose the VEDA FE it is possible to look at APPENDIX B.

After that the base year is implemented inside the code a first analysis is conducted.
This analysis do not provide new data about the base year, in fact the share, as well the demand, are fixed by the designer, so the model acts as it's supposed to do, without any possibility of decision.
This first analysis is used as tool in order to figure out if the model operates like it has to do and if any possible issues are present.
In the dedicated section, APPENDIX B, some worksheet extracted directly from VEDA FRONT END are reported and commented in order to clarify what said in the previous paragraphs.

3.5 SubRES IMPLEMENTATION

Once that the base year is properly defined, i.e. no possible issues arise from the definition of the model, it is necessary to implement all the set of technologies that the code has the possibility to chooses for the following years.
At this stage decision by the designer have to be done, in fact the model will evolve according to the possibility inserted into it, so a various set of technologies is needed.
Table 37 summarizes all the technical information of the new technologies implemented in the model that will be discussed separately in the following paragraphs.

		η_{el}	η_{th}	INV COST [M€/MW]	VAROM [€/MWhprod/y]	FIXOM [€/MW/y]	Lifetime [y]	References
PV	a-si	0.06	N/A	2	1	33333	20	(Bianchini, Gambuti, Pellegrini, & Saccani, 2016)
	m-si	0.165	N/A	2	1	12500	20	
HP	ASHP	N/A	3	1	N/R	40000	15	(Fleiter et al., 2016)
mCHP	ICE	0.29	0.64	1	13.323	N/R	25	(TOTEM asja group)
	MGT	0.16	0.78	0.94	5.365	N/R	20	(EHI, 2014)
	PEM	0.36	0.52	10	N/R	500000	15	(Ammermann et al., 2015)
	SOFC	0.54	0.27	10	N/R	500000	15	(Giarola et al., 2018)

Table 37 – New Technologies specifications

3.5.1 Photovoltaic generation

Since the great importance that PV systems represent nowadays for the renewable energy production, they are selected as one of the possible new technology that will contribute to the future share of the system for the production of electricity.
In order to give a more wide range of possible choice, two types of photovoltaic systems are introduced:
The first one, the amorphous silicon, represents a lower efficient system, instead the monocrystalline represents a system with higher cost but with higher efficiency with respect to the first one.
In order to guarantee a suitable implementation within the code the solar irradiance along the reference year has to be define in a Scenario file.
This is obtained by the use of historical data about the irradiation in Italy, provided by (Petrarca, Cogliani, & Spinelli, 2000).
For the economic assessments related to this technology, the study presented by (Bianchini et al., 2016) is considered as reference.

3.5.2 Heat Pumps

For what concern the space heating heat pumps are selected as one of the possible choice.
Thanks to the high efficiency, this type of technology is one of the most promising in the decarbonisation framework.
The type considered in this model is the Air Source Heat pump, that according to the bibliography can reach a COP up to 3 (Sandvall et al., 2017).
For what concern data about cost, some reference in literature are considered to properly define this technology within the model.
The investment cost is considered equal to 1 M€/MW from (Fleiter et al., 2016), instead for the operating cost, only the fixed one is available from literature, and it's considered equal to 40 k€/MW/y, taken from (Sandvall et al., 2017).

3.5.3 Micro CHP

An important emergent technology related to the decentralized production of energy is the micro CHP (mCHP).
These kind of systems can be considered as a centralized power plant but of very low size, in order to be installed directly on-site.
This technology, at the state of the art, is in an early stage with respect to the two above.
In this analysis four types of mCHP are considered, each one of them with a different core.
The first one with power unit an internal combustion engine, the second one with a micro gas turbine, the third and the fourth based on Fuel Cells, respectively PEM and SOFC.
All this technologies are fed with natural gas.

Looking at the table with technical specification it's possible to notice that this four types of technology represent a very wide range of output.
For example, while the SOFC system presents a very high output of electricity with respect to the thermal energy, the PEM based system is exactly the opposite.

Also ICE and micro GT show sensible differences, in fact the ICE system presents an higher electric efficiency, as well an higher cost, instead the GT system shows an higher thermal production and a lower cost.
Since these type of devices are still in an early stage, some difficulties arise in the process of data collection, especially for what concern installation as well operation and maintenance costs.
For the internal combustion engine systems, some studies already available in literature are taken as reference for what is related to the costs.
The investment cost is considered equal to 1 M€/MW_{el}, instead the operation cost is evaluated as 13.3 €/MWh_{el}.
This data are taken respectively from (Possidente, Roselli, Sasso, & Sibilio, 2006) and (Murugan & Horák, 2016).
In order to evaluate the efficiency of the kind of systems, an already available model in the market is taken as reference, with efficiency reported in the Table 37.
(Murugan & Horák, 2016) is also used as reference for the economic data related to the system based on micro gas turbine.
Even for these kind of systems the efficiency is obtained considering a commercial model.

Considering instead the second family of mCHP, the systems based on fuel cells, even in this case a certain amount of uncertainties arise:
In fact, even this type of system are in early stage in the market, so representative data are chosen from previous study.
In particular, for the costs, they are taken from (Ammermann et al., 2015), in which different costs function of the market penetration are explained:
The value selected, equal to 10,000 €/kW_{el}, is the one corresponding to the current level of standardisation of the production (above then 5,000 units produced by the manufacturers and lower than 10,000).
Instead, for what concern the efficiencies, the study conducted by (Giarola et al., 2018) is taken as reference.

3.5.4 Old Technologies

Defined the new set of technologies from which the model can decide the new installations, also the so called "Old Technologies", i.e. the technologies already existing at the base year, are newly defined.
In fact, the model is allowed to install a new capacity from the old set of technologies if they are considered convenient.
One exception for the old technologies is represented for the gas boilers, in fact, for this technology the new capacity that can be installed is considered at slightly higher efficiency with respect to the already existing, respectively with values 90% and 98%.

3.6 MODEL CONSTRATINS

Given the necessity of the model to reflect as much as possible a real behaviour for an energetic system, some boundaries are needed.
These boundaries are mainly of two types:
- On the CO2 emission
- On the technological share.

3.6.1 CO2 emissions

This first type of boundaries, considered as the target of the model, imposes an upper bound to the annual CO2 emissions.
This bound is calculated starting from the environmental policy for the years 2030 and 2050.
According to the 2030 climate and energy policy at least a reduction of the 40% in the greenhouse gasses emission is requested (with respect to the level of the 1990).
Since the considered system is not an existing one, an assumption is needed.
In order to calculate the reduction that has to be achieved, an intermediate step is requested.
According to the data of the ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale) in the 2015 a reduction of the 16.7 % with the respect of the 1990 was already achieved, so the percentage needed for the 2030 is 23.3%, that calculated on the level of the 2015 gives the 25%.
The same approach is used for the year 2050, but this time with two different targets, the first one, a reduction of the 60% in emission with respect to the 1990, and a second of reduction of 80%.
Even in this case, the percentage with respect to the 2015 is calculated.
The Table 38 shows the results of the emission constraints

Year	Target 1990 Reference year	Target 2015 Reference year
2030	40%	25%
2050	60%	45%
2050	80%	68%

Table 38 – Targets for GHGs emission

In order to allow the code to calculate the emission related to the processes, the implementation of an emission factor is required.
This is obtained by the means of the introduction of a factor on the usage of the Natural gas, as well a factor on the import of electricity.
In order to properly choose these factors data from ISPRA are taken as reference.
Data from databank assigns an emission factor to the natural gas equal to 369 g/kWh referred to the lower heating value (Caputo & Sarti, 2015).
The factor related to the import of the electricity is calculated considering the European mix in the electricity production.
Starting from the European share for the year 2015 the average emission factor is calculated.
Calculation and results are presented in Table 39.

	Share for electricity production 2015	Emission factors [gCO2/kWhel]
Renewables	0.3	0
Natural Gas	0.16	369
Coal	0.24	883
Oil	0.02	623
Nuclear	0.27	29
Average emission factor [gCO2/kWhel]	291	

Table 39 – Emission related to import of electricity 2015

Further considerations are important for this factor, in fact, since it's related to the mix for the electricity production it's therefore reasonable to considering it not constant during the simulation, in order to take into account the increase in the mix of the renewable as well the phase-out of the carbon.

To do this, projections about the evolution in the European mix for the electricity production are requested.
In order to carry out the calculation on the evolution of the emission factor related to the import of the electricity the European scenario EUCO33 is selected.
The latter is a scenario presented from the European commission that sets a target on the electricity production for the year 2030.
Using this scenario, and considering the evolution of the mix as linear it's possible to carry out the average emission factor related to the import of electricity for the next years until the 2050.
Results about this factor are shown in the Table 40.

Share for electricity production 2030 (EUCO33)		Linear interpolation	
		Year	Average Emission Factor [gCO2/kWhel]
Renewable	0.493	2020	263
Natural Gas	0.116	2025	235
Coal	0.151	2035	180
Oil	0.04	2040	152
Nuclear	0.228	2045	124
		2050	96
Average emission factor [gCO2/kWhel]	207.661		

Table 40 – Evolution of the Emission factor related to the import of electricity

3.6.2 Technological constraints

This second type of constraints reflects the necessity to give to the code bounds about the installation and dismantling of the technologies.
In fact, let the code acting without these boundaries will give as result hypothetical situation in which some technology existing at the base year will dismantled entirely before of the end of the technical life.
This behaviour, considered economically convenient by the code, won't reflect a realistic evolution of a system.
Technological constraints are fixed for the two milestone years, 2030 and 2050.

3.6.2.1 Technological constraints 2030

The constraints on the technologies for the year 2030 are presented in the Table 41.

Technology	Bound Type	Bound on	Value
DHN	Lower	Share	7%
CHP plant	Lower	Capacity	As the reference year

Gas Boilers DHW	Lower	Share	30%
Gas Boilers heating	Lower	Share	30%
Electric Boilers	Lower	Share	20%
mCHP GT	Upper	Capacity	10 MW
mCHP ICE	Upper	Capacity	10 MW
PV	Upper	Square meters	83000

Table 41 – Technological Constraints 2030

The Table 41 is structured in order to point out the main features of these constraints:
The first column reports the selected technology while the second shows the type of the bound, in fact it can be lower or upper.
Since the flexibility of the software it's possible to define these bounds on different quantities, in fact, while the CHP plant, for example, is defined on the installed capacity, the Electric and Gas boilers are defined on the percentage of the production mix.

An important remark is needed for the PV technologies, in fact, in order to give a proper bound to this technology the installed capacity has to be defined in square meters instead of MW.
After that the equivalence square meters MW is defined it's possible to define the bound, and this is done by the use of a previous study conducted by (Bergamasco & Asinari, 2011).
In this study the maximum available surface is calculated for Turin and the related hinterland:
In the hinterland, the city of Nichelino represents the one that mostly fits the data about population used in this thesis, so the maximum available surface for this town is taken as reference.

About the selection of these constraints it's possible to argue that they are selected in order to drive the model toward a reasonable evolution.
For example the centralized CHP plant is considered to remain at least at the size of the starting year until the technological life, in fact it will be unlikely that it will be dismantled before the end of his technological life.
Furthermore for some technologies, such as mCHP, a maximum capacity installed at the 2030 is defined, in fact being a very performant technology, the free code without constraints may decide to install a capacity out of a reasonable scale.

Another important specification for these boundaries has to be pointed out:
they are considered with a linear interpolation, i.e. starting from the base year until the milestone one, they arrive to the limit with a linear trend.
This decision is taken in order to have a gradual evolution of the system without steep variations.

3.6.2.2 Technological constraints 2050

In order to proceed with the simulation further technological constraints for the second milestone year are required.
In order to have a progressive reduction of the older technologies the constraints are defined considering a linear continuation of the ones already defined for the 2030.
So, Electric boilers and gas boilers are considered with a linear reduction for the minimum value, instead DHN as well CHP are not bounded anymore.
In fact, since the technological life is already over, the code is free to select again these technologies or not.
In Table 42 the technological constraints for the year 2050 are reported.

Technology	Bound Type	Bound on	Value
Gas Boilers DHW	Lower	Share	15%
Gas Boilers heating	Lower	Share	10%
Electric Boilers	Lower	Share	0%
PV	Upper	Square meters	83000

Table 42 – Technological Constraints 2050

4 RESULTS

Once that the model is completed the simulations can be performed and the results are available for the post processing.
This Chapter is devoted to the presentation of the results obtained through the simulations.

As already explained in the previous Chapter two main scenarios are analysed, according to the emission target:
- 60% reduction with respect to the 1990 level, called “SCEN60”,
- 80% reduction with respect to the 1990 level, called “SCEN80”.

In the following paragraphs the results about these two scenarios are presented, and then a comparison among them is performed, in order to point out the main similarities and differences as well.
The main aspects presented in these results are regarding:
– Technological share;
– CO2 Emissions;
– Costs.

4.1 SCEN60

This first analysed scenario is the less strongly constrained between the two, in fact the emission target is considerably less challenging than the second one.
In the following paragraphs the main features related to technological share, CO2 emissions and costs are shown.

4.1.1 Technological share

The first aspect considered in the phase of results organisation is the technological share adopted by the code in order to satisfy the demands as well achieve the emission targets.
In Table 43 shares in percentage value for the three demands are shown.

Share Percentage SCEN60		2015	2016	2020	2025	2030	2035	2040	2045	2050
Domestic Hot Water										
	Gas Boilers Old	0.5	0.48	0	0	0.13	0	0	0	0
	Gas Boilers New	0	0.05	0	0	0.17	0.25	0.25	0.19	0.21
	Electric Boilers	0.5	0.48	0.25	0.25	0.25	0.49	0.53	0.25	0.25
	ICE mCHP	0	0	0.75	0.75	0.45	0.26	0.23	0.56	0.54
Space Heating										
	District Heating	0.14	0.14	0.14	0.07	0.06	0.06	0.06	0.06	0.06
	Gas Boilers Old	0.86	0.86	0.71	0.48	0.24	0	0	0	0
	Heat Pumps	0	0	0.13	0.14	0.21	0.25	0.26	0.32	0.38
	GT mCHP	0	0	0	0.17	0.17	0.17	0.17	0.17	0.17
	ICE mCHP	0	0	0	0.13	0.21	0.25	0.24	0.20	0.15
	Gas Boilers New	0	0	0.02	0.02	0.11	0.28	0.28	0.25	0.25
Electricity										

CHP plant	1	1	0.78	0.46	0.30	0.24	0.14	0.14	0.13
Import	0	0	0.13	0.21	0.32	0.36	0.46	0.52	0.59
ICE mCHP	0	0	0.09	0.24	0.29	0.32	0.32	0.27	0.20
GT mCHP	0	0	0	0.09	0.08	0.08	0.08	0.08	0.08

Table 43 – Technological Share SCEN60

4.1.1.1 Space heating

Since this demand is the highest within the model, his evolution is the main factor that drives the change toward a less emitting technological share.
In Figure 34 the trend of the technologies used for the production of space heating is descripted.

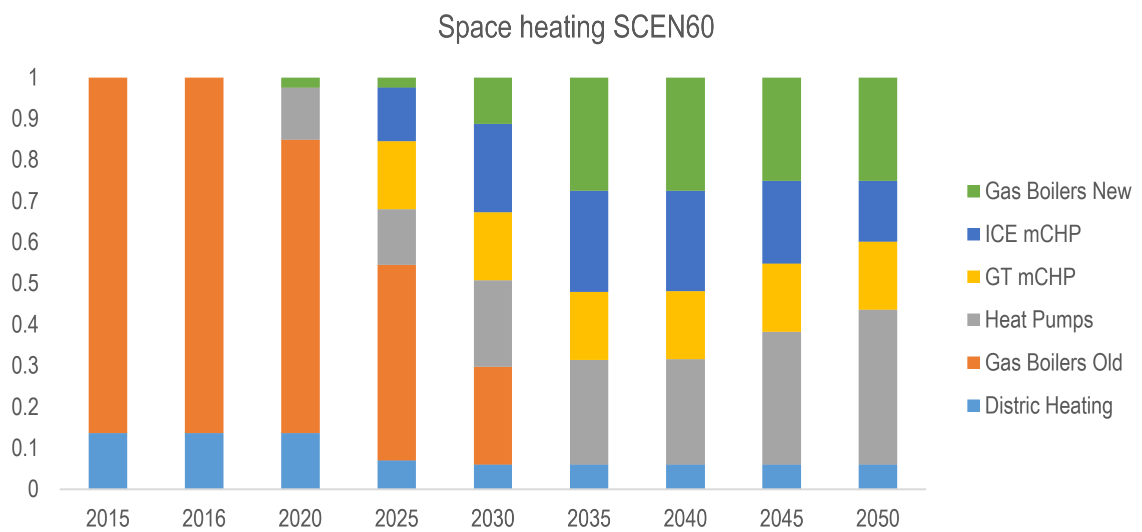

Figure 34 – Space heating Share SCEN60

From the previous Figure it is possible to understand the trend of the new technologies as well of the olds one:
In fact, starting from the initial share highly held by the gas boilers, until the 2050 a great importance is acquired from the micro CHP and from heat pumps.
The latter, in fact, acquire a share close to the 40% in 2050.
Also the micro CHP technologies hold a sensible part in the final share, with a total percentage higher than the 30%.
This percentage is almost equally divided between ICE and GT, while the fuel cells technologies are excluded from the final share.
However this result is not unexpected, in fact, at the state of the art the fuel cells technologies present a very high investment cost, that can't be counterbalanced from the performances.
Furthermore, these kind of systems are considered operating with Natural gas, so they emit as the other type of micro CHP, and as consequence there is not a gain from an emission point of view.
An important remark is also needed for the district heating, in fact it will decrease until the 2030 acquiring a share close to the 6% and then remains stable, even if no technical constraints are applied.
Since the high efficiency presented from the new gas boilers, supposed equal to 98% also this technology present a high share, with a percentage close to the 20%.

4.1.1.2 Domestic Hot Water

The second thermal demand is related to the domestic hot water.
In Figure 35 the technological share along the years of simulations is reported.

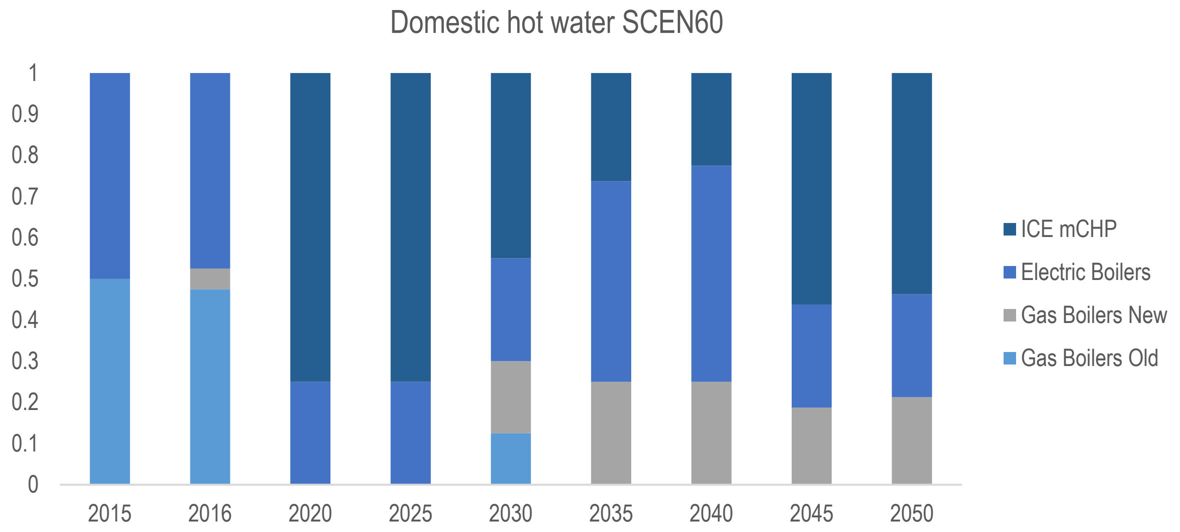

Figure 35 – Domestic hot water Share SCEN60

Starting from the initial share equally distributed between electric boilers and gas boilers, during the years the highest percentage of share is acquired from ICE mCHP technologies that hold more than the half production to the year 2050.
Since the trend of the system toward the electrification, also the electric boilers hold an important percentage at the last year of simulation, with one fourth of the share.
As in the case of the space heating, also the gas boilers are still present in the last year, being responsible for the 20% of the production.

4.1.1.3 Electricity

As already expected from the discussion about the decrease of the emission factor from the import of electricity, in this first scenario the import of electricity hold a very high percentage on the total production.
This can be observed in Figure 36.

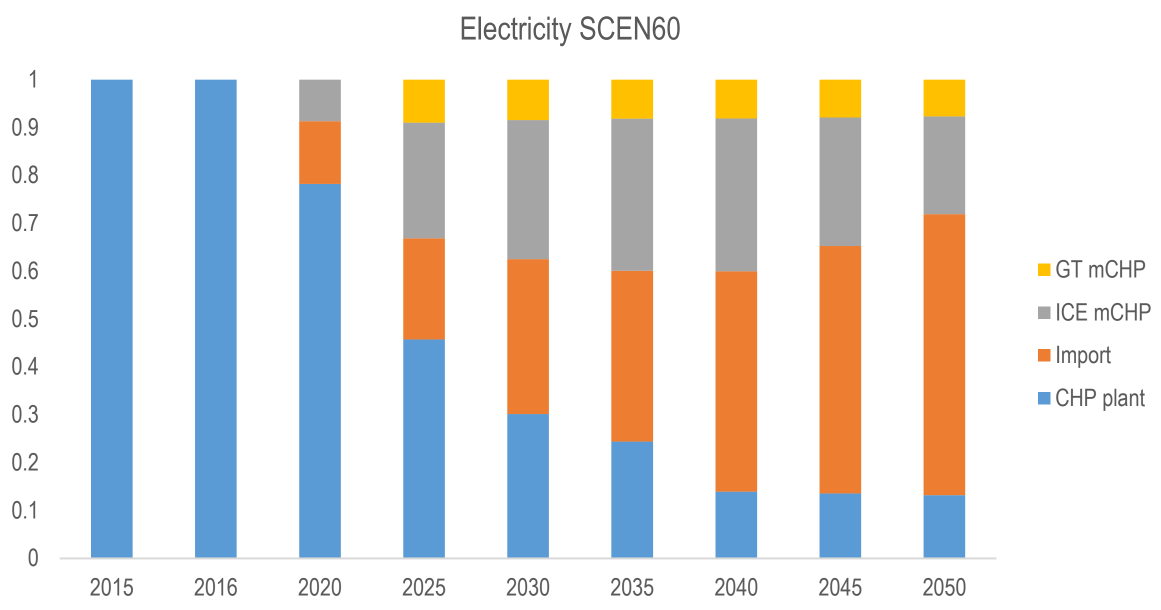

Figure 36 – Electricity production Share SCEN60

Starting from the first year of simulations, in which the centralized CHP plant provides all the electricity needed from the system, progressively the import acquires more share, until the 2050, in which it holds the 59%.
For the electricity production also the ICE systems penetrate in the technological mix from the first year in which they are available, considered in 2020.
The technological share for this kind of systems increases until 2040, and then decreases, due to the emission constraints.
Always concerning the micro CHP system a non negligible percentage is hold form the micro Gas turbines, that acquire the 8% in the 2025 and then remain stable until the end of the simulation.

4.1.2 CO2 emissions

Since the proposed thesis aims to a clear understanding of the pathway toward the decarbonisation in the urban context, the CO2 emissions are the main constraints in these simulations.
In fact, being the constraints fixed on the emissions, the whole model evolves in function of them.
In Figure 37 the emissions along the year of simulation are shown.

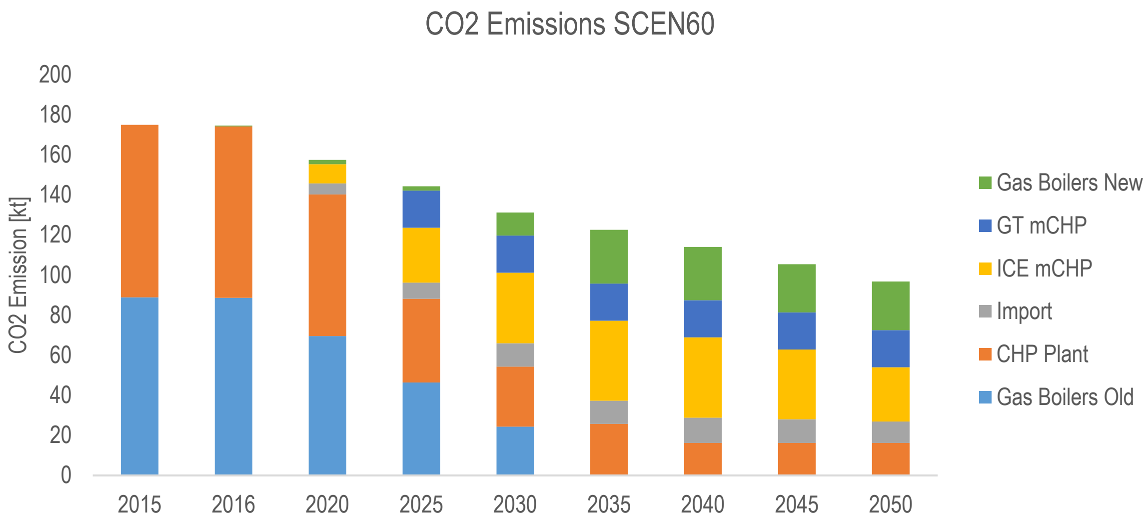

Figure 37 – CO2 Emission SCEN60

Starting from the initial value for the year 2015, equal to 175 kt, the emissions decrease along the years with a non linear pattern until the two milestone years.
The first, 2030, present emissions for 130 kt, so the 25% reduction is achieved.
As well, the 2050 accounts for 96 kt of CO2, so even the 2050 constraints equal to -45% is achieved.
In this general trend it is interesting to point out which are the main technologies that are responsible for these emissions.
Starting from the base year, in which the gas boilers and the centralized CHP plant were the only two emitting technologies, progressively the share of these two decrease, leaving the space for the new technologies.
In fact, in the last year of simulation the emission are distributed on the already discussed set of technologies and on the import as well.
Making a cross check on the import, even thought it holds the 59% in the production of electricity, on the emission side it holds only the 10%.
In Figure 38 it is possible to read all the percentage on the emission for the year 2050.

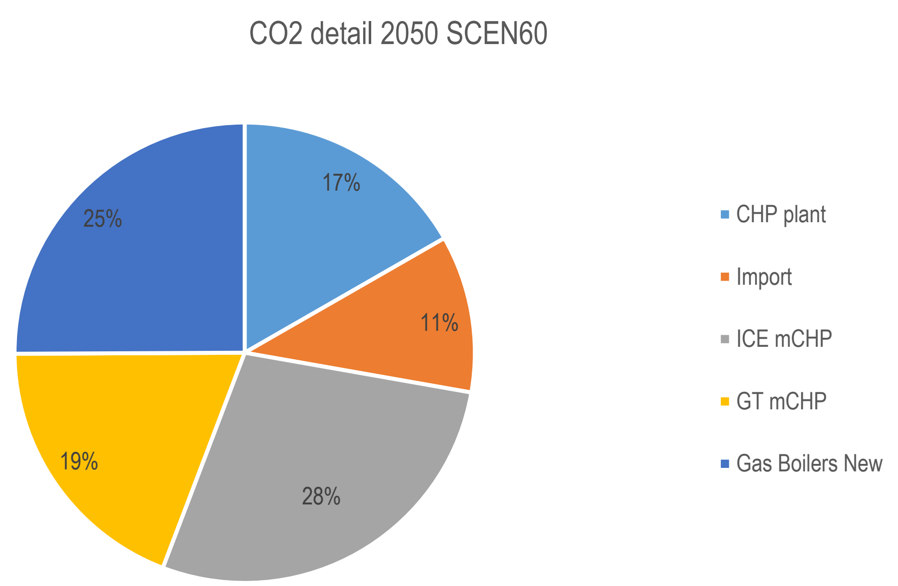

Figure 38 – CO2 Emission 2050 SCEN60

Looking at the previous figure it is possible to notice that there is not a great prevailing technology, in fact the higher percentage is hold from the ICE mCHP with the 28%.
In Figure 39 is possible to see the contribution on the CO2 emissions along all the years of simulation for each technology.

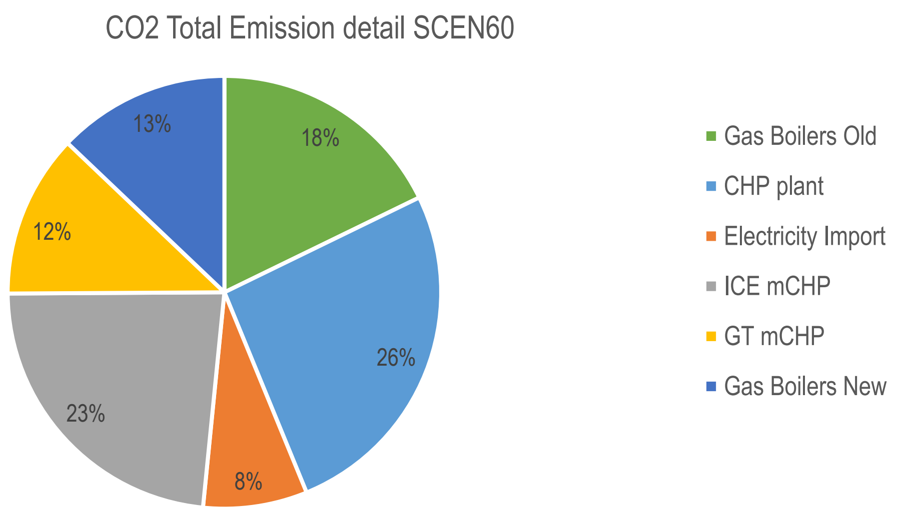

Figure 39 – Total CO2 Emission detail SCEN60

4.1.3 Costs

The last aspect considered in the result analysis is the one related to the system total cost.
This parameter, actually, it's the most important in term of optimisation, in fact the aim of the code is to obtain the configuration at lower cost that respect all the constraints.

In this analysis the costs are divided into three types:

1- Operation and Maintenance Costs, that include all the fixed as well variable cost related to the equipment;
2- Import costs, that include all the costs needed for the import of Electricity and Natural Gas;
3- Investment Costs, that account all the costs related to the investments on the equipment.

4.1.3.1 Operation and Maintenance Costs

In Figure 40 the O&M costs trend is reported.

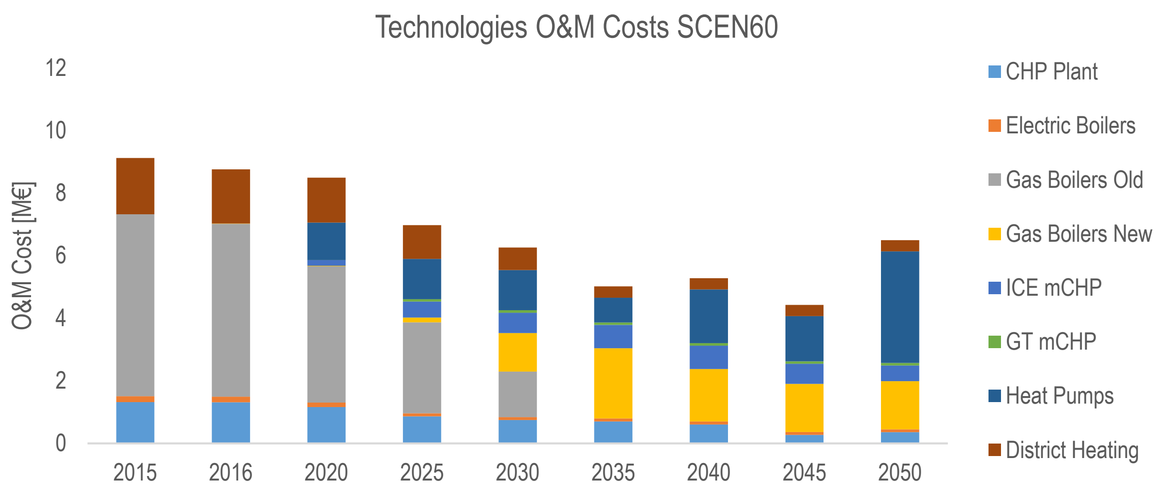

Figure 40 – Technologies O&M Costs SCEN60

From the previous figure it is possible to notice the trend of this type of cost:
In general it's quite stable until the 2020, then it decrease until the 2050, year in which a slightly increase is present.
This behaviour is given by the increase in the efficiency of the equipment along the years.
Furthermore, in Figure 41 the subdivision of these costs is presented.

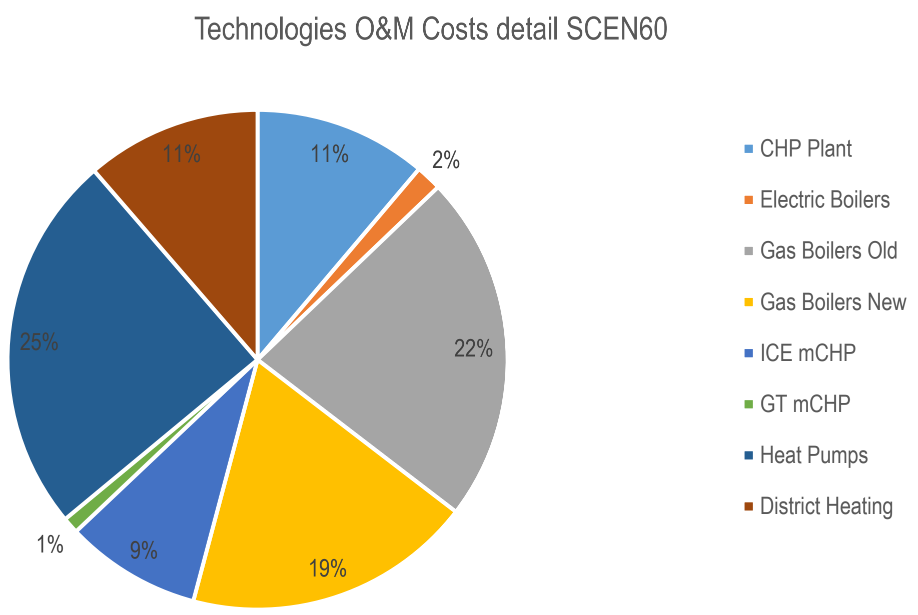

Figure 41 – Technologies O&M Cost detail SCEN60

4.1.3.2 Import Costs

This second section of the costs is related to the import of electricity and natural gas. In Figure 42 the trend for the import is shown.

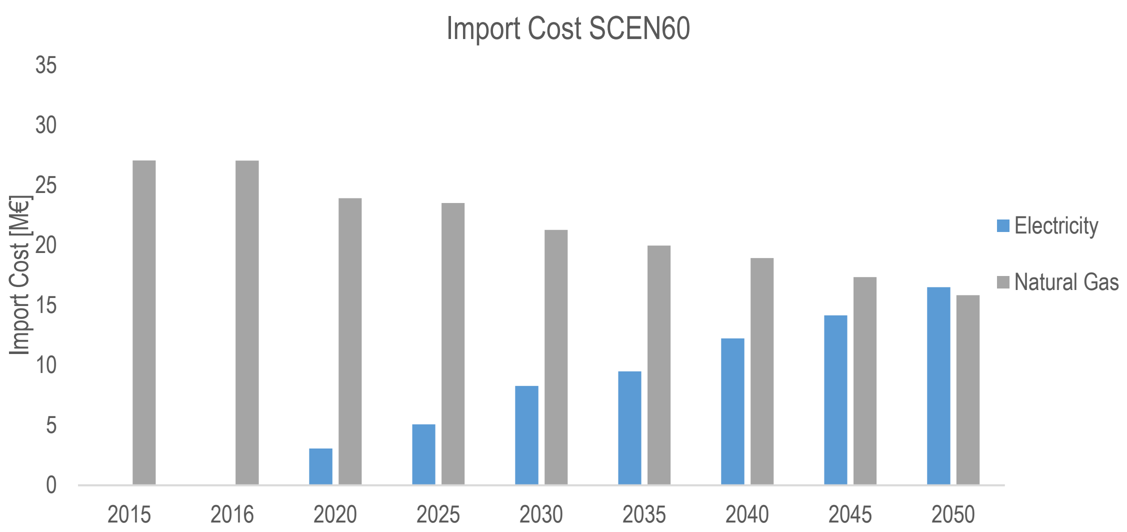

Figure 42 – Import Costs SCEN60

This behaviour was already predictable from the technological share, in fact until the last year of simulations the electric technologies such as heat pumps acquire an important percentage in the technological mix, so the necessity to meet the environmental constraints leads inevitably to the increase on the electricity import.

4.1.3.3 Investment Costs

The third type of costs are the ones related to the investment for the new technologies.
In Figure 43 the annuity for the years of simulation are shown.

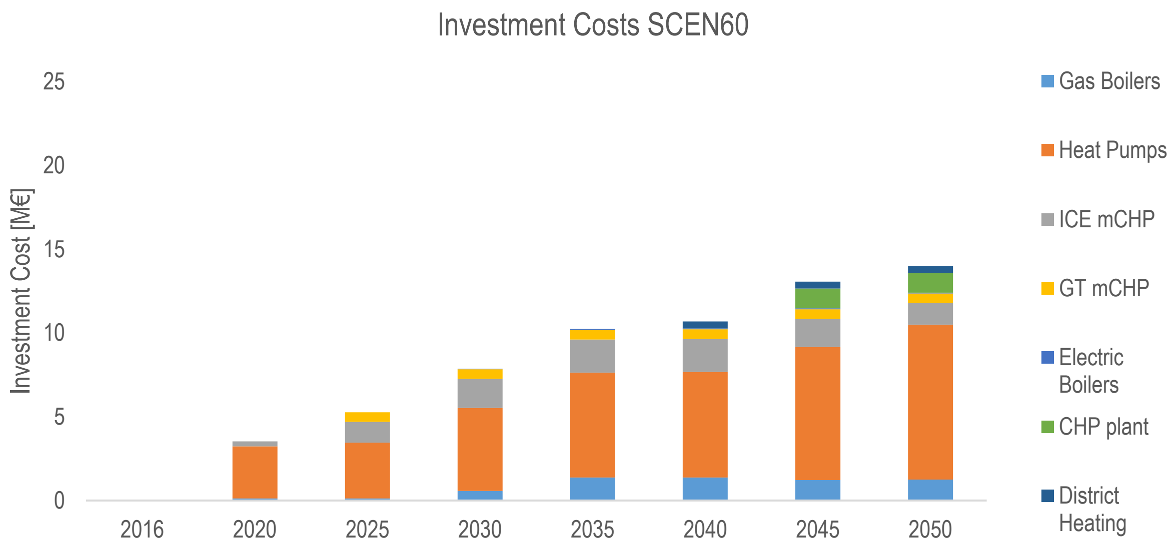

Figure 43 – Investment Costs SCEN60

Starting from the 2020 it is possible to notice the great impact of the heat pumps on the investments, in fact them account the highest percentage of investments for each year of simulation.
In Figure 44 the subdivision of the investments for each technology is presented.

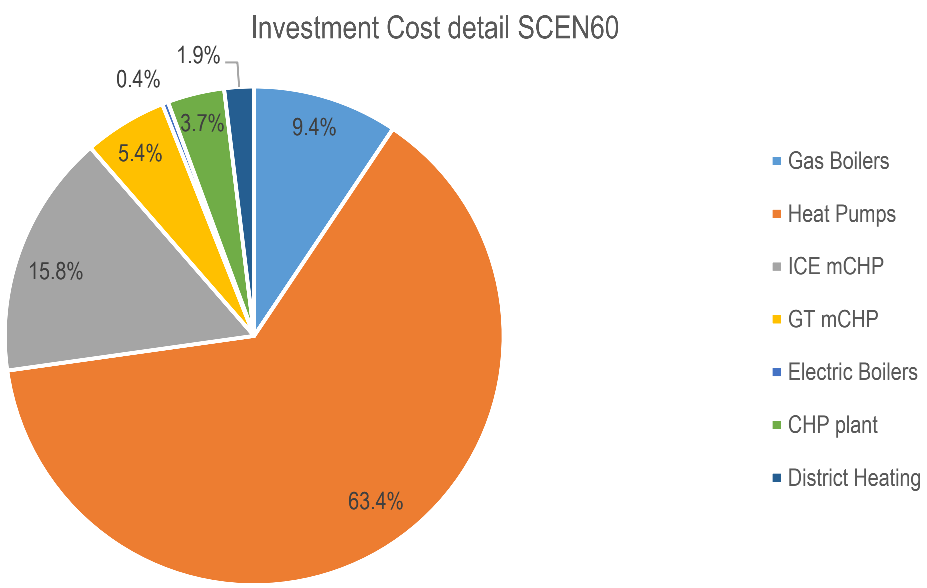

Figure 44 – Investment Cost detail SCEN60

From the previous figure what said regarding the heat pumps appears even more clear:
In fact, this type of technology accounts for the 63% of the total investments.

The second technology for investments is the ICE mCHP, but with a percentage sensibly lower equal to 15.8%.

4.1.3.4 Total Cost

Since all the type of costs are introduced it's possible to define the total cost for this first scenario.
A remark is needed for this section, in fact, the three type of costs already seen are expressed as annuity, so no discount rate is considered.
Thus, considering the total cost of the system, that's the objective function of the simulation, a discount rate is needed in order to actualize all the payment to the base year (2015).
The discount rate is considered equal to the 5%.
In Figure 45 the total actualized cost per sector is presented.

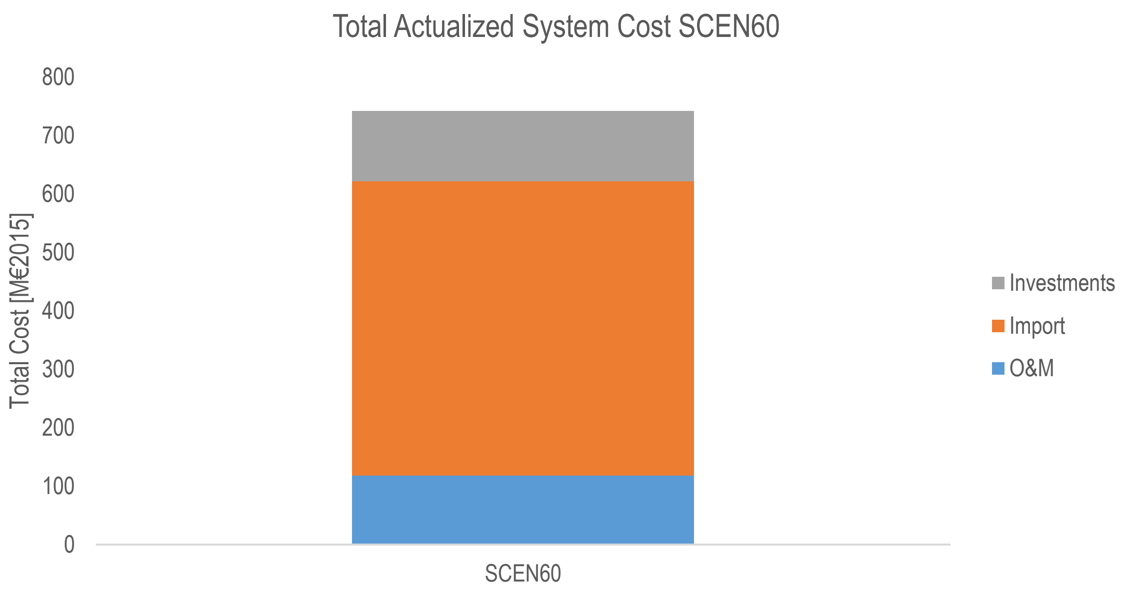

Figure 45 – Total Actualized System Cost SCEN60

Looking at the chart above it's possible to have a more clear picture of the details related to the total cost of the system.
In fact, what already seen in the dedicated sections is now presented in a single chart, having the total cost.
The total cost, that is equal to 742 M€ actualized to the 2015 is splitted into unequal parts, in fact as already mentioned, the import sector is the one that holds the highest percentage, with a value close to the 68%.
The remaining percentage is almost equally splitted between the Operation and Maintenance and the investments.
This consideration about the division is evidenced in Figure 46.

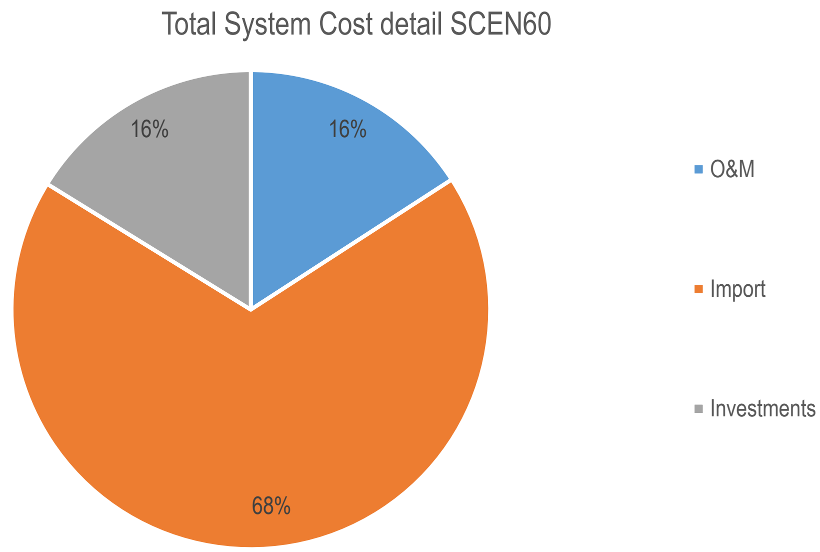

Figure 46 – Total System Cost detail SCEN60

4.2 SCEN80

The second scenario proposed is the one with the highest constraints, in fact a reduction of the 80% in CO2 emission with respect to the 1990 level has to be achieved.
The structure of the results that follow is the one already proposed for the first scenario.

4.2.1 Technological Share

Even in this case the first aspect considered is the technological mix adopted from the system in order to satisfy the demands but at the same time absolve to the emission target, that are more restrictive than the first scenario.
In Table 44 these information about the mix for the production are summarized for the years of simulation.

Share Percentage SCEN80		2015	2016	2020	2025	2030	2035	2040	2045	2050
Domestic Hot Water										
	Gas Boilers Old	0.50	0.48	0	0	0.13	0	0	0	0
	Gas Boilers New	0	0.05	0	0	0.17	0.25	0.25	0.19	0.15
	Electric Boilers	0.50	0.48	0.25	0.25	0.25	0.49	0.53	0.25	0.25
	ICE mCHP	0	0	0.75	0.75	0.45	0.26	0.23	0.56	0.60
Space Heating										
	District Heating	0.14	0.14	0.14	0.07	0.07	0.06	0.06	0.06	0.06
	Gas Boilers Old	0.86	0.86	0.71	0.48	0.24	0	0	0	0
	Heat Pumps	0	0	0.08	0.11	0.22	0.30	0.51	0.69	0.85
	GT mCHP	0	0	0	0.17	0.17	0.17	0.03	0	0
	ICE mCHP	0	0	0	0.11	0.20	0.20	0.20	0.12	0.04
	Gas Boilers New	0	0	0.07	0.07	0.11	0.28	0.20	0.13	0.05

Electricity										
	CHP plant	1.00	1.00	0.73	0.43	0.31	0.14	0.12	0.11	0.10
	Import	0	0	0.18	0.25	0.33	0.52	0.63	0.75	0.83
	ICE mCHP	0	0	0.09	0.22	0.28	0.27	0.23	0.15	0.08
	GT mCHP	0	0	0	0.09	0.08	0.08	0.01	0.00	0

Table 44 – Technological Share SCEN80

4.2.1.1 Space Heating

In Figure 47 the technological share for the production of space heating is shown.

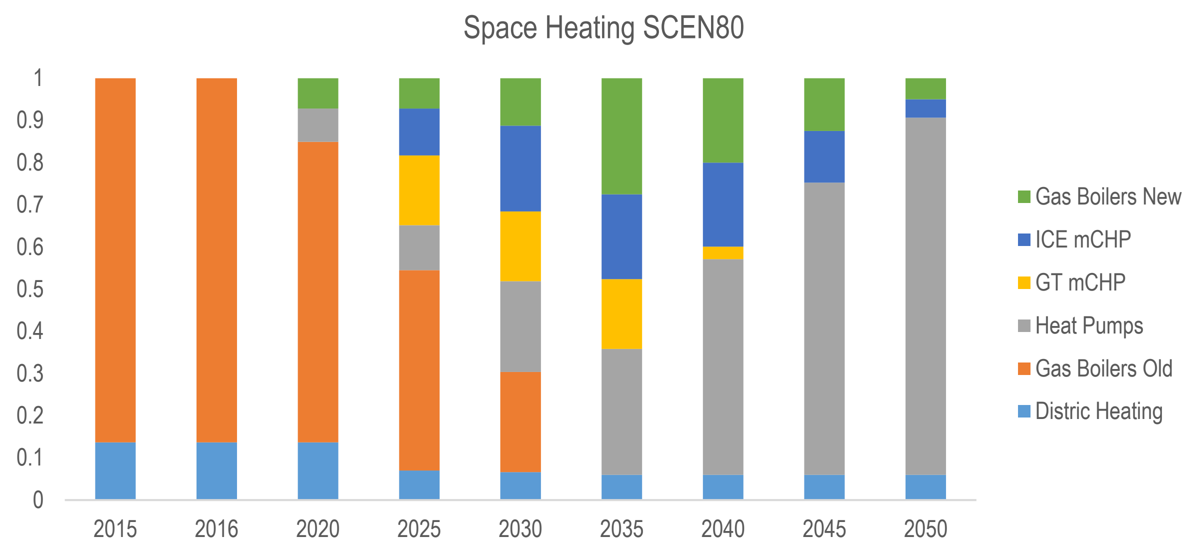

Figure 47 – Space Heating Share SCEN80

Even in this case it is possible to notice an huge increase in the percentage acquired from the heat pumps starting from the 2020 until the last year of simulation.
This increase is even more marked than in the first scenario, in fact in the last year, 2050, this technology holds a very high percentage in the mix, close to 85%.
As well for this second scenario the mCHP technologies are involved in the production mix, but with a smallest percentage that decrease until the 2050 due to the more stringent constraints on the CO2 emissions.

4.2.1.2 Domestic How Water

In Figure 48 the technological share for the production of domestic hot water is shown.

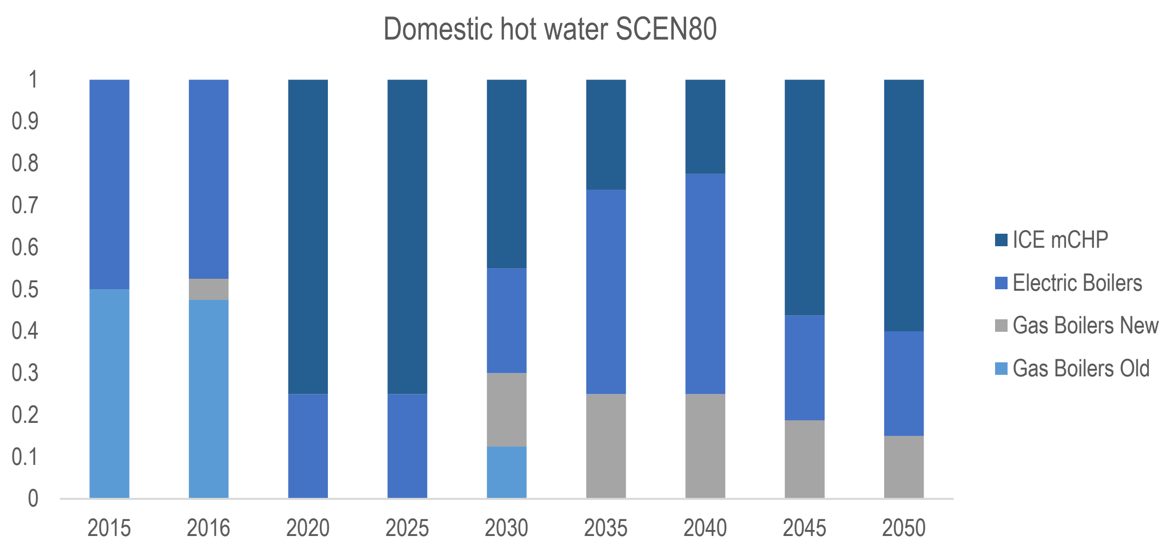

Figure 48 – Domestic Hot Water Share SCEN80

Looking at the above mix it is possible to notice that even in this case the highest percentage is held by the internal combustion engine systems.

4.2.1.3 Electricity

In Figure 49 the share for the production of electricity is reported.

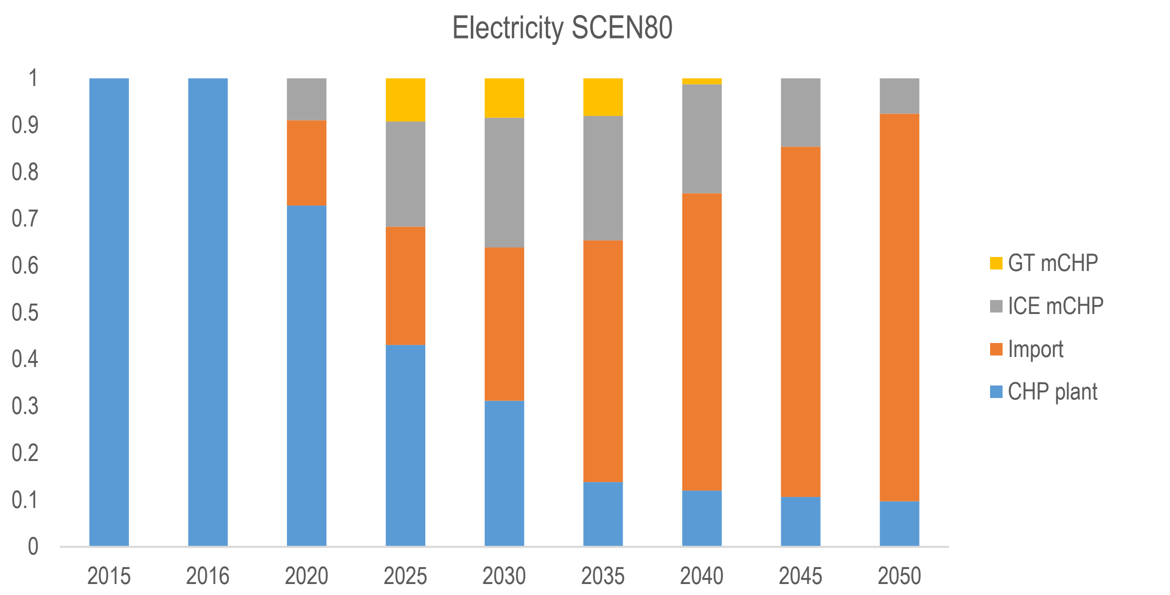

Figure 49 – Electricity production Share SCEN80

Even in this case, but even more than the first case, the percentage of the import is the highest. This aspect is not unexpected, in fact, due to the massive use of the heat pumps in the space heating sector, the consumption of electricity is even bigger than the SCEN60.

This consideration is well represented by the Figure 49 in which is possible to notice the high percentage held from the import proceeding on the years of simulation.

4.2.2 CO2 Emissions

Even for this second scenario the CO2 emissions are exposed.
In Figure 50 the emissions along the years of simulation are pointed out.

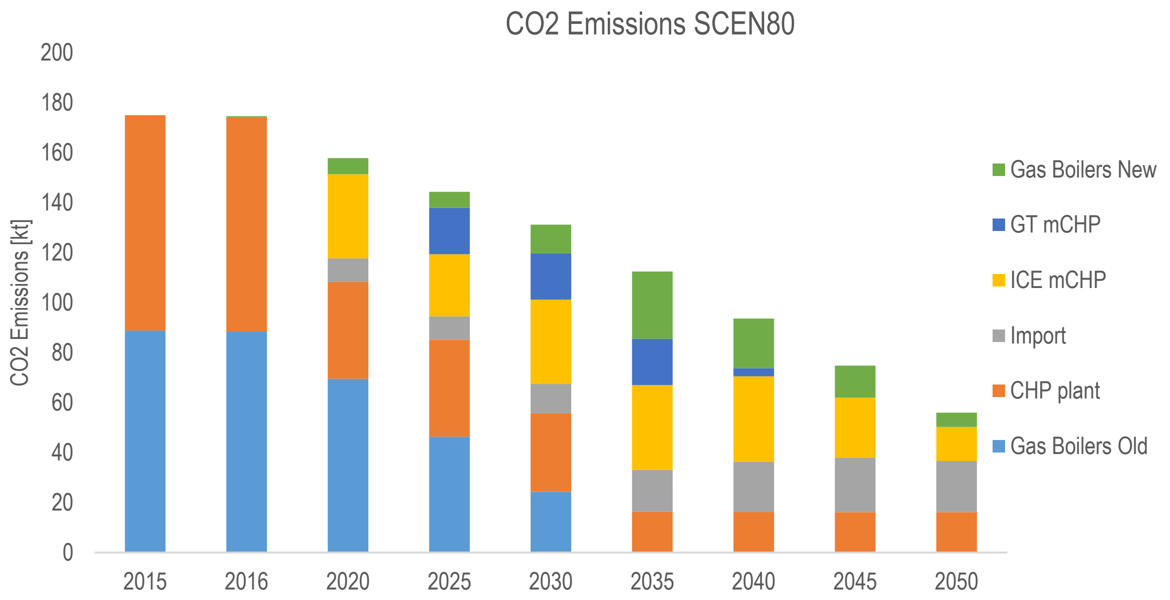

Figure 50 – CO2 Emission SCEN80

Starting from a value close to 175 kt for the 2015, the emissions progressively decrease until the 2050, year in which the environmental target is achieved.
The reduction, considered as -68% of the 2015 and discussed in the paragraph 3.6.1 CO2 emission, is achieved exploiting a very intensive use of heat pumps coupled with import of electricity.
In fact, for the year 2050, the emissions are under the 60 kt.
In Figure 51 the contributions of each technology in the emission for the year 2050 are reported.

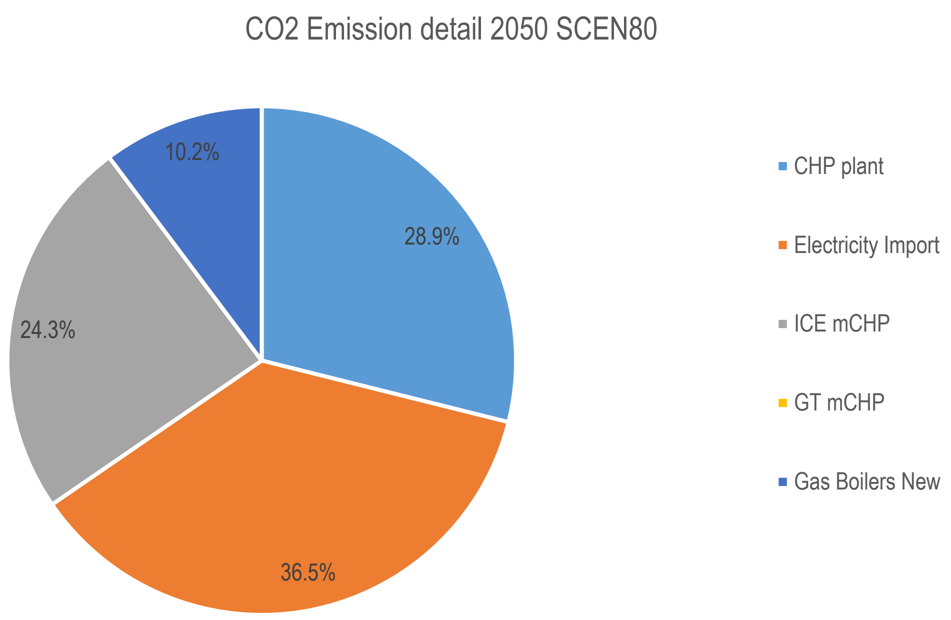

Figure 51 – CO2 Emission 2050 SCEN80

In the figure above the main technologies that have an impact on the CO2 emission are presented: The highest percentage is held by the electricity import, and even in this case, this is an expected result, being the import of electricity one of the main sector in this second scenario.
In Figure 52 the percentages for each technology on the total emission are presented.

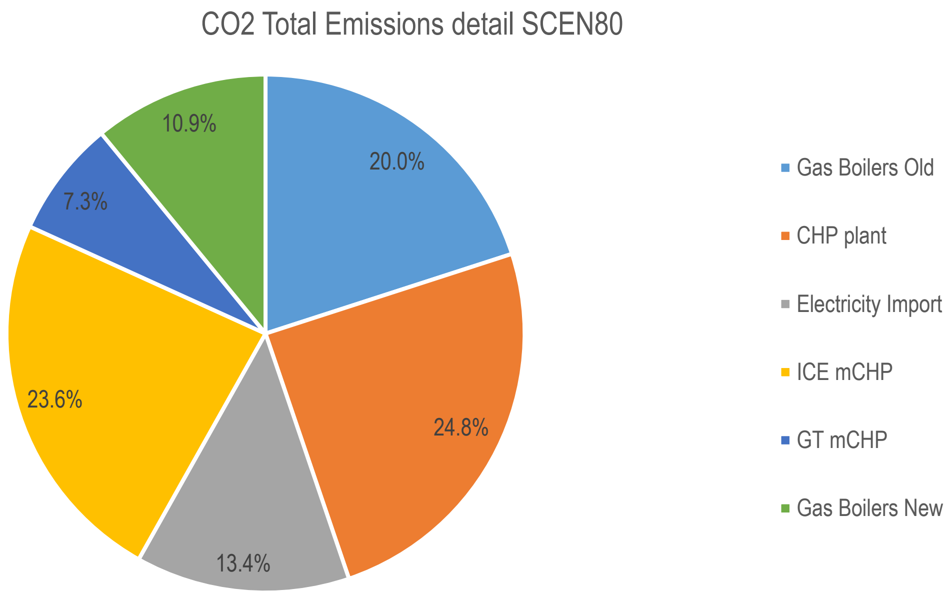

Figure 52 – Total CO2 Emission detail SCEN80

In this second scenario, as well in the first, the main technologies that have a bigger impact on the emissions are the CHP centralized plant, the internal combustion engine micro CHP and the Gas boilers.

4.2.3 Costs

Since that the technological share, as well the CO2 emissions, are already characterized for this second scenario, results about costs are reported in the following paragraphs.

4.2.3.1 Operation and Maintenance Costs

In Figure 53 the annuities for O&M cost are reported for the years between 2015 and 2050.

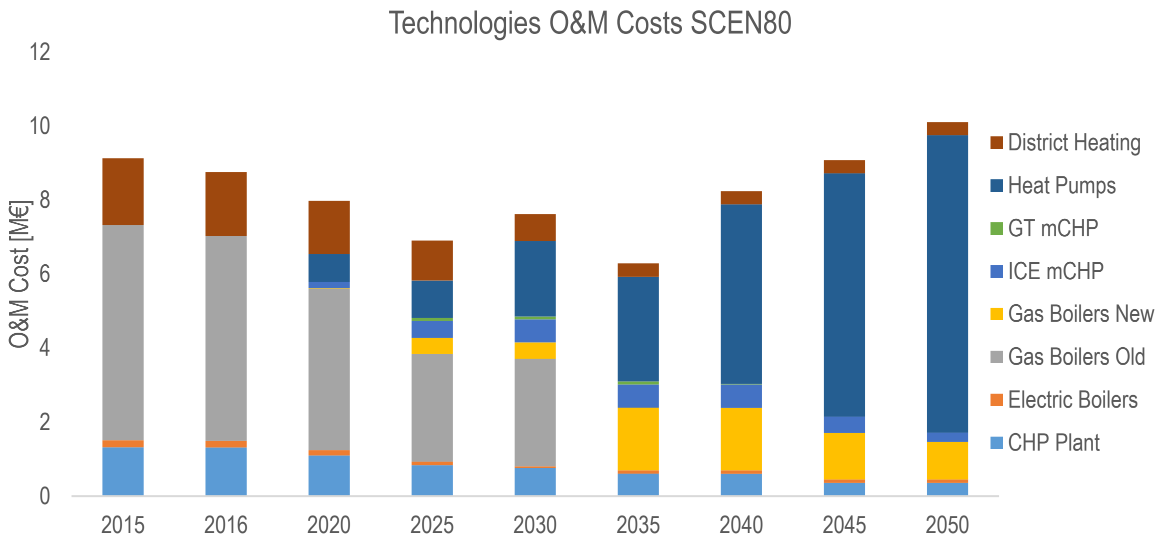

Figure 53 – Technologies O&M Costs

The decreasing behaviour, until 2030, and then the increase until 2050 was already seen, with a lower impact, in the first scenario.
In fact, in this second scenario, this trend is even more marked, due to the more stringent constraints, that lead inevitably to higher operation costs.
In Figure 54 details about the contributions for these costs are reported.

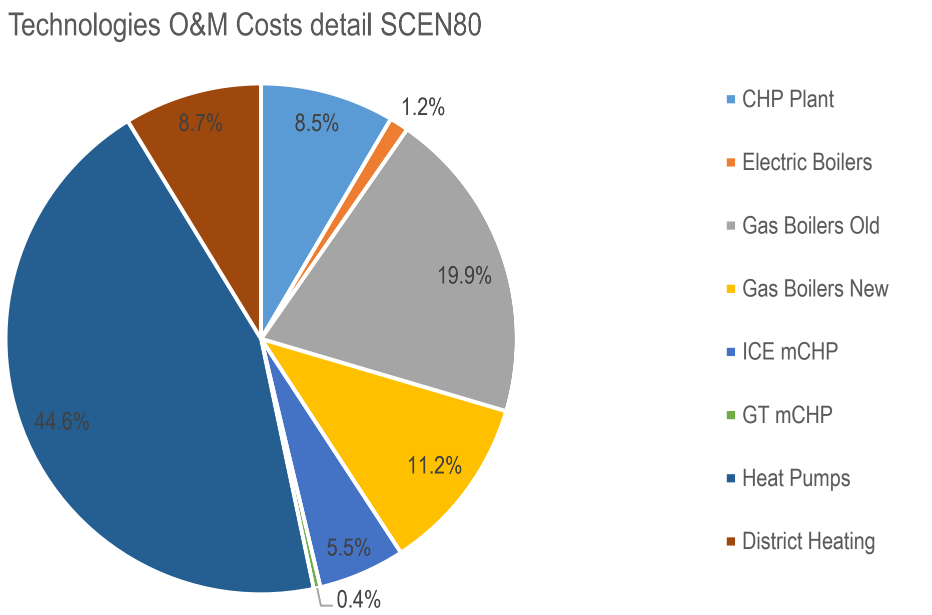

Figure 54 – Technologies O&M Costs detail SCEN80

In this second scenario the biggest part of costs are held by the heat pumps, since they are the main widespread technology for the space heating.

4.2.3.2 Import Cost

In Figure 55 annuity for the import cost are shown.

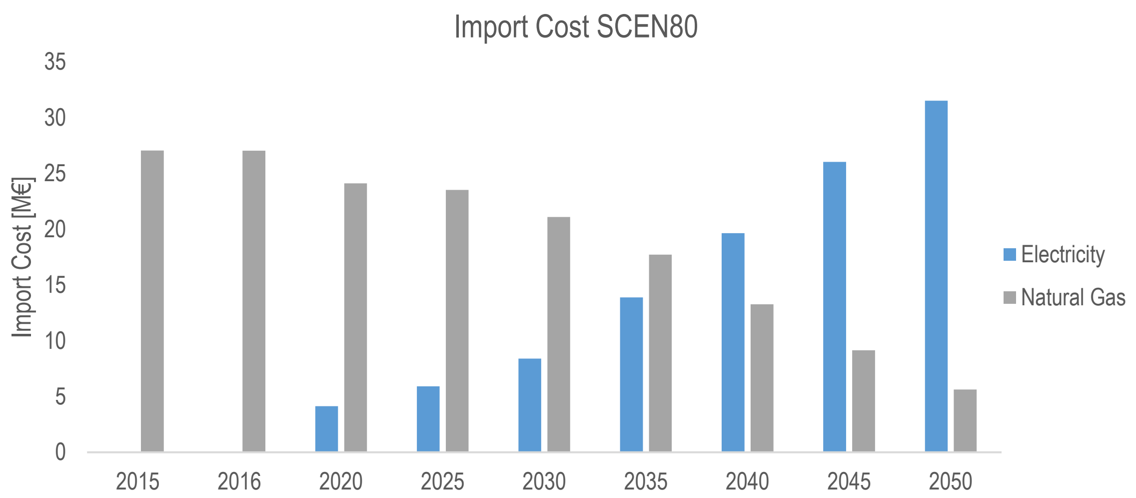

Figure 55 – Import Costs SCEN80

In this case starting from 2020 the import of electricity acquires an increasing percentage until 2050 when more than 70% of the costs related to the import are due to the import of electricity.

This behaviour is due to the large exploiting of the heat pumps technology that require electricity in order to operate.
Being fixed the amount of CO_2 that can be produced, the system tends to import electricity from the outside, since the low emission coefficient related to the process of import.

4.2.3.3 Investment Costs

In Figure 56 the annuity related to the investment for the system are reported.

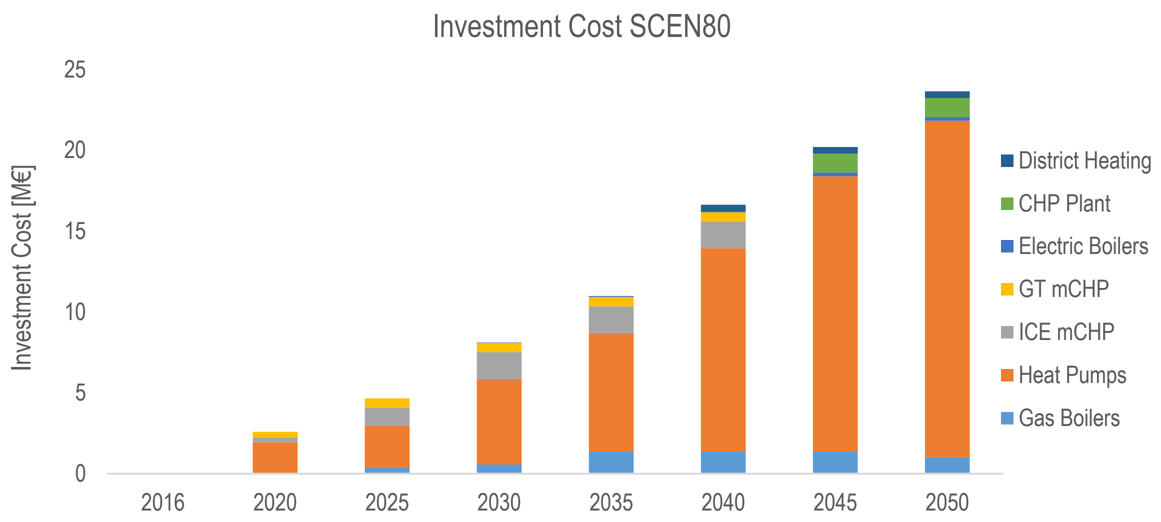

Figure 56 – Investment Costs SCEN80

How already predictable, the major impact in the investment costs is given by the heat pumps, that hold the highest percentage.
In Figure 57 details about the contributions to the total investment cost are presented.

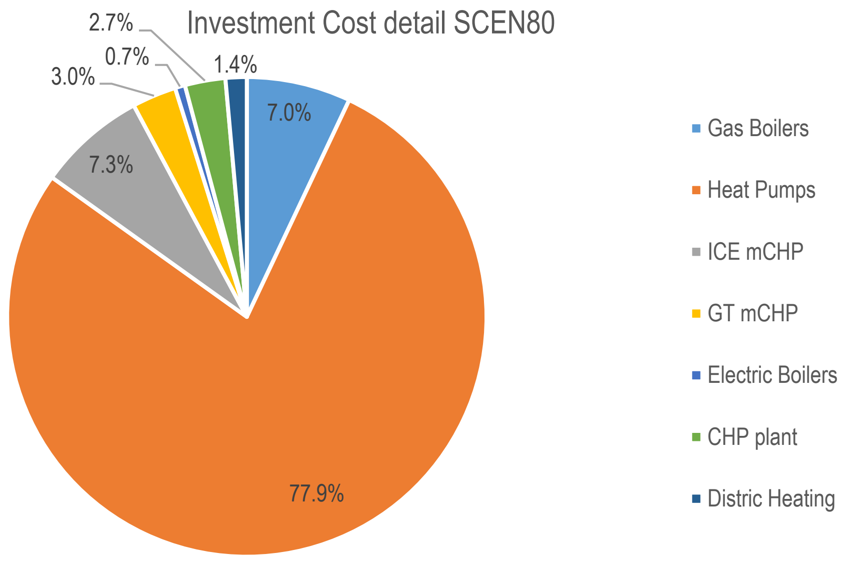

Figure 57 – Investment Costs detail SCEN80

From the previous chart what already said about the heat pumps appear even more clear, in fact they account for the 78% of the total investment along the whole simulation.

4.2.3.4 Total Cost

Even in this case the objective function for the code is the total discounted cost of the system. In Figure 58 the total actualized system cost is reported.

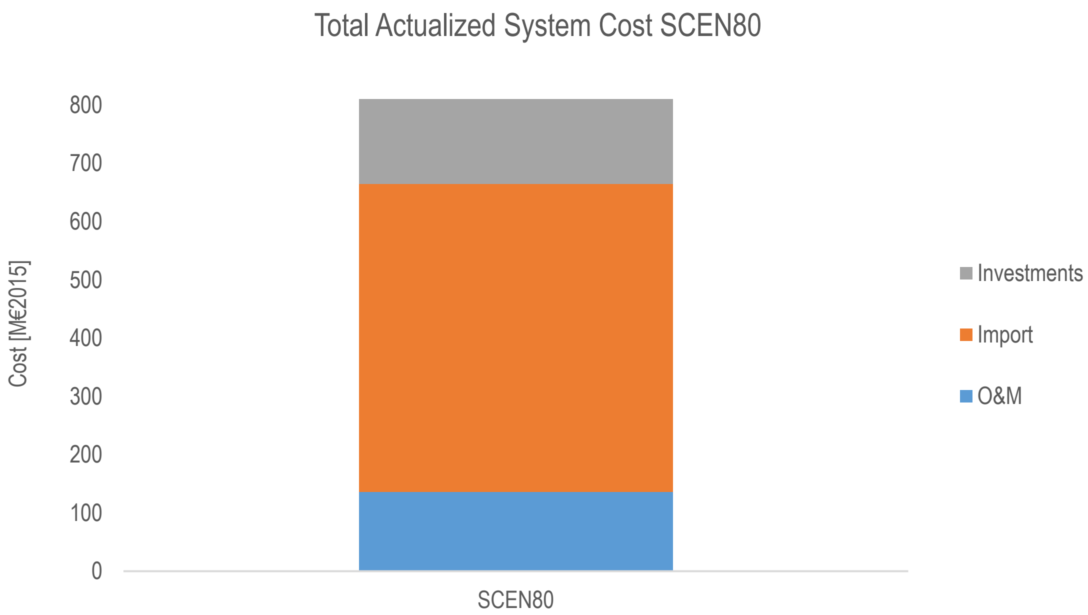

Figure 58 – Total Actualized System Cost SCEN80

As expected the total cost is higher than in the first scenario, in fact, the requirements related to the emissions impose higher efficiency to the system, that is translated into a higher total cost.

Even in this case the import holds the highest percentage of the total cost, while operation and maintenance and Investment hold the remaining percentage.
The detail of the total cost is reported in Figure 59.

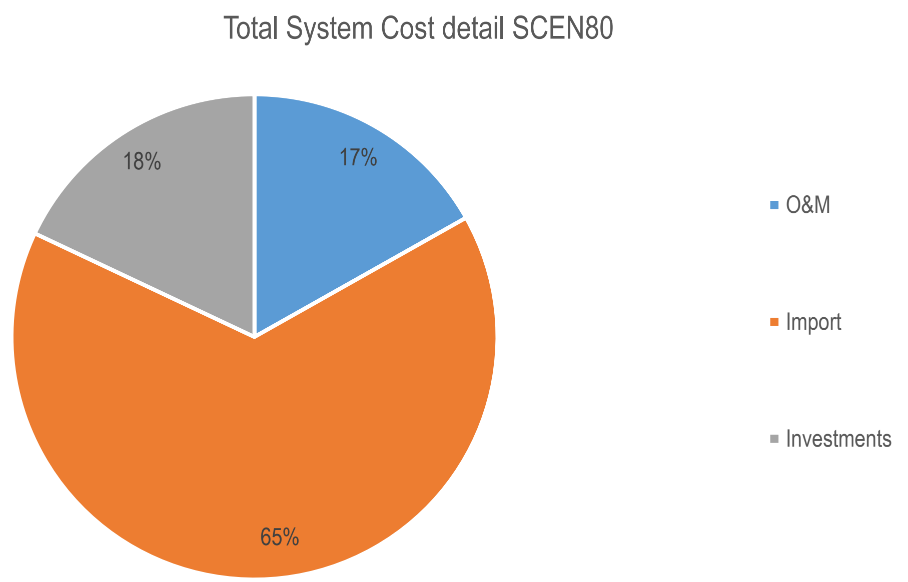

Figure 59 – Total System Cost detail SCEN80

4.3 SCENARIOS COMPARISON

Since that the two scenarios are characterized in term of technological mix, emissions, as well costs, further consideration can be done.

First of all a brief recap of the previous results is done with some charts that compare the two scenarios already discussed.
Then a third scenario is considered:
This scenario does not involve any constraints related to the emissions.

This third scenario that consider the Business As Usual (BAU) is introduced in order to have a baseline suitable for economic and environmental comparisons.
In fact, having the configuration that represent the optimal point only by the economic point of view it is possible to perform some comparisons that leads to the definition of the cost of carbon abatement.

4.3.1 SCEN60 SCEN80 Comparison

This brief paragraph aims to summarize the information contained in the paragraphs above, in order to have a clear picture of the differences between these two scenarios.

In Figure 60, Figure 61, Figure 62, Figure 63 some comparison are reported regarding technological share as well CO_2 Emissions.

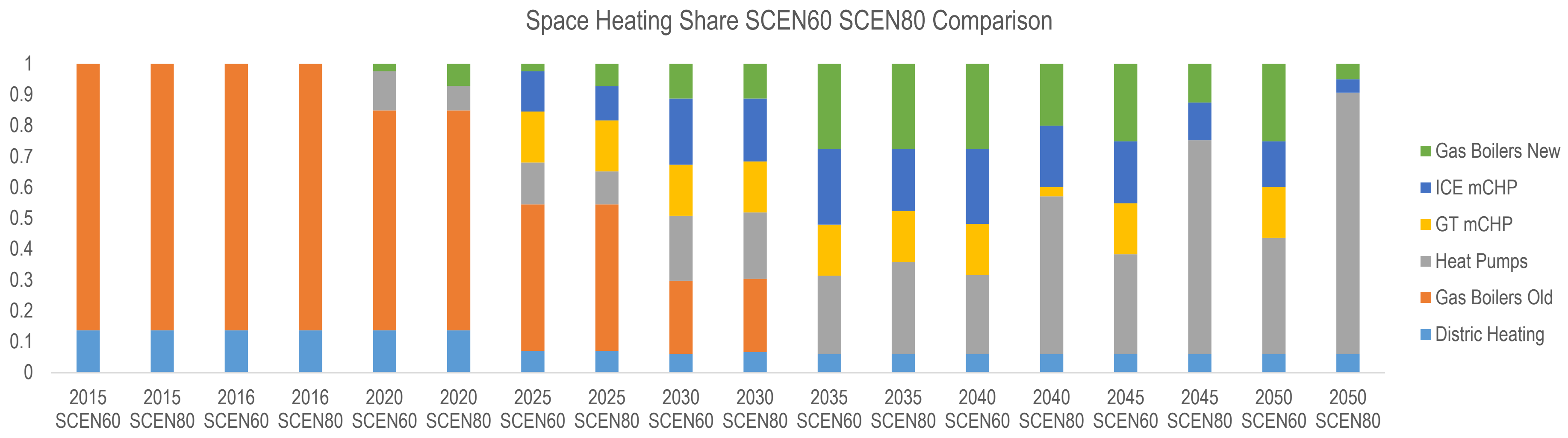

Figure 60 – Scenarios Space Heating Comparison

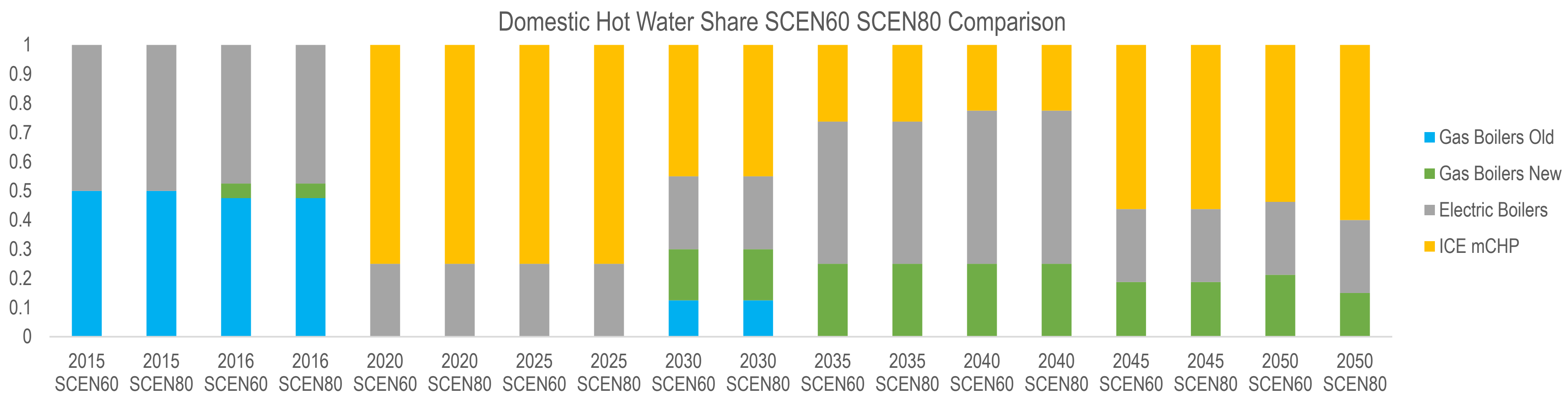

Figure 61 – Scenarios Domestic Hot Water Comparison

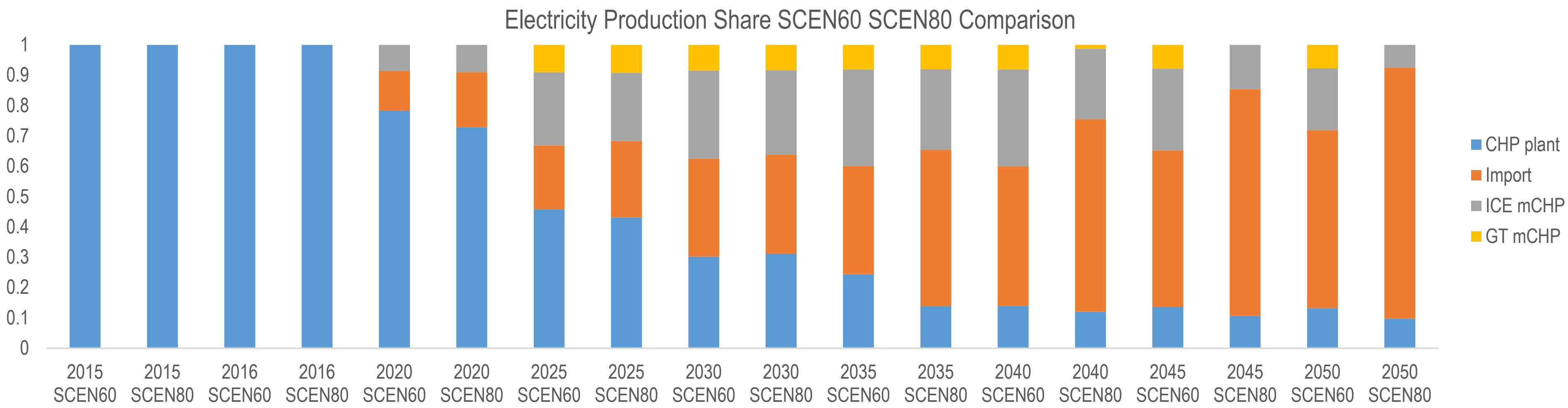

Figure 62 – Electricity Production Share SCEN60 SCEN80 Comparison

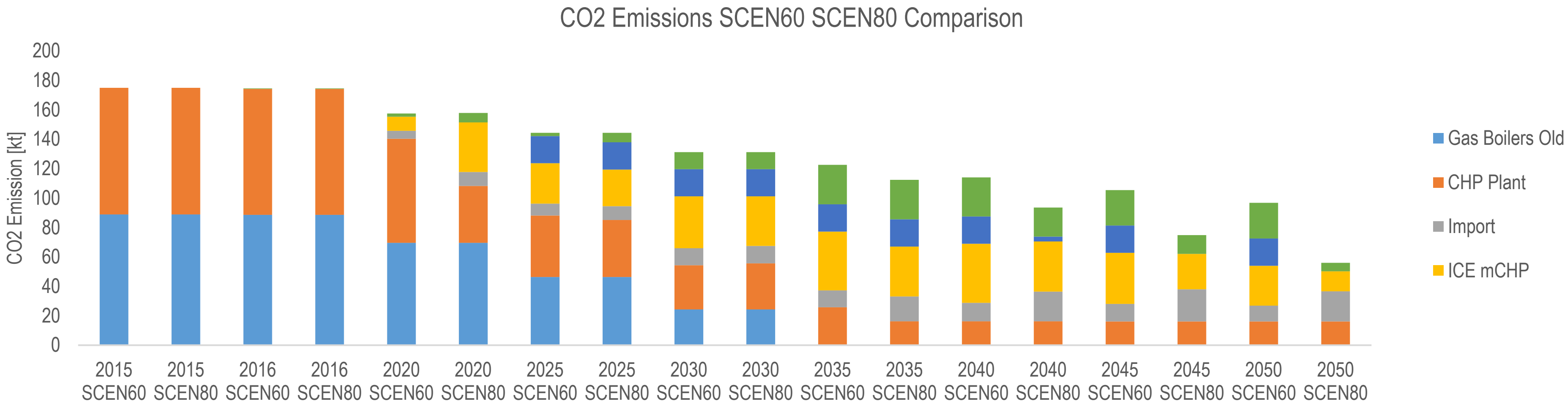

Figure 63 – CO2 Emissions SCEN60 SCEN80 Comparison

4.3.2 Business as Usual Comparison

In order to have a more clear understanding of the two scenarios analysed, a BAU scenario is introduced.
This scenario is obtained with the same assumption of the two already proposed, with the only difference that no constraints on the emissions are imposed.
This difference leads to a different type of optimization, in fact, only the economic point of view is considered.
Since only the economic aspect is accounted in the BAU scenario, making a comparison between it and the two principal scenarios allow us to define the cost needed for the decarbonisation of the system analysed.

In Figure 64 a comparison between the three scenarios for the space heating production is reported.

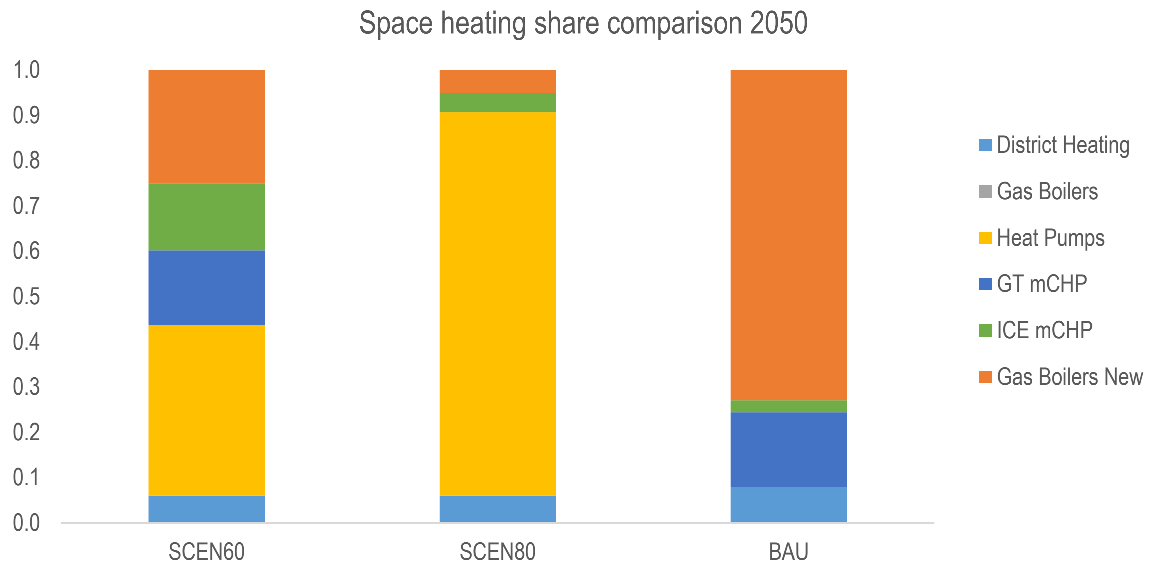

Figure 64 – Space Heating Scenarios

From the previous chart appear clear that whereas for the SCEN60 and SCEN80 the technological mix is very similar with differences in the percentage, the BAU scenario presents only the technologies that allow the system to produce at the lowest cost.
In fact, in the third scenario the Space heating production at the 2050 is dominated by the Gas Boilers that present lower costs with respect to the heat pumps, that is the most widespread technology for the others two constrained scenarios.
The comparison regarding the production of domestic hot water is reported in the Figure 65.

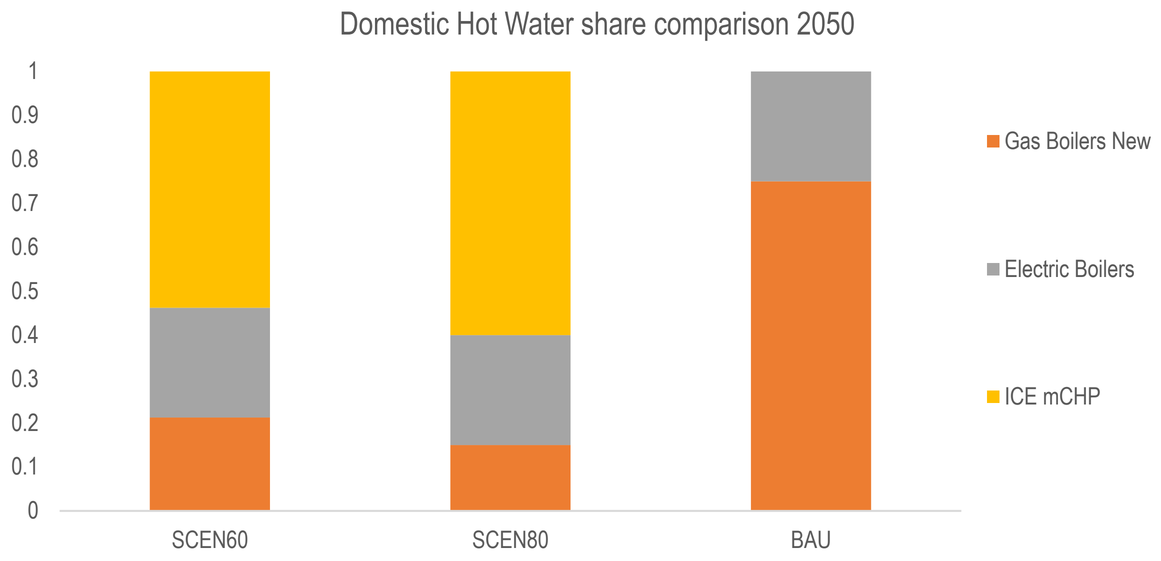

Figure 65 – Domestic Hot Water Scenarios

Even in this second comparison for the year 2050 appear clear that the new and more efficient technologies, such as the ICE mCHP, are not convenient from an strictly economic point of view, in fact the production of domestic hot water in the BAU scenario is held only by electric and gas boilers.

The same comparison for the production of electricity is proposed in Figure 66.

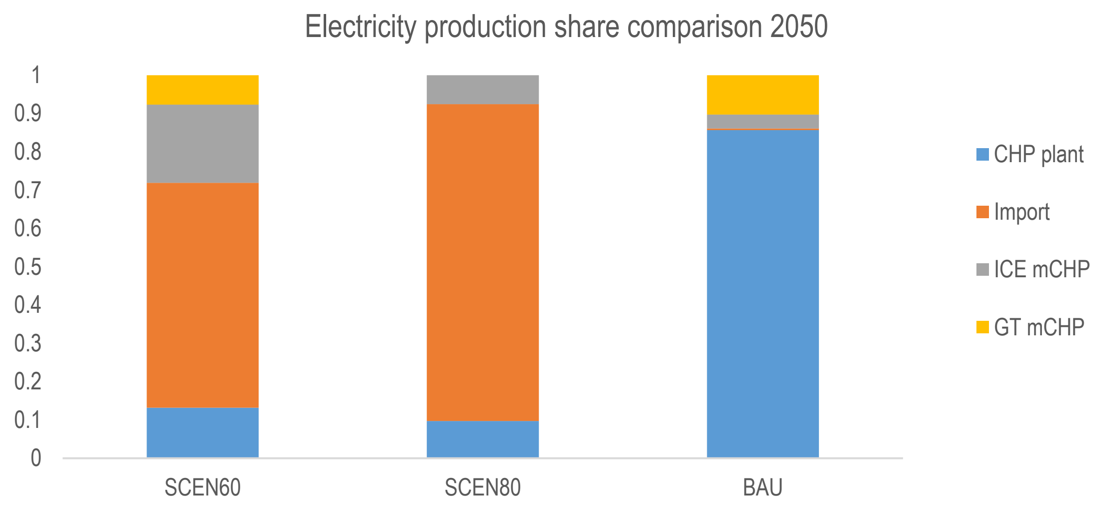

Figure 66 – Electricity Production Scenarios

Looking at Figure 66 it is possible to notice once again that the oldest technology, in this case the centralized CHP plant is the one that is preferred by an economic point of view.
In fact, the import, that holds the highest percentage in the SCEN60 and SCEN80 ensures lower emissions, but at the same time implies higher cost.

4.3.3 CO2 Abatement Cost

Once that the different mixes of production for the three scenarios are characterized a substantial difference in the total emission is expected.
The total CO2 emissions for the three scenarios are reported in Figure 67.

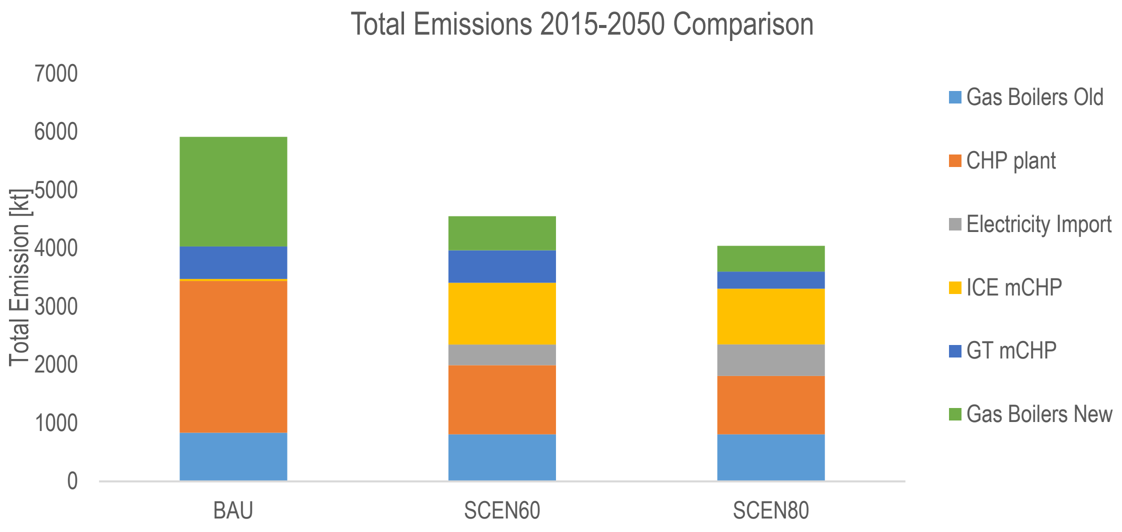

Figure 67 – CO2 Emissions scenarios

As already expected from the details about the technological share, the BAU scenario shows a great difference from the point of view of CO2 emissions:
In fact, in the years between the 2015 and 2050 the SCEN60 shows a saving in CO2 emissions equal to 23%, instead the SCEN80 a saving of 32%, with the respect to the BAU scenario.

If from the environmental point of view a very strong saving in CO2 emitted is achieved, on the economical point of view higher costs are involved in the constrained scenario.
In Figure 68 the comparison for the total discounted system costs is shown.

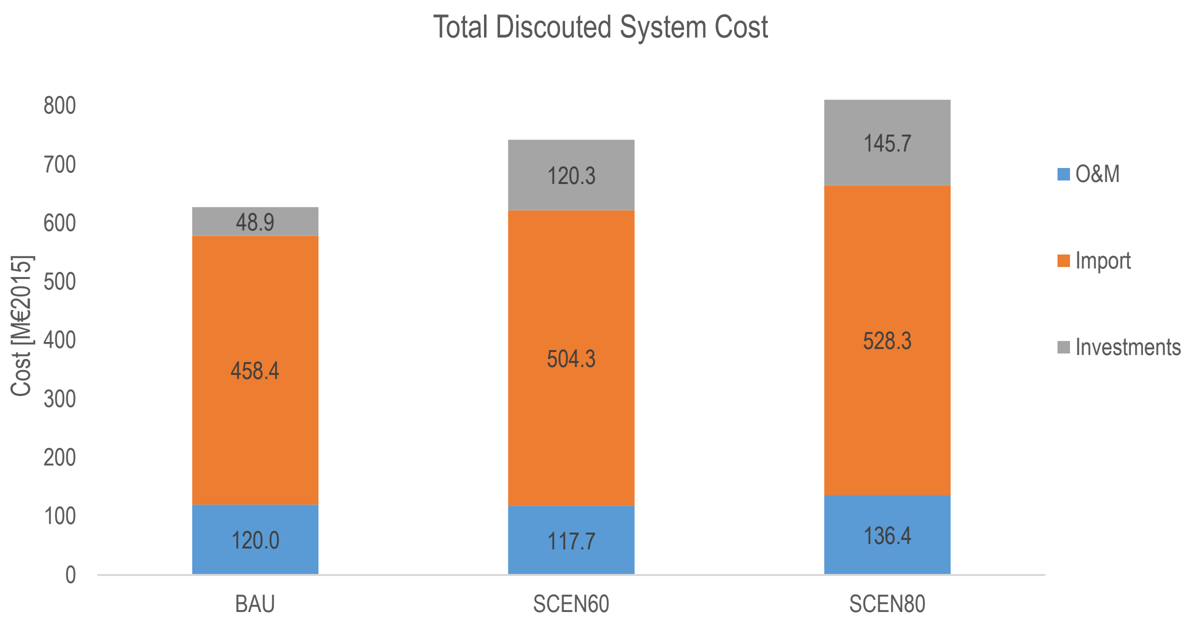

Figure 68 – Total discounted system cost scenarios

From the previous chart it is possible to have a deepest understanding of the big difference in monetary terms between these scenarios.
In fact, while the total discounted cost for the BAU scenarios is around 627 M€, the constrained scenarios show respectively a cost equal to 742 M€ and 810 M€.
So an increase of cost equal to 18% and 29% respectively is needed in order to obtain a progressively less emitting system.
Since the total CO_2 emissions as well the total discounted cost are defined for the three scenarios, considerations about the cost of abatement of the CO_2 are possible.
In Table 45 the cost associated to the emission reductions is shown.

Scenario	BAU	SCEN60	SCEN80
Actualized total cost [M€2015]	627	742	810
Total CO2 Emissions [kt]	5912	4551	4042
CO2 Saved [kt]		1361	1870
CO2 Saved [%]		23%	32%
Delta Cost [M€]		115	183
Delta Cost [%]		18%	29%
CO2 Abatement [€/tCO2]		84.4	97.9

Table 45 – CO2 Abatement Cost

In the table above some important information about the CO_2 abatement emerge:
In fact, a non linear correlation is shown passing from the SCENA60 to the SCEN80.
Whereas in the SCEN60 a reduction in CO_2 emission of the 23% involves an increment in the total cost equal to the 18%, in the SCEN80 a CO_2 saving of the 32% implies an increment in the costs equal to 29%.
This means that, a marginal increment in the CO_2 saving of the 9% implies an increment in the cost equal to the 11%.

This result, can be interpreted considering that, in general, higher is the efficiency of a system, higher is the marginal investment needed in order to increase the efficiency of it.
In order to have a value that can be assigned to the abatement of the CO2, the ratio between the cost of a scenario and the CO2 saved both with respect to the BAU is performed.
This cost, that in this analysis is called CO2 abatement cost, shows different values according to the selected scenario.
While, for the SCEN60 it results equal to 84.4 €/t_{CO2}, for the SCEN80 it results equal to 97.9 €/t_{CO2}.

5 DISCUSSION

For the two scenarios considered in this work, SCEN60 and SCEN80, the important role of the new efficient technologies is observed.
In the urban area considered, characterized by the residential sector and the tertiary sector, the high thermal demand has a big impact on the optimisation process:
In fact, how it is possible to notice from the previous results, the technologies based on the production of heating or combined production have a central role in the process of decarbonisation.
Among them, besides the heat pumps, already affirmed in the market, the micro CHP systems play a central role in the process that aims to the achievement of the environmental targets.
Considering the sector of the heat production, both for space heating and domestic hot water, these new systems hold a very high percentage in the SCEN60 and a still high, but slightly lower, in the SCEN80.
This behaviour, already marked in this analysis, is affected by the high investment cost of the micro CHP nowadays, that nevertheless, allows the optimisation process to select the micro gas turbine system as well the internal combustion engine ones.
Since these kind of systems are in an early stage in the market, expectation about the decreasing trend of the investment cost are strong:
In this thesis, anyway, the price is considered constant, in order to don't affect the simulation with considerations that can be considered speculations.

Always considering the role of the price for the equipment, some considerations must be done for the technologies that at the end of the simulations remain excluded by the process of optimisation.
Among them it is possible to find already affirmed technologies, such as the photovoltaic systems, as well, emergent technologies, such as PEM and SOFC fuel cells.
Concerning the photovoltaic systems, a reason that can bring the code to does not select them can be found in the definition of the consumption of the area:
In fact, being an urban area, the thermal consumption is the principal one, so systems that provides only electricity, and have a quite high investment cost, aren't considered convenient by the code.
Concerning instead the fuel cells based micro CHP, other reasons can be found in that exclusion:
In fact, in these simulations, only the natural gas feeding is considered, so CO2 emissions are present for this technology.
This assumption doesn't provide any vantage in the selection of the fuel cells with respect to the other micro CHP systems, that show even very high performances, but at the same time, sensibly lower investment costs.
Even if the district heating is not entirely excluded by the optimisation process, it holds a quite low percentage in the final mix.
This result is driven by the partial dismantling of the centralized CHP, that at the end of the simulations plays a marginal role.
In fact, how it is pointed out by the simulations, the trend is toward the decentralization of the production, with a strong growth of the on-site production.
Though in this work is not considered any other possible use of the district heating, in the bibliography some interesting proposal are exposed.
For example, (Jalil-Vega & Hawkes, 2018) propose a model in which central heat pumps of large size provide heating to the urban areas by the mean of the district heating grid.

One of the main result obtained in this work is the CO2 abatement cost.
Since it strongly depends by the system as well the assumption considered, the values obtained are to be contextualized in the proposed model.

In the literature many other studies are present regarding this abatement cost, and a comparison, although partial, can be done.
For example, (Lind & Espegren, 2017) found different values according to the scenario analysed, that stay around the 90 €/t_{CO2}.
Also (Nauclér & Enkvist, 2009) proposed a study centred on the definition of this cost, finding values sensibly lower than the one obtained in this analysis, in the range between 1-5 €/t_{CO2}.
Another work in the framework of CO2 abatement is proposed by (Bakhtyar et al., 2014), in which the cost for the abatement is expressed as subsidy.
In this work, the investigated cost changes according to the selected Nation, with values that stay in the range between 43 - 287 €/t_{CO2}.
Another aspect related to the CO2 abatement cost is the carbon tax.
This tax, already in use in some Nations across the world, such as United Kingdom, Australia, Sweden, and others, is an interesting incentive to the process of decarbonisation.
In fact, it imposes a price to be paid for the emission of the CO2, generally expressed as €/t_{CO2}.
Since the reduction of the CO2 emissions is not the most convenient pathway under the economic aspect, as demonstrate by the BAU scenario, imposing this kind of tax can lead to a faster change in the energy efficiency.

In this phase of comment of results a remark is needed about the process of import of electricity.
In fact, as explained in the paragraph 3.6.1 CO2 emission, the import of electricity is considered with a not constant emission factor along the years of the simulations.
Of course, this assumption has a strong impact on the results, being the import of electricity largely exploited both in the SCEN60 and SCEN80.
Nevertheless, since the calculation about the emission factor are based on European scenarios about the electricity production, it cannot be considered as a general speculation, but instead as a quite safe consideration for the years to come.
Related to the electricity sector, in the model construction also the export process was defined:
As pointed out from the results, it isn't exploited by the system, in fact, the revenue form the export, considered equal to the PUN, can not balance the investment as well the O&M costs related to an overproduction of electricity.

Another important factor to be analysed in this sections is the discount rate.
It is widely known the importance of this parameter on the final results and the degree of uncertainties related to the selection.
Since the several years involved in the proposed analysis, as well the uncertainties on the risk associated to the process of decarbonisation, a social discount rate equal to 5% is selected.
This value is largely used in the literature about the long term planning:
For example, (Sandvall et al., 2017) in the proposed analysis on the possibility of new low energy building in the urban context adopted this value.
In general, the most common values in literature stay in the range between the 3-7%.

To conclude this section, a brief excursus on the possible developments of this thesis is proposed.
As already explained, the focus of this analysis is on the urban context, so the residential and the service sector are considered.
Nevertheless, also the transport sector plays an important role on the CO2 emissions, so considering it will provide a deeper understanding of the process of decarbonisation.
Furthermore, several new energy carriers can be implemented, such as biomass, biogas and hydrogen.
The latter, in fact, provides a different prospective for some technologies, such as the Fuel cells, that operating with the hydrogen do not take part in the CO2 emission process.

6 CONCLUSION

European Union has ambitious plans for the next years in the framework of CO2 saving as well energy efficiency:
The TIMES model proposed was used to address the problem related to the emission abatement for a representative urban area of the North Italy.
The integrated model proposed aimed to the definition and the evolution of the principal aspects in the energy consumption for a typical urban area.
Since the energy planning for the 2050 is nowadays ongoing, two possible scenarios were considered:
The first one, in which the emission target is set to a reduction of the 60% with respect to the 1990 level, and a second one, in which the target is more challenging, set to 80%.
Despite these two scenarios have sensibly different constraints the results obtained are comparable.
In fact, the results obtained showed that achieve the emission target to the year 2050 is possible, but the changes needed are not so small:
While the current energy system is more addressed toward the centralized production, as well the high consumption of fossil fuels, the energy system capable to leads this change is more addressed toward the on-site production as well electrification by high renewable share.
The comparison between the two constrained scenarios, SCEN60 and SCEN80, with the Business as Usual one, pointed out that this transition is not the economic optimum.
This discrepancy inevitably leads to a defiance between the economic aspect and the environmental aspects, so drive this change toward a less emitting system can be challenging under several aspects.
In fact, not only an economic effort must be done, quantified around 84-97 €/t_{CO2} saved, but also an important change in the infrastructure, as well final users habits is needed.

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APPENDIX A

Method raw data

This section is devoted to the raw data used in order to build up the method that are not reported in the main section.

In Table 46 the external temperatures according to the heated season, as well the differences from the set point are reported.

		SET POINT = 20 [°C]		
Hour	Fall $T_{reference}$ [°C]	Difference from s.p. [°C]	Winter $T_{reference}$ [°C]	Difference from s.p [°C]
0	8.1	11.9	0.0	20.0
1	7.9	12.1	-0.1	20.1
2	7.7	12.3	-0.4	20.4
3	7.6	12.4	-0.4	20.4
4	7.5	12.5	-0.5	20.5
5	7.4	12.6	-0.5	20.5
6	7.4	12.6	-0.5	20.5
7	7.8	12.2	-0.3	20.3
8	9.2	10.8	0.1	19.9
9	10.5	9.5	2.3	17.7
10	11.6	8.4	2.4	17.6
11	12.5	7.5	3.3	16.7
12	13.2	6.8	4.1	15.9
13	13.8	6.2	4.8	15.2
14	13.7	6.3	4.5	15.5
15	13.0	7.0	3.7	16.3
16	11.8	8.3	2.9	17.1
17	10.5	9.5	2.1	17.9
18	9.8	10.2	1.7	18.3
19	9.2	10.9	1.4	18.7
20	8.8	11.2	1.1	18.9
21	8.6	11.4	0.9	19.1
22	8.4	11.6	0.7	19.3
23	8.1	11.9	0.4	19.6

Table 46 – External Temperature

The first coefficient, that takes into account the hours at home used in order to build up the heating consumption model, is reported in Table 47 according to the hours of the day.

Hour	α	Hour	α
0	1	15	0.66
1	1	16	0.66
2	1	17	0.70
3	1	18	1
4	1	19	1
5	1	20	1
6	1	21	1
7	1	22	1
8	0.38	23	1
9	0.38		
10	0.38		
11	0.38		
12	0.38		
13	0.66		
14	0.66		

Table 47 – α coefficient

Table 48 shows the β coefficient, second coefficient used in the heating consumption model that considers the hours of heating according to the selected season.

Start hour	β (Winter)	β (Fall)
0	0.2	0.15
1	0.2	0.15
2	0.2	0.15
3	0.2	0.15
4	0.2	0.2
5	0.4	0.4
6	1	0.8
7	1	0.8
8	1	1
9	1	1
10	1	1
11	1	1
12	1	1
13	0.8	0.8
14	0.8	0.8
15	1	1
16	1	1
17	0.8	0.8
18	0.8	0.6
19	0.8	0.6
20	0.7	0.55
21	0.7	0.5
22	0.3	0.25
23	0.2	0.15

Table 48 – β coefficient

The third coefficient used for the heating consumption, σ, that takes into account the difference of temperature from the internal set point is presented in Table 49.

Hour	σ (Fall)	σ (Winter)
0	0.95	0.98
1	0.96	0.98
2	0.98	0.99
3	0.99	1.00
4	0.99	1.00
5	1.00	1.00
6	1.00	1.00
7	0.97	0.99
8	0.86	0.97
9	0.75	0.86
10	0.67	0.86
11	0.60	0.81
12	0.54	0.77
13	0.49	0.74
14	0.50	0.75
15	0.55	0.79
16	0.65	0.83
17	0.75	0.87
18	0.81	0.89
19	0.86	0.91
20	0.89	0.92
21	0.90	0.93
22	0.92	0.94
23	0.94	0.95

Table 49 – σ coefficient

In order to build up the heat demand for the non-domestic sector, the hourly percentage is reported in the Table 50.

Hour	Hourly percentage	Hour	Hourly percentage
0	0	12	0.14
1	0	13	0.06
2	0	14	0.06
3	0	15	0.06
4	0	16	0.06
5	0	17	0.06
6	0	18	0
7	0	19	0
8	0.14	20	0
9	0.14	21	0
10	0.14	22	0
11	0.14	23	0

Table 50 – Non-Domestic Hourly Percentage

In Table 51 and Table 52 the deviation analysis both for winter and fall is presented, in order to verify the quality of the model.

Hour	$\delta_{abs}\ Winter$	$\delta_{rel}\ Winter$
0	0	0.03
1	0.0010	0.07
2	0.0014	0.1
3	0.0020	0.14
4	-0.0007	0.05
5	0.0005	0.02
6	0.0071	0.09
7	0.0019	0.03
8	-0.0121	0.22
9	-0.0100	0.19
10	0.0037	0.07
11	-0.0019	0.04
12	-0.0036	0.07
13	-0.0072	0.18
14	-0.0010	0.02
15	0.0048	0.09
16	0.0029	0.06
17	-0.0023	0.05
18	0.0026	0.05
19	0.0046	0.08
20	-0.0010	0.02
21	0.0054	0.11
22	0.0022	0.11
23	-0.0002	0.01

Table 51 – Deviation Analysis result Winter

Hour	δ_{abs} Fall	δ_{rel} Fall
0	-0.0087	0.62
1	-0.0082	0.58
2	-0.0060	0.42
3	-0.0046	0.32

4	0.0018	0.10
5	0.0109	0.28
6	0.0094	0.12
7	0.0225	0.30
8	-0.0023	0.04
9	-0.0109	0.20
10	0.0013	0.03
11	-0.0086	0.17
12	-0.0061	0.13
13	-0.0088	0.24
14	-0.0030	0.08
15	0.0094	0.20
16	0.0155	0.29
17	0.0088	0.17
18	0.0030	0.06
19	0.0035	0.07
20	0.0011	0.02
21	0.0026	0.06
22	-0.0078	0.34
23	-0.0149	1.07

Table 52 – Deviation Analysis result Fall

Given the necessity of the number of houses for the construction of the electricity consumption model, Table 53 reports the number of houses according to the different classes of inhabitants.

Inhabitants	50000	Single Houses	6456
Single percentage	0.13	Couple of retired houses	3467
Single number	6456	Single retired houses	6400
Retired percentage	0.27	Families without sons houses	2806
Retired number	13333	Families with sons houses	6537
Retired who live alone percentage	0.48		
Retired who live in a family	6933	Total houses	25666
Retired that live alone number	6400		
Families without sons percentage	0.11		
Families without sons number	5613		
Families with sons percentage	0.49		
Families with sons number	24598		

Table 53 – Number of Houses

APPENDIX B
VEDA Worksheet

This section aims to a more clear understanding of what already explained in the dedicated Chapter 3 about the model implementation.
In order to achieve this goal, in this appendix some example of VEDA FRONT END worksheet are reported and commented.

Base year

First of all a brief explanation of the sections of the VEDA FE navigator is reported.

B-Y Templates

In this section the main features of the base year are defined;
In particular the set of technology, the energy demands, as well the imports and exports.
In order to create a suitable model that provides manageable results, it is necessary to define the real technologies, as well fictitious ones.
This comes out from needs, related to the process of modelling a real system inside a code.
In fact, also the TIMES code has some technical constraint related to the definition of the system.
Just to provide a practical example, if the electric boilers for the production of domestic hot water have to be defined, it is not sufficient to define the technology with just as input electricity and as output hot water.
First of all, if the import of electricity is considered, the electricity imported has to be “transformed” into user consumption, so a variation of cost with respect to the PUN is necessary, so a fictitious technology is required.
This technology operates with as input electricity from the import and as output final consumption electricity.
As well the electric system efficiency has to be introduced, that takes into account the losses of electricity due to the transmission.
This can be applied to all the set of technologies, in fact, if the gas boilers are considered, the same approach has to be applied;
The natural gas imported has to be transformed into user consumption:
Furthermore, in order to reflect the real behaviour, also the efficiency of the gas grid is implemented.
So if all the real technologies has to be implemented, as well a second set of fictitious is necessary.

B-Y Trans and SysSettings

The SysSettings file is used to declare the basic elements of the model that includes region, time slices, starting year and units of measure.
The BY_Trans contains transformation files that are used to update information included in the B-Y templates, and to insert new information, for example insert new attributes for existing processes in the B-Y templates.

Scenarios

These files are used to update existing information and/or to insert new information in any part of the RES.
This section is also used to define user constraints (discussed in the paragraph 3.6).

SubRES

The SubRES files are used in order to define new commodities, as well new technologies that are not present in the base year.
In this model these files are used to define the new set of technologies that can be introduced in the years after the base one.

Demand Scenario

This section is used to define some aspects of the energy demand for the system but is not used in this work

Trade Scenario

This section allow the designer to model the trades between regions in model which consider a multi-region system, so even this section is not used in the present work.

Since all the sections of the Navigator are presented, it is possible to pass to the various sections of the model.

In Figure 69 and Figure 70 an example of import tables is reported.

Sector Name	Commodity	Description	Default Unit		Currency Unit		
IMPORT	**GAS**	**Natural Gas**	**MWh**		**M€2015**		
				~FI_T			
TechName	**Comm-IN**	**Comm-OUT**	**Year**	**LimType**	**CUM**	**COST**	**ACT_BND**
*Technology Name	Input Commodity	Output Commodity			Reserves Cumulative Value	Cost	Annual Production Bound
*Units					MWh	M€/MWh	MWh
IMPGAS1		GAS				2.2E-05	

Figure 69 - Natural Gas Import 1

~FI_Comm								
Csets	**Region**	**CommName**	**CommDesc**	**Unit**	**LimType**	**CTSLvl**	**PeakTS**	**Ctype**
*Commodity Set Membership	Region Name	Commodity Name	Commodity Description	Unit	Sense of the Balance EQN.	Timeslice Level	Peak Monitoring	Electricity Indicator
NRG		GAS	Natural Gas	MWh		DAYNITE		

~FI_Process								
Sets	**Region**	**TechName**	**TechDesc**	**Tact**	**Tcap**	**Tslvl**	**PrimaryCG**	**Vintage**
*Process Set Membership	Region Name	Technology Name	Technology Description	Activity Unit	Capacity Unit	TimeSlice level of Process Activity	Primary Commodity Group	Vintage Tracking
*								
IMP		IMPGAS1	Import of Natural Gas Step 1	MWh		DAYNITE		

Figure 70 – Natural Gas Import 2

In these figures it is possible to identify the main features related to the definition of the import process.
In fact, in the first table, Figure 69, the name of the technology, as well the output and the price are defined.
After that, the process features are defined:
To do this, it is necessary to define the commodity itself, first table Figure 70, as well the process, second table Figure 70.
The same approach is used for the other imports of the model.

In Figure 71 the so called “Sector Fuels” is presented.
This worksheet plays a very important role within the model, in fact in this section it is possible to define all the fictitious technologies.

Sector Name	Commodity	Description	Deafult unit	Currency Existing
		Sector Fuel	**MWh**	**M€2015 E**

~FI_Comm

Csets	Region	CommName	CommDesc	Unit	LimType	CTSLvl	PeakTS	Ctype
*Commodity Set Membership	Region Name	Commodity Name	Commodity Description	Unit	Sense of the Balance EQN.	Timeslice Level	Peak Monitoring	Electricity Indicator
NRG	REG1	RSDGAS	Residential Natural Gas	MWh		DAYNITE		
		ELCGAS	Electricity Plants Natural Gas	MWh		DAYNITE		
		RSDELC	Residential Electricity	MWh		DAYNITE		
		DHHET	Distric heating Heat	MWh		DAYNITE		
		ICEELC	Electricity from ICE mCHP	MWh		DAYNITE		
		FCELC	Electricity from FC mCHP	MWh		DAYNITE		
		MGTELC	Electricity from MGT mCHP	MWh		DAYNITE		
		PVASIELC	Electricity from PVASI	MWh		DAYNITE		
		PVMSIELC	Electricity from PVMSI	MWh		DAYNITE		
		CLENGAS	NGAS for FC	MWh		DAYNITE		
		SOFCELC	Electricity from SOFC mCHP	MWh		DAYNITE		
ENV	REG1	EMCO2	CO2 Emissions	kg		DAYNITE		

~FI_T

TechName	Comm-IN	Comm-OUT	START	STOCK	VAROM	EFF	LIFE
*Technology Name	Input Commodity	Output Commodity		Existing Installed Capacity		Efficiency	Lifetime
*Units				MWha			Years
FTE-RSDGAS	GAS	RSDGAS			0.00001950000	1.00	200
FTE-ELCGAS	GAS	ELCGAS				1.00	200
FTE-RSDELC	ELC	RSDELC			0.00009315167	1.00	200
	ELC20						
	ELC25						
	ELC30						
	ELC35						
	ELC40						
	ELC45						
	ELC50						
RE-DHHET	HET	DHHET				1.00	200
FTE-CHPELC	ELCCHP	RSDELC				1.00	200
FTN-MGTELC	MGTELC	RSDELC	2019			1.00	200
FTN-ICEELC	ICEELC	RSDELC	2019			1.00	200
FTN-FCELC	FCELC	RSDELC	2019			1.00	200
FTN-PVASIELC	PVASIELC	RSDELC	2016			1.00	200
FTN-PVMSIELC	PVMSIELC	RSDELC	2016			1.00	200
FTN-CLENGAS	GAS	CLENGAS	2016			1.00	200
FTN-SOFCELC	SOFCELC	RSDELC	2016			1.00	200

~FI_Process

Sets	Region	TechName	TechDesc	Tact	Tcap	Tslvl	PrimaryCG	Vintage
*Process Set Membership	Region Name	Technology Name	Technology Description	Activity Unit	Capacity Unit	TimeSlice level of Process Activity	Primary Commodity Group	Vintage Tracking
*								
PRE	REG1	FTE-RSDGAS	Sector Fuel Existing Residential Sector- Natural Gas	MWh	MWha	DAYNITE		
		FTE-ELCGAS	Sector Fuel Technology Existing Electricity Plants Natural Gas	MWh	MWha	DAYNITE		
		FTE-RSDELC	Sector Fuel Existing Residential Sector- Electricity	MWh	MWha	DAYNITE		
		RE-DHHET	Sector Fuel Existing heat DH	MWh	MWha	DAYNITE		
		FTE-CHPELC	Sector Fuel Existing CHP Electricity	MWh	MWha	DAYNITE		
		FTN-MGTELC	Sector Fuel New mGT Electricity	MWh	MWha	DAYNITE		
		FTN-ICEELC	Sector Fuel New ICE Electricity	MWh	MWha	DAYNITE		
		FTN-FCELC	Sector Fuel New FC Electricity	Mwh	MWha	DAYNITE		
		FTN-PVASIELC	Sector Fuel New PVASI Electricity	MWh	MWha	DAYNITE		
		FTN-PVMSIELC	Sector Fuel New PVMSI Electricity	MWh	MWha	DAYNITE		
		FTN-CLENGAS	Fictitious for NGAS for FC	MWh	MWha	DAYNITE		
		FTN-SOFCELC	Sector Fuel New SOFC Electricity	MWh	MWha	DAYNITE		

Figure 71 – Sector Fuels

Even in this case, the sheet is divided into three tables, with the same functions of the Figure 70, but the purpose is totally different.
For example, the first row is dedicated to the definition of the process that “transform” the natural gas imported from the system into residential natural gas.
In this process, the difference of price is applied under the “VAROM” column.
The second part of this table is dedicated to process that allow a more clean and simple analysis of the results:
In fact, all the technologies which name begin with “FTN-…” are fictitious technologies that transform the commodity produced by a technology into a final user commodity.
Thanks to this approach, in the results it is possible to have a clear picture of which kind of technologies produce the commodity under consideration.

In Figure 72 the space heating sector is characterized.

			~FI_T									
TechName	Comm-IN	Comm-OUT	YEAR	STOCK	EFF	AFA	INVCOST	FIXOM	LIFE	START	CAP2ACT	ENV_ACT
*Technology Name	Input Commodity	Output Commodity		Existing Installed Capacity	Efficiency	Utilisation Factor	Invesctment Cost	Fixed O&M Cost	Lifetime			Activity Emission Coefficient
*Units				MW			M€2015/MWh	M€2015/Mwa	Years			kt
DCHETGAS	RSDGAS	DCHET	2015	190	0.90	0.25		0.030	20		8760	
DCHETDH	DHHET	DCHET	2015	60	0.69	0.25		0.030	25.00		8760.00	
DTHETGT	MGTHET	DCHET			1.00		0	0.00	50.00	2025	8760	
DTHETICE	ICEHET	DCHET			1		0	0	50.00	2025	8760	
DTHETFC	FCHET	DCHET			1		0	0	50.00	2019	8760	
DTASHPHET	ASHPHET	DCHET			1.00		0	0	50.00	2016	8760	
DTHETSOFC	SOFCHET	DCHET			1.00		0	0	50.00	2019	8760	

Figure 72 – Space Heating Technologies

Also in this case the technologies that produce space heating are defined with the same approach already discussed.
In this table it is possible to distinguish already existing technologies, which are characterized by a stock as well an utilisation factor, and new technologies, which are used only to distinguish in the final results the share of production in the space heating.
These kind of technologies, that are fictitious, are characterized by unitary efficiency and null costs.

After that the reference energy system is defined it is necessary to implement the energy demand of the system.
This is done in a separately worksheet, characterized by two section.
The first, Figure 73, is a table in which the total annual demand for each commodity is defined, the second, Figure 74, is dedicated to the subdivision of the demand within the time steps.
In the latter, only the division of the space heating in the fall days is reported for simplicity reasons.

Sector Name	Commodity	Description	Default Unit		Currency Uni
DEM			MWh		M€2015
	~FI_T				
Attribute	CommName	*Unit	2015		
*	Demand Commodity Name	Demand Unit	Demand Value		
*Units			MWh		
Demand	DCHET	MWh	432900		
Demand	DCDHW	MWh	40302		
Demand	DCELC	MWh	122000		

Figure 73 – Energy Demand

COM_FR	DCHET	F0	0.0050
COM_FR	DCHET	F1	0.0051
COM_FR	DCHET	F2	0.0051
COM_FR	DCHET	F3	0.0052
COM_FR	DCHET	F4	0.0070
COM_FR	DCHET	F5	0.0140
COM_FR	DCHET	F6	0.0281
COM_FR	DCHET	F7	0.0271
COM_FR	DCHET	F8	0.0214
COM_FR	DCHET	F9	0.0199
COM_FR	DCHET	F10	0.0188
COM_FR	DCHET	F11	0.0179
COM_FR	DCHET	F12	0.0171
COM_FR	DCHET	F13	0.0134
COM_FR	DCHET	F14	0.0135
COM_FR	DCHET	F15	0.0170
COM_FR	DCHET	F16	0.0194
COM_FR	DCHET	F17	0.0191
COM_FR	DCHET	F18	0.0171
COM_FR	DCHET	F19	0.0181
COM_FR	DCHET	F20	0.0172
COM_FR	DCHET	F21	0.0159
COM_FR	DCHET	F22	0.0081
COM_FR	DCHET	F23	0.0050

Figure 74 – Demand fraction

SUB-RES Implementation

Once that the base year is already implemented it is possible to add further information needed by the code in order to develop the simulations.

In Figure 75 the implementation of the micro CHP systems is presented.

TechName	TechDesc	Comm-IN	Comm-OUT	START	EFF	CHPR	AF	Life	CAP2ACT	INVCOST	FIXOM	VAROM
\I:Technology Name	Technology Description	Input Commodity	Output Commodity	Starting Year	Efficiency	Output to Power Ratio	Annual Availability Factor	Lifetime of Process	Capacity to Activity Factor	Investment Cost	Fixed O&M Cost	Variable O&M Cost
MGT	GT mCHP	RSDGAS	MGTELC	2020	0.16	4.9		20	8760	0.94	0	0.00000536
			MGTHET									
ICE	ICE mCHP	RSDGAS	ICEELC	2020	0.29	2.206896552		25	8760	1	0	0.000013
			ICEHET									
FC	PEM mCHP	RSDGAS	FCELC	2019	0.36	1.444444444		15	8760	13	0.5	0.000013
			FCHET									
SOFC	SOFC mCHP	RSDGAS	SOFCELC	2019	0.538	0.508178439		15	8760	13	0.5	0.000013
			SOFCHET									

~FI_Comm

Csets	CommName	Unit	CTSLvl	PeakTS	Ctype
\I: Commodity Set Membership	Commodity Name	Unit	Timeslice Tracking Level	Peak Monitoring	Electricity Indicator
NRG	RSDGAS	MWh	DAYNITE		
NRG	CLENGAS	MWh	DAYNITE		
NRG	MGTELC	MWh	DAYNITE		ELC
NRG	ICEELC	MWh	DAYNITE		ELC
NRG	FCELC	MWh	DAYNITE		ELC
NRG	SOFCELC	MWh	DAYNITE		ELC
NRG	MGTHET	MWh	DAYNITE		
NRG	ICEHET	MWh	DAYNITE		
NRG	FCHET	MWh	DAYNITE		
NRG	SOFCHET	MWh	DAYNITE		

~FI_Process

Sets	TechName	Tact	Tcap	Tslvl	Vintage
\I: Process Set Membership	Technology Name	Activity Unit	Capacity Unit	Timeslice Operational Level	Vintage Tracking
CHP	MGT	MWh	MW	DAYNITE	
CHP	ICE	MWh	MW	DAYNITE	
CHP	FC	MWh	MW	DAYNITE	
CHP	SOFC	MWh	MW	DAYNITE	

Figure 75 – mCHP implementation

Even in this case, the template follow the scheme already seen, with three tables, each one with a dedicated purpose.
Looking at the first table, all the input and output data, as well the economic assessment are defined for each type of these technologies.
The second and the third tables are dedicated respectively to the definition of the commodity produced and the definition of the process itself.
This procedure is repeated for all the technologies that are not present in the base year.

The last step needed before the run of the simulations is the definition of the constraints.
In Figure 76 an example of constraint is proposed.

UC_N	Pset_Set	Pset_PN	Pset_CI	Pset_CO	Cset_CN	Attribute	Year	LimType	UC_FLO	REG1
GASBOILER_HEATING_MIN	DMD		RSDGAS		DCHET		2030	LO	1	-35%
GASBOILER_HEATING_MIN	DMD		RSDGAS		DCHET		2050	LO	1	-5%

Figure 76 – Constraint of the minimum usage of Gas Boiler for the space heating

In this example the constraint related to the minimum share of the gas boilers is reported:
In this table, the minimum amount of space heating provided by the selected technology is defined in the last column.
In order to state which technologies are constrained, the two columns “Pset_CI” and “Pset_CO” are used, the first in which the input commodity of the process is defined, the second in which the output is defined.
In order to identify if the limit is a lower or and upper limit, the column “LimType” is used, with the abbreviation “LO” that stands for lower.