POLITECNICO DI TORINO

Master's Degree in "Ingegneria energetica e nucleare"

Master's Degree Thesis

Analysis of the decarbonisation of the Italian energy system: modeling the long-term effects of Covid-19 on energy related behaviour

Supervisors and tutor:

Stefano CORGNATI

Cristina BECCHIO

Giulia CRESPI

Roberta ROBERTO

Candidate:

Mattia RUGGERI

December 2021

Abstract

The restrictions imposed to contain the Covid-19 pandemic during 2020 and beyond have affected many aspects of daily life, some of these changes will have a strong impact on the future energy behaviour of Italian citizens. The long-term effects will be studied with the help of the energy modelling software EnergyPLAN. The use of energy models and long-term analysis main purpose is to support policy-makers to understand the possible trajectories of the energy systems; this work fits into this context.

This thesis aims to evaluate the effects of the change in behaviour due to the pandemic on the decarbonisation pathway of the Italian energy system in 2040. It focuses on the COVID-19 consequences in terms of reduced private mobility and increased energy efficiency in residential buildings, in turn associated with an increase of flexible remote working and citizens' awareness on environmental issues related to climate change consequences.

Residential and transport sectors are selected for this analysis because they are the sectors where citizens can have a major impact. In Italy, these two sector account for 28% of the final energy use and for 51% of green house gasses emissions from the energy system.

In the first part of this work, the historical trends of the Italian energy system are studied with a focus on the effects of the pandemic. Then a review of the European and Italian energy policies up to 2050 is developed.

Based on the statistical and political review, a Reference Energy Model for 2018 is developed using EnergyPLAN.

A Base Scenario for 2040 is built assuming that the targets defined in PNIEC ("Piano Nazionale Integrato per l'Energia e il Clima") for 2030 will be met and that the full decarbonization targets for 2050 will be reached.

Furthermore, in order to include the effects of Covid-19 pandemic on the Italian energy trends up to 2040, different Post-Pandemic Scenarios have been hypothesized and modelled. They have been built considering the impacts that an increased diffusion of remote working and a higher citizens' environmental awareness could have on Italian energy consumption and GHG emissions.

The results of this study suggest that the effects taken into account will have a sensible potential on the Italian decarbonisation.

Until now, in literature, the decarbonisation pathways and the effects of remote working and citizens' behaviour on the energy system have been studied mainly separately. This thesis aims to unite them using the Covid-19 pandemic as a common thread.

Dedico questo lavoro a mio nonno materno, mancato a pochi giorni dalla sessione di laurea. Grande uomo e fonte di ispirazione. Devo la scelta del mio percorso di studi anche a lui e alle giornate passate nella sua officina durante la mia infanzia
13-11-2021

Table of Contents

List of Tables

List of Figures

Acronyms

TPES
: Total Primary Energy Supply

RES
: Renewable Energy Sources

VRES
: Variable Renewable Energy Sources

GDP
: Gross Domestic Product

GHG
: Green House Gases

EU
: European Union

IEA
: International Energy Agency

WEO
: World Energy Outlook

NDC
: Nationally Determined Contribution

RED
: Renewable Energy Directive

EED

Energy Efficiency Directive

EGD

European Green Deal

NECP

National Energy Climate Plan

BEN

Bilancio Energetico Nazionale

SDG

Sustainable Development Goal

UN

United Nations

CCUS

Carbon Capture, Utilisation and Storage

CSP

Concentrated Solar Power

REM2018

Reference Energy Model 2018

BS2040

Base Scenario 2040

LPG

Liquefied Petroleum gases

ETBE

Ethyl Tertiary Butyl Ether

CAES

Compressed-Air Energy Storage

PP

Power Plants

ICT

Information Communication Technology

HVAC

Heating, Ventilating, and Air Conditioning

OECD

Organisation for Economic Co-operation and Development

LDV

Light Duty Vehicle

HDV

Heavy Duty Vehicle

ILO

International Labour Organization

Chapter 1

Introduction

The effects of the spread of Covid-19 on the energy system during the pandemic have been severe. In Italy, the demand of primary energy dropped by 10% during 2020, this energy contraction has been the highest ever seen since World War II [1]. In addition to these measurable effects, also the people lifestyle has experienced important changes. Remote working has become the new normality for more than 30% of the Italian workers [2] and people have understood that social and personal choices can influence a global crisis. Remote working and the new citizens' awareness have a potential to influence the future energy-related behaviour of the people.

These changes due to the pandemic must also be seen from the perspective of climate change, focusing in particular on the role of the energy sector. According to the last report edited by IPCC [3], the anthropogenic emissions of GHG (Green House Gases) are the cause of an increase of 1.07°C compared to the pre-industrial level. If the global carbon neutrality will not been reach by the end of the century, the effects of the rise in temperature will be drastic [3]. At global level, the leading cause of GHG emissions is the energy sector: it accounts for more than 70% of total emissions. Italy is particularly vulnerable to the climate changes effects, in particular to the heat waves and to the drought. The coastal zone and floodplain are at risk of suffer the effects of the increasing sea level and of the heavy rainfall due to climate changes [4]. For these reason, the decarbonisation of the energy sector is of primary importance. The European Union (EU) has demonstrated its commitment in the fight against climate changes through several policies and guidelines, setting the 2050 as the maximum year in which to reach the carbon neutrality. According to these new policies and guidelines, also the Italian energy system will have to go under drastic changes to reach the decarbonisation.

In this context, the main question of this thesis becomes: what are the potential impacts of the changes in energy-related behaviour due to the pandemic on the Italian decarbonisation pathway?

The choice of this theme is rise from the awareness that the climate and the pandemic crisis have been two of the most discuss topic in the last years and their evolution and consequences will continue to have an important impact in the future. Beyond their obvious differences, they have some points in common: they are both global and, in both, the actions of individuals can have a crucial role to mitigate their effects. Furthermore, there are some lessons that Covid-19 taught about how to tackle a global emergency, that can be applied to the climate change crisis.

This this thesis has been developed during an internship at ENEA (Italian National Agency for New Technologies and Sustainable Economic Development). The internship activities are included in ENEA research area about smart energy systems and integrated energy systems, and in the European project IMEAS (Integrated and Multi level Energy Model for the Alpine Space).

The main tools used to carried out this analysis are: first of all, Microsoft Excel [5], in which the models of interest have been developed, and then the software EnergyPLAN [6], that is the energy model in which the models from Excel are implemented to develop the complete analysis of the scenarios.

The year chosen for this analysis is the 2040, because it is distant enough in time from Covid-19 crisis to assume that the economic effects will be negligible, but not too far in time, so that the effects on the behaviours taken into account will be potentially influential in the scenarios.

At the beginning of this elaborate, to have a general vision of the past on which to construct a coherent future, the historical trends of the Italian energy system from 2004 to 2019 are studied. Then the effects of Covid-19 pandemic on energy demand and supply in 2020 are analyzed, with a particular focus on the effects of remote working and the links between the pandemic and the environmental and climate crisis. To have a foundation on which to construct the scenarios, then the European and Italian policy contexts are analyzed, focusing on the targets set up to 2050.

Starting from the literature, a Reference Energy Model for 2018 is developed using Excel and EnergyPLAN; the obtained results are then compared with the main statistics, in order to calibrate the model and to obtain a base model for further scenarios development.

A Base Scenario for 2040 is built, considering no Covid-19 pandemic occurrence, and assuming that the targets defined in PNIEC ("Piano Nazionale Integrato per l'Energia e il Clima") for 2030 will be met and that the full decarbonization targets for 2050 will be reached. To do so a complete scenario is developed for 2030 to check the achievement of PNIEC targets, while for 2050 the scenario is only partially developed to draw the trajectories up to 2040. The main strategies taken into account are the electrification of the end-use sector, energy efficiency measures and growing renewable energies share in the generations sector. This reasoning is applied to all sectors using PNIEC for 2030 and sector studies for the period between 2030 and 2050 as main sources. In this work, only technical simulations are developed, while economic variables are not considered.

In the last part, the potential impacts of the citizens' changes in energy-related behaviour in 2040 are analyzed. First, the analysis focuses on the remote working and its impact on the transport sector for different penetration of remote workers over the total workforce. Second, the increased environmental awareness of Italian citizens is taken into account and its possible effects on the transport and residential sector are studies.

In order to includes these effects, 6 different Post-Pandemic Scenarios are hypothesized and modelled, to analyze different impacts of the variable involved.

Form the results of the scenarios, it will possible to see that the variables take into account have a significant potential on the Italian decarbonisation pathway, especially when the decreasing demand of private mobility is coupled with the increasing share of electric vehicle in the private transport and the increasing efficiency of the residential sector.

Chapter 2

Energy and policies context

2.1 Italian historical energy trends

The historical energy trends of the Italian energy system, from 2004 to 2019, are taken into account in order to have a general vision of the past that will allow to construct a coherent future. The main source used to developed this analysis is the Italian National Energy Balance (BEN) edited by Eurostat [7]. For some sections, also the International Energy Agency (IEA) [8] and TERNA [9] are taken as sources.

The period of time analyzed in this part goes from the 2004 to 2019. This choice is due to a change in the definition of the commodities made by Eurostat between 2003 and 2004, in particular for the heat generation and consumption.

The year 2020 will be examined in more detail in the next section (2.2), speaking about the effects of the pandemic on the energy system.

2.1.1 Total Primary Energy Supply and final use

The TPES (Total Primary Energy Supply) is the total amount of primary energy that a country has available. It takes into account the import, the export (that are subtracted) and the national production. It is useful to understand on which primary energy a certain country relies on.

The Italian TPES peaked in 2005, with a value of 2167 TWh, then generally decreased until 2014. Between 2015 and 2019, the TPES remained quite constant (figure 2.1), with a value around 1750 TWh. This value is similar to the one in 1990 and below the level of the period before the 2009 economic crisis.

The share of fossil fuels over the total TPES went from 92.4% in 2004 to 80.6% in 2019. While oil products and coal linearly decreased, the absolute value of natural gas remained constant. The share of RES (Renewable Energy Sources), in the same period, increased and their absolute value doubled.

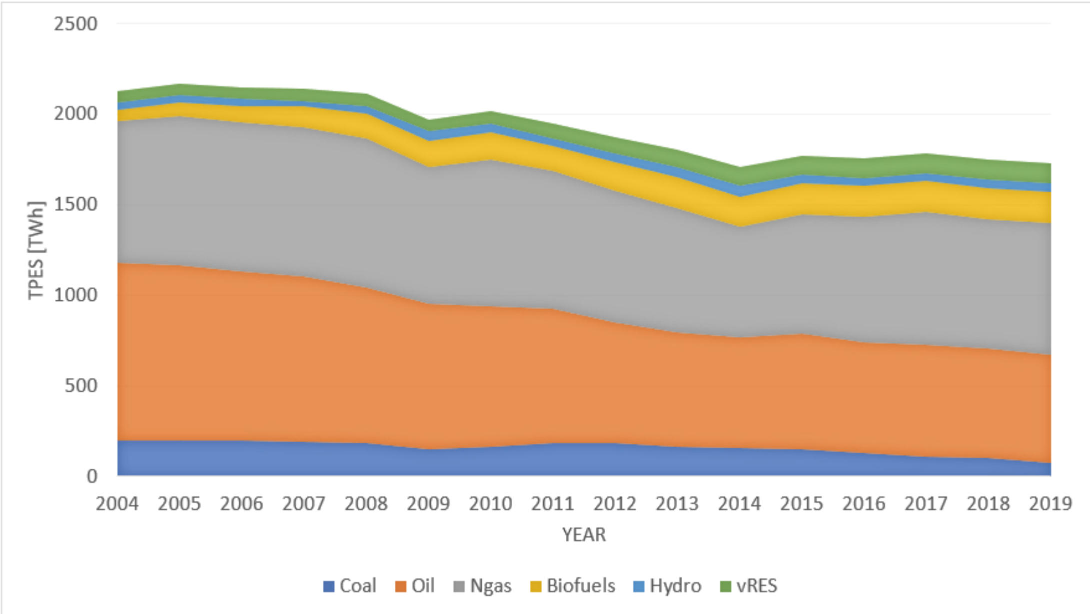


Figure 2.1: Total Primary Energy Supply (TPES) by source 2004-2019 [10] [7]

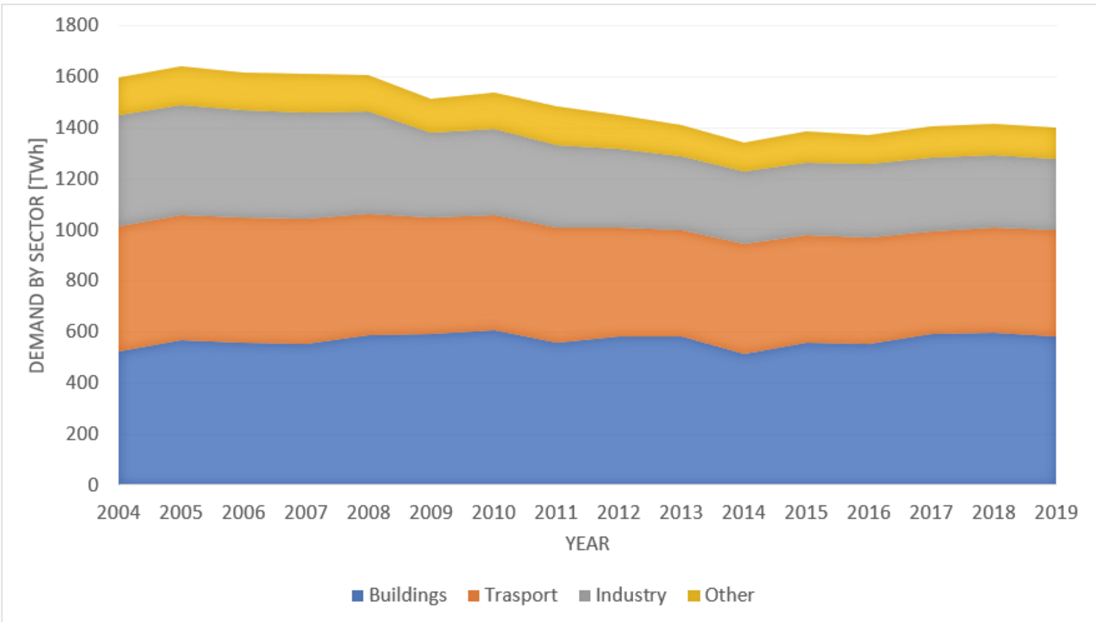


Figure 2.2: Final use by sector 2004-2019 [7]

In figure 2.2 is shown the the final energy demand divided by sector. In 2019 the total final energy consumption in Italy was 1316 TWh. As for the TPES, there was a peak in 2005 (1529 TWh) and then a general decrease. The main energy demand reduction was experienced by the industry sector where, between 2005 and 2019, it decreased by 35%. In the same period, the transport sector energy demand decreased by 14% and the buildings sector increased its energy consumption of 3%. In general, the share of fossil fuels in the final energy consumption decreased, while electricity and biomass had a sensible increase.

In both the figures (2.1 and 2.2), is possible to appreciate the effects of the 2009 economical crisis. Between 2008 and 2009 the TPES has fallen by 6.6% and the final energy use by 5.5%. The most influenced sector was the industry, with a decrease of 17,3%. The other end-use sectors in the same period had a trend consistent with their past. As consequence of the industry slowdown the most affected commodity was natural gas, with a decrease of 21.4%.

2.1.2 Buildings sector

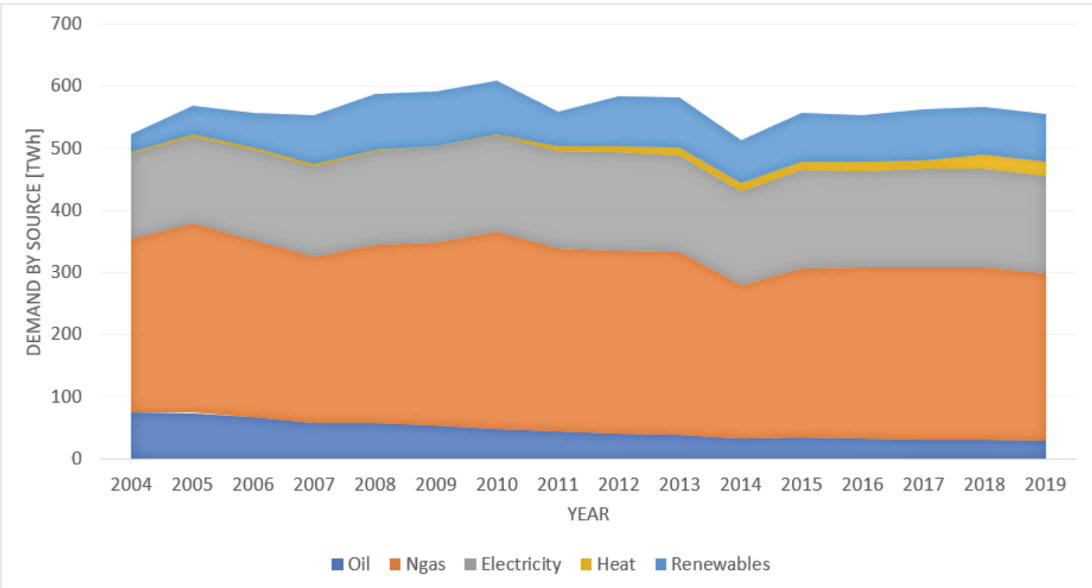


Figure 2.3: Energy demand by source in buildings sector 2004-2019 [7]

In this thesis, to refer to the residential sector, and services and public sector, it will be used the definition *"buildings sector"*.

In 2019, the share of residential sector over the total energy consumption by buildings sector was 63%, while in 2004 was 70%. Over the same period its absolute value remained quite constant and around 380 TWh. Instead, the services and public sector saw a sensible increase, from a value of 157 TWh in 2004 to 217 TWh in 2019.

In figure 2.3 is shown the energy consumption of buildings sector divided by energy source. The energy consumption had a slow growing trend between 2004 and 2019, mainly driven by the growth of the tertiary sector.

The renewable sources increased their share nearly three times between 2004 and 2019, passing from 5.4% over the total consumption in 2004 to 13.9% in 2019. In the same period fossil fuels consumption decreased by 15%, but natural gas still remained the main actor in the energy mix, with a share of 48.6% in 2019. Derived heat had an important growth, thanks to the diffusion of district heating in several cities. In general, also electricity increased its share. This increase is due to the electrification of the heating sector, to the diffusion of cooling systems and to the growth of the tertiary sector.

2.1.3 Transport sector

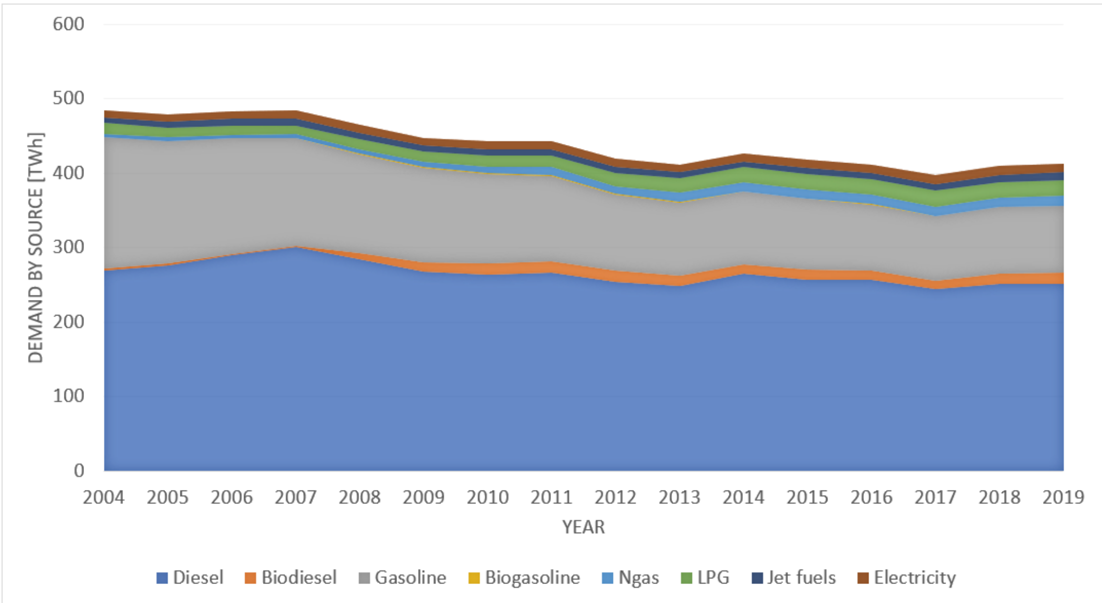


Figure 2.4: Energy demand by source in transport sector 2004-2019 [7]

In figure 2.4 is shown the the energy demand by transport sector for the period 2004-2019. It peaked in 2007 at the value of 484 TWh, then it saw a general decrease, due mainly to the increase in the energy efficiency of the engines. In 2019 the energy demand value was similar to the 90s level. In the period from 2004 to 2019 the fossil fuels share passed from 97.4% to 93.6%. Between the fossil fuels, gasoline saw the most drastic reduction, while natural gas and LPG (Liquefied Petroleum Gases) had an important growth. Thanks to the European legislation, biofuels are slowly increasing their share in the energy mix, but their role is still marginal, just as for the electricity.

2.1.4 Industry

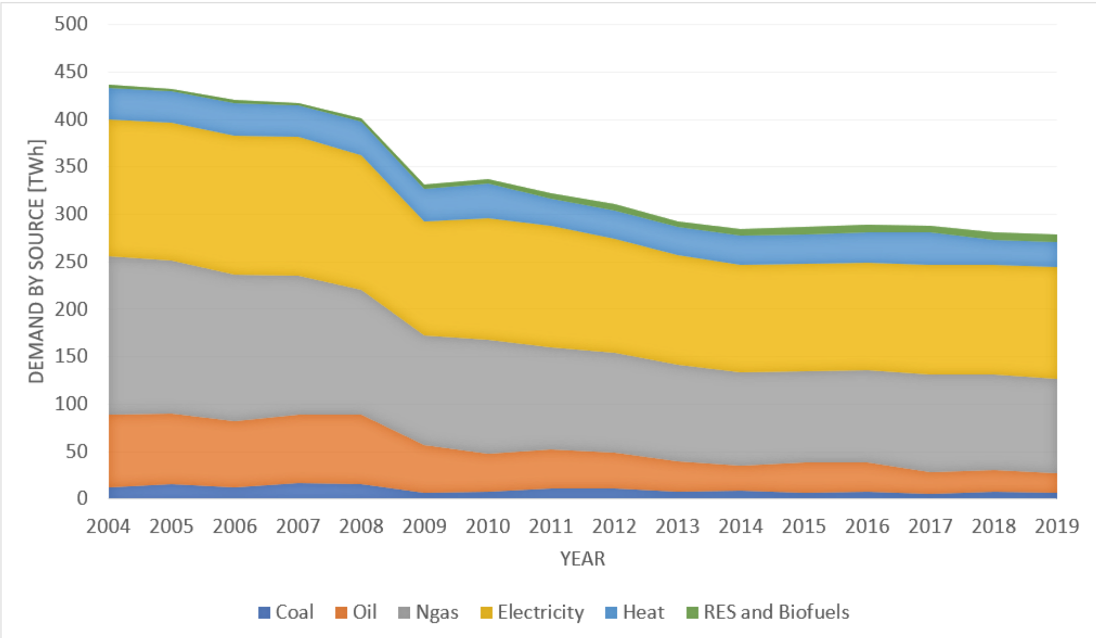


Figure 2.5: Energy demand by source in industry sector 2004-2019 [7]

In figure 2.5 is shown the energy consumption from the industry sector divided by energy source. Between 2004 and 2009, the total energy demand decreased by 36%, passing from 436 TWh to 279 TWh. It is clearly visible the effect of the 2009 economic crisis: between 2008 and 2009 the energy demand dropped by 17.3%.

Between 2004 and 2019 the fossil fuels share over the total consumption passes from 58.7% to 45.3%, while renewable and biofuels tripled their value, passing from a share of 0,8% to 2.9%. A general process of electrification is going on, with the electricity share that increased from 33.0% to 42.3% between 2004 and 2019.

In 2019 the most energy consuming sub-sector was minerals industry, with a share of 17.4% over the total consumption, followed in order by: iron & steel (15.0%), machinery (14.5%), chemical & petrochemical (12.7%) and food & beverage (11.55%).

2.1.5 Generation

The total installed capacity for electricity and heat production in Italy went from 77.8 GW in 2004 to 121.2 GW in 2019 (figure 2.6). This growth is mainly due to the installation of RES plants, which have a lower capacity factor with respect to the conventional thermal plants. Over the same period, the electricity and heat demand remain quite constant (figure 2.7).

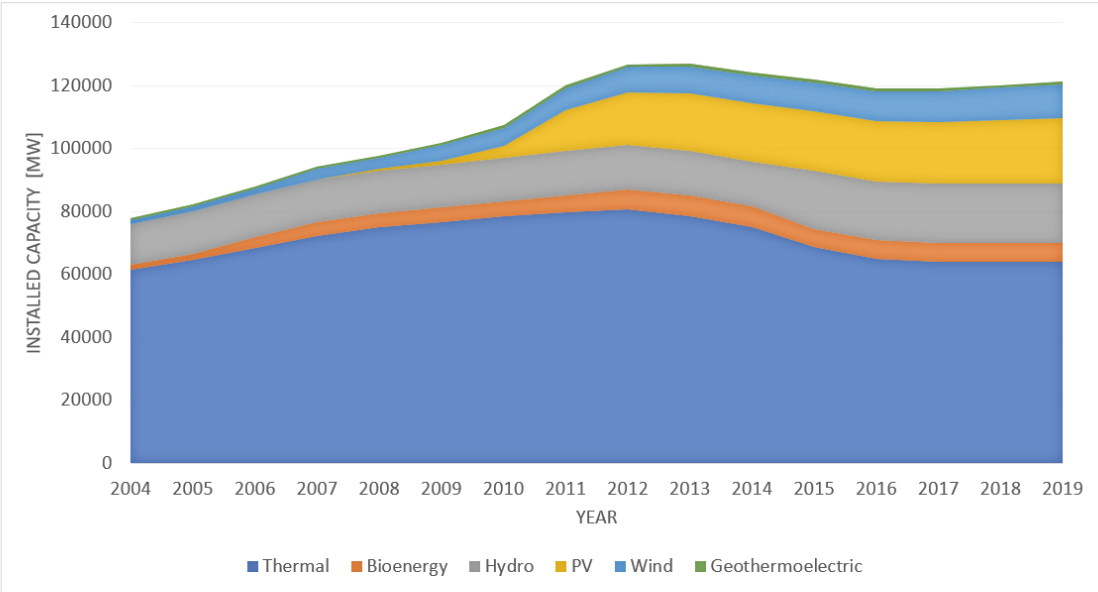


Figure 2.6: Gross efficient installed capacity by source 2004-2019 [11]

The thermal plants had a peak of installed capacity in 2012 at 8.1GW, subsequently, they decreased to reach in 2016 the 2004 level of about 6.5 GW and then the capacity remain stable until 2019. From 2004 to 2019 their share, over the total installed capacity, linearly decreased, passing from 79.1% to 52.8%.

Among the renewable sources, PV plants saw the bigger increase in the installed capacity. In particular, between 2010 and 2012, their share passed from 3.3% to 13.2%. In 2019 they accounted for 17.2% of the total installed capacity. Also wind and bioenergies had an important increase: the capacity of wind power plants passed from 1.1 GW in 2004 to 10.7 GW in 2019 and bioenergies capacity passed from 1.2 GW to 5.7 GW in the same period. Hydro and geothermal power plants saw a little growth, but their share remained quite constant.

Looking at the energy generation divided by source (figure 2.7), it is possible to see the big decrease in the electricity and heat produced by coal and oil. The two sources in 2004 accounted for 35.0% of the total energy and in 2019 they only accounted for 10.7%. In the same period, the natural gas share remained quite

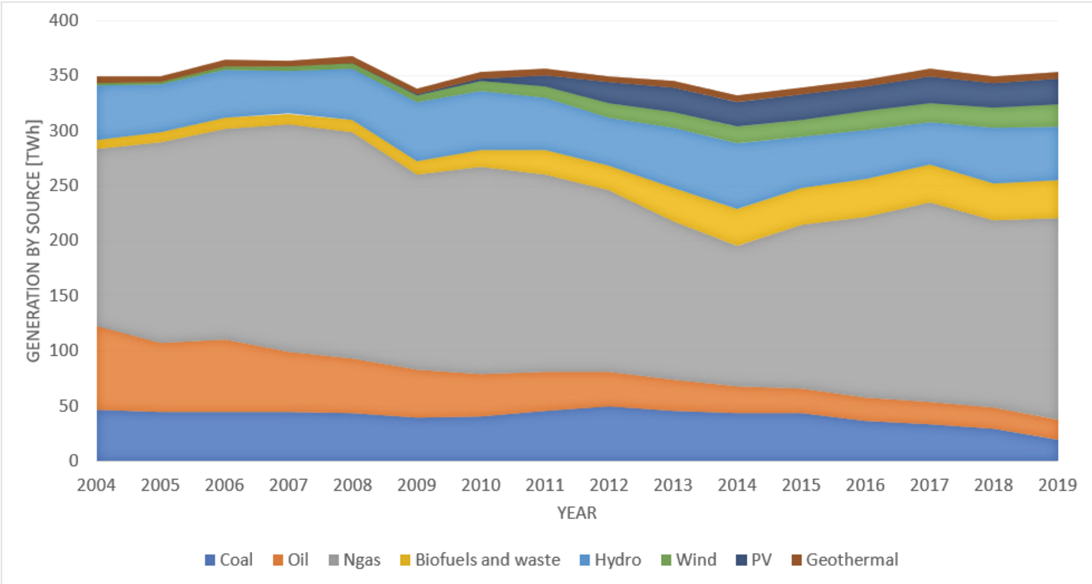


Figure 2.7: Electricity and heat generation by source 2004-2019 [7]

constant around the value of 50% of the total energy produced.

RES had a sensible increase, passing from a share of 18.8% in 2004 to a share of 38% in 2019. As for the installed capacity, the bigger growth was for PV, wind and bioenergies. After the thermal plants, the major energy producer was always the hydro power plants, with a stable share of about 14%.

The overall energy production remained quite constant during the whole period, around the value of 350 TWh.

2.1.6 GHG emissions

Over the analyzed period, the CO_2 produced by the Italian energy system was always decreasing, passing from 455 Mton in 2004 to 309 Mton in 2019, which corresponds to a reduction of 32.0% (figure 2.8). The biggest drop was between 2008 and 2009 when in only one year the reduction was of 45 Mton of CO_2 (-10.5%). In 2004, the major CO_2 emitters were the heat and electricity producers, with a share of 35%. Their emissions between 2004 and 2019 saw a reduction of 40.7%, thanks to the increasing RES capacity in the generation mix. Only in 2019, the transport sector become the first CO_2 producer, with a share of 32.7%, passing the generation sector. While the share of CO_2 produced by the generation and industry sectors were always decreasing, the ones of transport and buildings were always increasing. The absolute values of CO_2 per year, for all the sector, as anyway seen a significant reduction (-66 Mton the generation sector, -23 Mton the transport

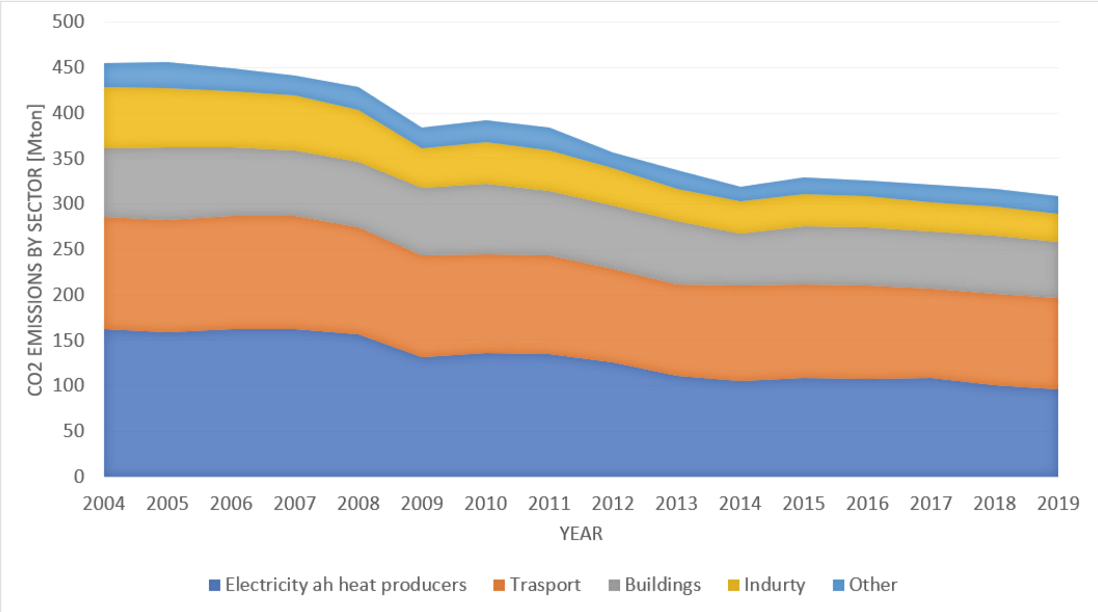


Figure 2.8: CO_2 emissions 2004-2019 [8]

sector, -37 Mon the industry sector and -14 Mton the buildings sector).

2.2 Covid-19 effects on the energy system and behaviour

Starting from the beginning of the 2020 the SARS-CoV-2 diffusion has changed the world equilibrium.

Covid-19 pandemic and the mitigation measures, undertaken to contain it, had a huge and unprecedented impact on healthcare systems, economies, societies and energy systems. In 2020, according to the World Bank, the pandemic led to the hardest economic recession since World War II. Thanks to the vaccination campaigns and the investment for recovery, the global economy is expected to grow in 2021 and more than compensating the 2020 drop [12].

In the energy field, the impacts were severe: during the first period the countries that were under full lockdown condition (March-April 2020) has experienced an average 25% decline in energy demand [13]. Over the whole year, the global energy demand fell by 4% with respect to 2019 and now is expected to grow up to 0.5% above the pre-Covid 2019 level in 2021 [12].

The energy sector has been affected in many different ways. The restrictions during the pandemic have strongly influenced the transport sector that accounts for around 60% of the total oil demand. Air passenger during 2020 was 66% below the 2019 levels and, during the lockdown, the road transport dropped between 50% and 75%. That's why oil was the commodity more affected by the pandemic [12].

At global level, also electricity demand has seen a fall caused by an important reduction of the industrial output and services sector. Only the residential energy use was higher compared to previous levels.

This reduction in demand also led to a change in the generation mix. While the traditional sources had an important decrease, the renewable sources share increased, thanks to low operating costs and priority access to the grid. In Italy, during the first lockdown, a new record was set, touching 63% of weekly max of VRE share [14].

The demand reduction and the change in the energy generation mix have also led to a 5.8% global reduction in CO_2 emissions, equal to 2.000 millions tonnes [15].

At the Italian level, the demand of primary energy in 2020 was 10% lower compared to the 2019 level, this reduction was only exceeded between 1943 and 1944 during the World War II. The 2009 crisis led to a reduction of 6.6% in the TPES and the main driver was the reduction in the industry outcome. The main reduction in 2020 has been recorded during the first lockdown, in the first trimester of the year, with a contraction of about 20% [1].

During the pandemic, the main driver of the energy demand decrease was the restriction of the mobility. The sharp fall in demand for transport in Italy led to a 17% contraction in the oil products: that were the commodities that more suffered the crisis. In particular, the aviation sector has seen the major reduction with a decrease of 70% in jet fuels demand between 2019 and 2020, while, between 2018 and 2019, increased by 4%. The coal demand saw a 20% fall in its demand emphasizing the past trend (the coal demand was decreasing on average 10% per year in the period 2016-19) [1].

The Italian electricity demand saw a reduction of 17 TWh compared to 2019, driven by the decrease of the services and industry activity. The electricity generation was only 11 TWh lower with respect to the previous year, due to the lower dependence from imported electricity (-6 TWh with respect to 2019). In 2020 fossil fuels were the main character in the generation mix (72%), but with a reduction of 2% with respect to the previous year. At the same time, the natural gas confirmed itself as first source in the electricity generation mix with a share of 37%, while RES increased their share by 1%.

Regarding the final energy uses, in 2020 the overall reduction in energy demand due to the pandemic was 10% with respect to 2019 (-23% transport, -7% industry, -3% buildings due to decrease in services activity and climate factor).

In addition to the effects on the energy system, the pandemic also affected the people way to live. From the beginning of March 2020, the Italian government imposed a national lockdown. This measure forbade all the unnecessary travel, and suspended teaching activities in presence, sport activities, demonstrations and events. Then the restrictions became softer during the summer, while, with the arrival of the autumn, more stringent norms came back with different levels of restriction, according to the health crisis of the different regions.

During this difficult period, people have experienced different changes in their lifestyle and in the way of seeing the world. Some of these changes could affect the future of the Italian energy system. In this work, the main citizens' behavioral changes taken into account are the increasing share of remote workers and the increased citizens' awareness of their responsibilities in addressing global crisis. The impacts of these behaviours on the future will be analyzed more in detail in chapter 5 during the scenarios construction.

Starting from the first identified behaviour change, the way of working was strongly affected by the pandemic. According to the "Osservatorio sullo smart working" of the "Politecnico di Milano", [2] during April 2020, 37% of European workers were working from home; in Italy the percentage was higher standing at 40%. During March 2020, in Italy, 6.6 millions workers were working from home, while, in September 2020, the workers who were working remotely were still 5.1 millions. Always according to the "Osservatorio sullo smart working" [2], in the future after the pandemic, the telework potential for the Italian "new normality" will be of 5.4 millions workers. This potential will be studied more in detail during the scenarios construction in section 5.1.

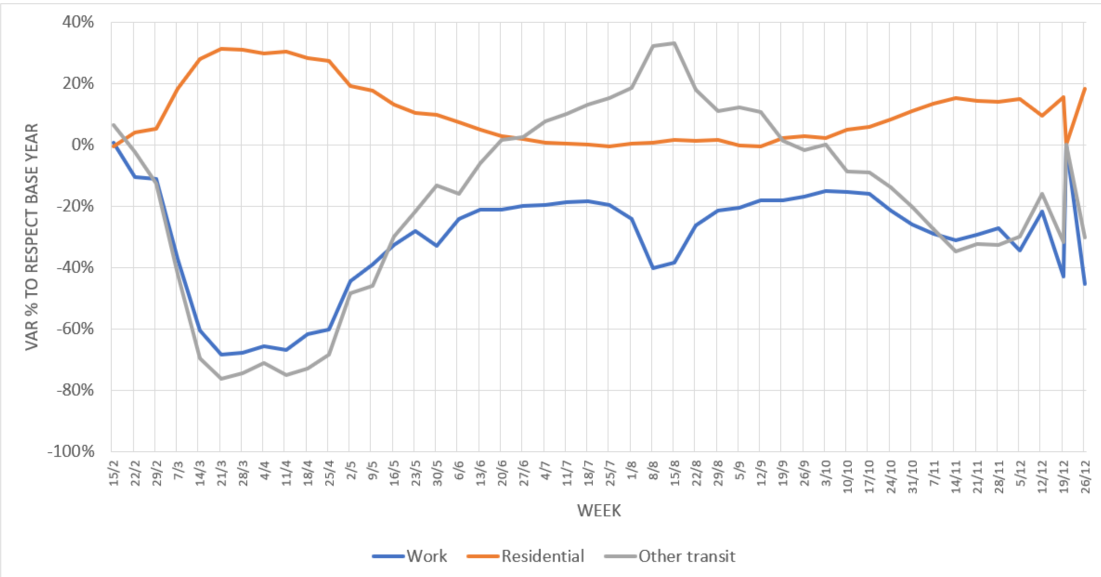


Figure 2.9: Mobility variation compared to baseline for work, residential and other transit from 02/2020 to 12/2020 [16]

The effects of telework on the transport during the pandemic can be clearly seen from figure 2.9. In this figure is shown the elaboration of the data from the "Community Mobility Reports" by Google [16]. In these reports are analyzed the mobility trends during the pandemic. The data given by Google are the daily variation between travels in specific location (like work places, park, stores and the time spent at home) and a baseline. The baseline is calculated as the average for each weekday, in the period between the 3rd of January and the 6th of February 2020.

In figure 2.9 are shown the Italian data from the 15th of February 2020 to the end of the same year, divided by week. The three lines represent the variation with respect to the baseline for the work travels (blue line), the average hours spent at home (orange line) and the average variation of other travels (grey line). The effects of working from home on the travels for work was important, with a variation between -70% in March, when the restrictions were stricter, and -20% when there was more freedom of movement.

The pandemic brought a big challenge in the daily life of the people. Millions of individuals, led by politicians and public information, have drastically changed their lifestyle to reach a common goal. In particular, in the early stages of the pandemic, the actions taken were drastic and the citizens life style was changed dramatically. In this critical situation, Italy was one of the country hardest affected by the pandemic. The key role in this challenge has been the responsibility of the citizens.

The pandemic has forced the citizens to face the fact that their actions can influence a global crisis. Everybody had to revise their own personal norms to deal with the pandemic. The reaction of the people was fast and forceful and their actions helped to contain the crisis.

People had this rapid reaction because the effects of the pandemic and the effects of their actions were easy to understand and directly measurable. In addition, the public information coverage of the crisis was wide and constant [17]. In section 5.2 will be deepened the connection between this reaction to the pandemic crisis and the response to the climate and environmental crisis.

The effects of the changes in behaviour does not only influenced the pandemic, but also the environment. During the lockdowns, thanks to the reduced mobility, people experienced clearer skies and more breathable air. In northern Italy, during the first lockdown, the concentration of nitrogen dioxide (NO_2) saw a gradual reduction trend of about 10% per week in the period between February and March [18] (figure 2.10). These experiences could have influenced the future mobility behaviours of the citizens. This correlation will be deepened in section 5.2.

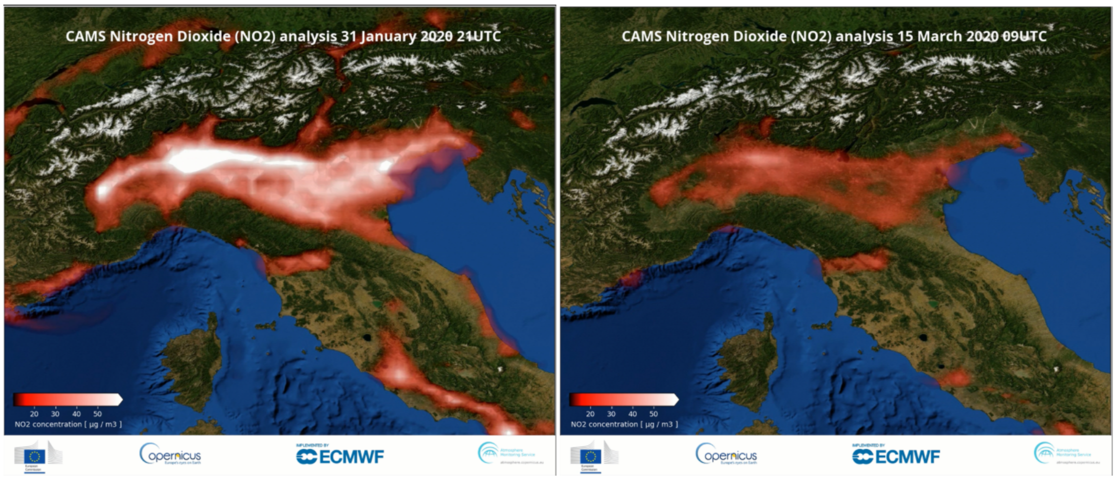


Figure 2.10: Surface concentrations of nitrogen dioxide over northern Italy, comparison between 31 January and 15 March 2020 [18] [19]

2.3 Energy policies and future energy objectives

According to the Sixth Assessment Report by IPCC [3], the increasing concentration of GHG in the atmosphere since 1850 is unequivocally caused by human activities. The CO_2 concentration reached 410 ppm in 2019, the highest value since 2 million years. This phenomenon resulted in an average increase of the earth surface temperature of approximately 1.07°C compared to the pre-industrial level. The effects of global warming and climate changes are multiple: extreme weather events became more common, desertification, melting glaciers, rising sea level etc. All these effects come with a very high economical and social cost. In all the IPCC scenarios, these trends will not stop at least until the mid-century and the global surface temperature by 2100 will set between +1.0°C (very low GHG emissions) and +5.7°C (very high GHG emissions), compared to 1850 [3].

The energy sector (including generation and final uses) is the first responsible for GHG emissions and it accounts for more than 70% of global human emissions. Therefore, in this context it is possible to see how the decarbonisation of the energy sector is one of the biggest challenges of our century. All around the world countries are implementing energy policies, in order to mitigate the climate changes. The main policies aim to: increase the energy efficiency in all sectors, introduce high level of renewable sources in the generation mix, organise a greener mobility and decarbonise the industry sector without compromising the competitiveness.

2.3.1 EU context

The European Union (EU27) contributed for 7.52% to global GHG emissions in 2019, while it accounted for 6.9% of the world's population [20]. EU has successfully reduced its CO_2 emissions by 20% between 1990 and 2017, bringing them to 4.333 million tonnes of CO_2 equivalent. The main actions include the improvements in the energy efficiency and the increasing share of low carbon energy sources in the energy mix. In 2017 fossil fuels still represented 72% of the European TPES, where the largest share was by the oil products, standing at 33% of the TPES. Nuclear energy accounted for 13%, biofuels and waste for 10%, and other renewables for 5%. The TPES peaked in 2006 at 20.930 TWh, then it decreases by 10% until 2017, reaching approximately the 1990 value. In 2017 the energy production by fossil fuels was 41% of the total, nuclear energy 29%, bioenergy and waste 20% and other renewables 10% [21]. While fossil fuels and nuclear energy declined, bioenergy and the other renewables increased their share, especially wind and solar.

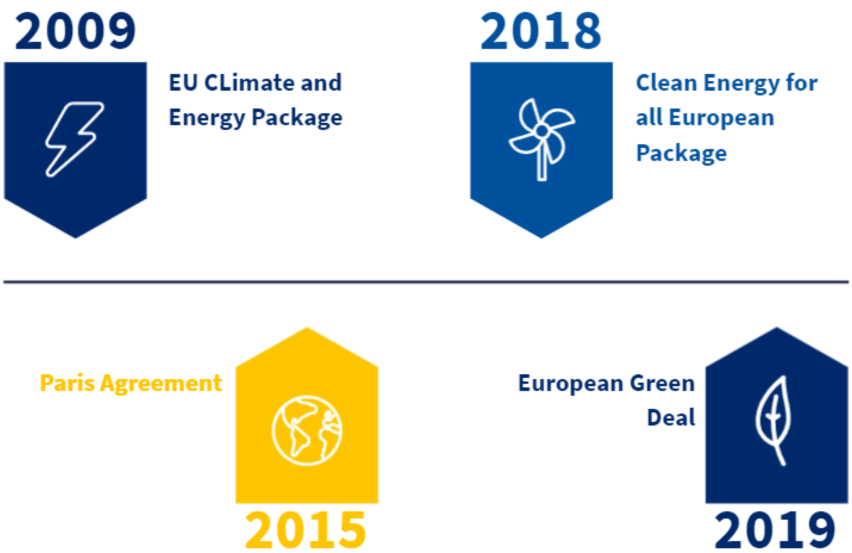


Figure 2.11: The EU policies pathway

The EU has implemented specific energy policies and targets covering the period up to 2020 and 2030, and the guidelines for the carbon neutrality up to 2050. These targets will be now presented to give a picture of the European pathway towards the decarbonisation, the policies pathway is summarized in figure 2.11.

EU Climate and Energy Package

The climate and energy targets for 2020 were first set in 2009, in the *"EU Climate and Energy Package"*, that includes the *"Renewable Energy Directive 2009/28/EC"*

(RED). In the RED the main goals set for 2020 were:

- To reduce greenhouse gas emissions by 20% (from 1990 levels)
- To increase share of renewables to 20%
- To reduce the energy consumption by 20% thanks to energy efficiency actions
- To reach 10% biofuels share in transport sector

The targets about GHG emissions, energy from renewable and biofuels were reached in the years just before 2020. While the 20% reduction in the energy consumption may not have been reached despite the pandemic. The last forecasts before the pandemic estimated this value for 2020 around 10%, far from the RED's goal. The package also included the *"Energy Efficiency Directive 2012/27/EU"* (EED) and the *"Energy Performance in Buildings Directive 2010/31/EU"* (EPBD) to help EU to reach the 20% energy efficiency target. In the EPBD and the EED focused on public buildings and national long-term renovation strategies, including the requirement for newly constructed buildings from 31 December 2020 to be nearly zero-energy.

Paris Agreement

In 2015, EU countries participated to the Paris Agreement at COP21. The different participating states has committed themselves to limit global warming "well below" 2°C and below 1.5°%, compared to pre-industrial level. To do this, the countries undertake to peak global emissions as soon as possible and to reach a balance between emissions and removals in the second half of the century. Every part in the agreement was supposed to develop a national climate action plans, called Nationally Determined Contribution (NDC). The EU, as NDC, is committed to reduce the GHG emissions of -40% emissions by 2030 compared to 1990.

Clean energy for all Europeans package

In 2018 the Commission proposed the *"Clean energy for all Europeans package"* in which were set the initial targets for 2030 and consists of eight new laws. The *"Renewable Energy Directive"* was updated (RED II - Directive EU 2018/2001) setting the new targets for 2030. The most important targets were: 32% renewable share in the energy mix and minimum of 14% of renewable energy in the road and rail energy consumption. It also imposed new strengthened criteria for biofules and their definition based on the materials of origin. The member states were also called to increase the share of renewable energy in the heating and cooling sector by 1.3% as annual average and to increase by 1% per year the renewable district heating in the period 2021-2030. In the updated *"Energy Efficiency Directive II"* (EED II - Directive EU 2018/2002) the key target for 2030 is the energy consumption reduction of at least 32.5%. According to the EED II the EU countries have also to achieve an annual reduction of energy consumption of 0.8% in the period 2021-2030.

In addition, the package contains the guidelines useful for the countries to establish their National Energy and Climate Plans (NECPs) for the period 2021-2030, introduced under the *"Regulation on the governance of the energy union and climate action (EU/2018/1999)"*. The member states had to present their final NECPs before the end of 2019 and the EU Commission will monitor the progress and the achievement of the targets through periodic national reports.

In 2018 the Commission also presented a long-term vision up to 2050 called *"A clean planet for all"* containing different pathways aiming to reach the EU's climate neutrality.

European Green Deal

The European Commission developed the *"European Green Deal"* (EGD) in December 2019. The EGD is a strategy setting the actions needed to put Europe on a pathway to a sustainable future. In the EGD are contained ambitious targets for cleaner energy and sustainable growing economy, to reach the climate neutrality by 2050.

In the EGD are also proposed: a new strategy on adaptation to climate change, new targets for the countries NECPs, the intention to revise RED II and EED II, the intention to present a strategy for sector integration and the intention to adopt a plan for smart and sustainable mobility [22].

The last updates for the EGD were proposed in the *"Fit for 55 Package"* in July 2021. In this package the new main targets for 2030 were:

- At least 55% reduction in GHG emissions
- 38-40% renewable share in final consumption
- 39-41% reduction of primary energy consumption

The legislative process for this package has just started and it will be not approved until the first trimester of 2023.

2.3.2 Italian context

PNIEC - Piano Integrato per l'Energia e il Clima

The Italian PNIEC is the NECP requested by EU. It is the energy and climate plan for the period 2021-2030. In December 2018 the draft was sent to the European Commission and in January 2020 was released the final text.

PNIEC is an ambitious strategy to reach the European Union targets, it is structured around 5 dimensions:

- Decarbonization
- Energy efficiency
- Energy security
- Internal market
- Research, innovation, and competitiveness

The general objectives of PNIEC are, first of all, to accelerate the decarbonisation process towards 2050; secondly, to make the citizens and the company actors and beneficiaries of the transition through the distribution of the energy generation; then to promote the energy efficiency and electrification in all the sectors and, finally, to improve the research and innovation. At the same time, these general objectives have to work in accordance with PNIEC goals of sustainability, security and competitiveness.

The main specific targets about renewables, energy efficiency and GHG emissions are reported in table 2.1. The other targets used in this work, that will be more deeply analyzed in the scenarios construction, are: the CO_2 reduction per each sector, the RES targets by source in the heating sector, the biofuels and electricity targets for transport, the coal phase out, the targets for capacity and energy for electricity from RES and the storage targets.

		2030
RES share in gross final consumption		30%
RES share in transport sector final consumption		22%
Reduction of GHG emissions (compared to 1990)		40%
RES share in heat generation		33.9%
RES share in electricity generation		55%
Energy savings (from 2020)	Buildings	66.3 TWh
	Transport	30.2 TWh
	Industry	11.6 TWh

Table 2.1: PNIEC main targets [23]

PNRR - Piano Nazionale Ripresa e Resilienza

The PNRR (Piano Nazionale Ripresa e Resilienza) is part of the European program Next Generation EU (NGEU), that is the European package to support the member states in response to the pandemic crisis. The PNNR presents the plans to use the economic aid from the EU. The three main topics are: digitisation & innovation, ecological transition and social inclusion. In this section the attention will be focused on the ecological transition.

According to the PNRR, 40% of the European economical aid will be allocates to the ecological transition.

The objectives of the PNRR for the "green revolution" are related, first to the upgrade of the recycling of waste (55% electric, 85% paper, 65% plastic, and 100% textile) and to improve the waste-to-energy sector, second to the improving of building efficiency (50.000 private and public buildings) and last to the development of research and support to the use of hydrogen in the transport sector.

The PNRR, then, also focuses on the sustainable mobility, with objectives related to the modernisation and development of the regional rail sector and to development of the "green ports".

Chapter 3

Modelling the Italian energy system with EnergyPLAN

3.1 Purposes and classification of energy models

As shown in the previous chapter the energy sector is responsible for 70% of global GHG emission and is a key driver of modern economies. So it is very important for policymakers to have information about different possible scenarios of its evolution.

For this purpose, since the 1970s, several energy models has been developed trying to better represent the energy systems. An energy system is the combination of processes and fluxes aiming to meet the demand of energy commodities in the final uses. Energy models are often combination of different disciplines including: economics, engineering and management science. They can be created with different aims, for instance, to understand the environmental impact of a system or to understand the interactions between economy and energy, and also with different spatial scale, sector definition and time frame.

A first classification of energy models can be done dividing theme into deterministic and stochastic models. Stochastic models, based on probability, are often used to build the final demand and are based on regression techniques of historical data, they don't need detailed description of technologies and are time consuming. Instead, deterministic model are simpler, the input variables have fixed values and are processed by systems of equations, for a given set of inputs they will always give the same outputs.

Models can be also divided in top-down and bottom-up models. Top-down models are based on the interaction between energy and economy, technologies are seen as aggregated and are not described in detail, they can be useful to study the evolution of prices or macro-economic parameters. On the contrary, bottom-up models are technology based, so any technology is well described by both technical and economical parameters and macro economic data are always exogenous, they can be used to compare different energy policies and to study the environmental impact of energy system.

The last classification is based on the modelling technique. Under this division it is possible to have optimization or simulation models. Optimization models aim to minimize/maximize an objective function, finding the optimal system configuration under a certain number of constrains. Instead, simulation models can not find an optimal configuration, but they can be used to compare different scenarios. The simulation models can be coupled with optimization tools in order to have hybrid models.

It is important to remember how the approximations in the description of the energy system and the scenarios implemented in the energy model influence the results. Especially in the long-term studies, the model will be always affected by exogenous variables like future prices, technology switches or population and GDP forecast. A clear example is the Covid-19 crisis, that has influenced the whole world economy and asset in a unpredictable way. Long-term energy forecast can be very useful to compare different possible pathways for the future, but the results has to be taken with criticism, knowing that the future is unpredictable and the sources of uncertainties are manifold.

3.2 Description of the software and its operation

The software used for this study is EnergyPLAN [6], it was developed since 1999 by the Sustainable Energy Planning Research Group at Aalborg University in Denmark and programmed in Delphi Pascal. The version used in this thesis is the 15.1, released on September 15, 2020. The main aim of EnergyPLAN is to study the impacts of different, regional and national, energy strategies on the environment and on the economy. In particular the software, as well as the conventional plants, focuses on the innovative solutions. Hydrogen, biofuels, CCUS, smart charge vehicles, advanced CAES, synthetic electro-fuels and the respective system of production, are some examples of future technologies and commodities that can be implemented in the software. A scheme of the main energy flows, technologies and final sectors of the software is shown in figure 3.1.

EnergyPLAN is an input/output deterministic model and it is defined as a simulation model, but some optimisations occur during the run of the scenario, giving the priority to the renewable energy sources.

The main inputs that are requested by the software can be divided in demand, supply, storage and costs. The demand side is, in turn, divided in different tab: electricity, heating, industry, transport and desalination. In each tab are required the energy consumption, the efficiencies of the different technologies and the hourly

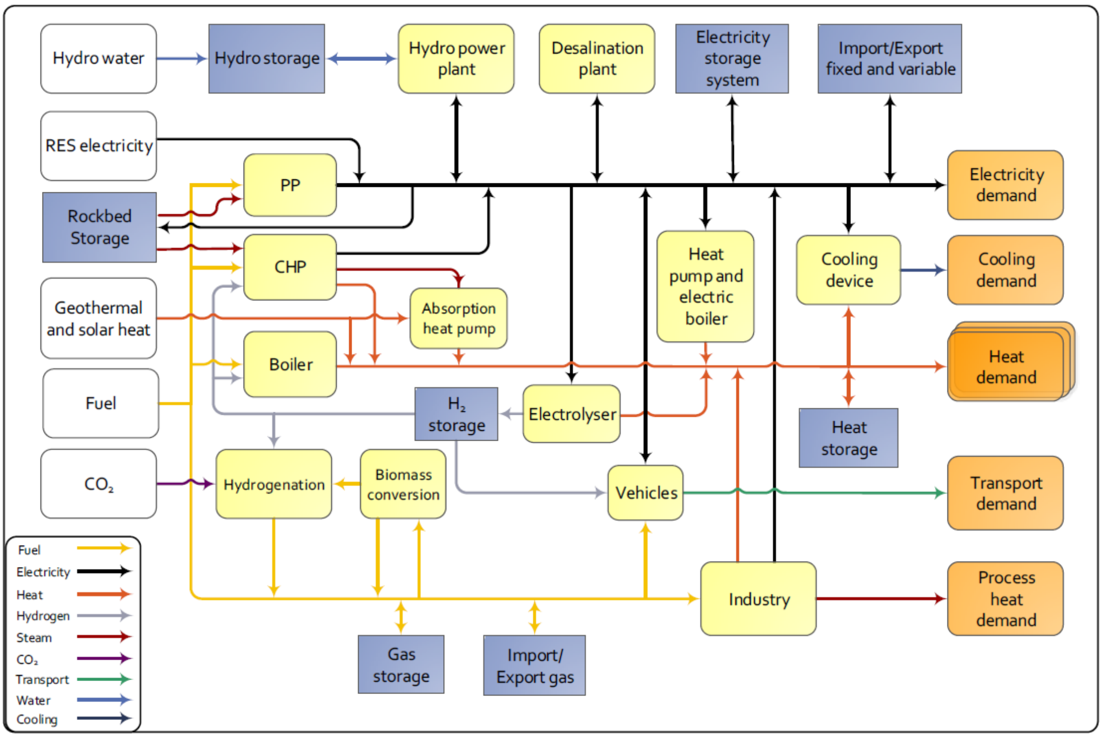


Figure 3.1: EnergyPLAN structure [6]

distributions. The supply side is divided in heat and electricity, central power production, variable renewable electricity, heat only, waste and CO_2. For each tab in the supply sector are required the installed capacities, the efficiencies, the fuel consumption and the hourly distributions [6].

The simulation that the software carries out is an analysis over one year made hour-by-hour. In order to allow this kind of analysis, are required the hourly distribution for the demand and supply technologies. These distributions are made taking the absolute values of the variable of interest over one year and dividing it by its maximum value.

The software gives the possibility to choose between two different simulation strategies, one is the *Technical Simulation*, that does not take into account the prices and costs, but only the balance between demand and supply. The other one is the *Market Simulation* that is based on the short-term marginal costs to minimize the prices for the costumers [6]. During this work all the simulations are carried out using the *Technical Simulation* strategy, letting EnergyPLAN to balance the supply and demand for heat and electricity.

The software EnergyPLAN has been chosen for this thesis due to its wide use in the literature and also because it is free and continuously updated. Its use in other researches allows to have some important references for the construction of the reference energy model and for the construction of scenarios, like the several works done by Sara Bellocchi and Michele Manno [24] [25] and the Heat RoadMap Europe 4 project (HRE4) [26].

3.3 The Reference Energy Model

The Reference Energy Model used in this work (REM2018) is the representation of the Italian energy system for 2018 and it is used to calibrate the software and to have a base year to compare the scenarios.

The year 2018 was chosen because is the most recent year for which the data in the official sources are available. The main source used to build it is the National Energy Balance (BEN) given by Eurostat [7]. REM2018 is developed based on the work done by engineer Sara Bellocchi and professor Michele Manno (Industrial Engineering Department - University of Rome, Tor Vergata) [24] for the year 2017. Then, engineer Martina Bembi has updated the data for 2018 in her master thesis in collaboration with ENEA [27]. During the present work the REM2018 has been fixed and updated to better fit the objectives of this thesis and to improve its accuracy. In particular has been improved: the data for the heat pump consumption, the cooling demand in civil sector, the district heating demand (and its fuels and RES consumption), and the thermoelectric plants definitions and consumption with a focus on the waste-to-energy sector.

The following sections summarize the main assumptions and data used in order to build REM2018.

3.3.1 Demand

Electricity

In the tab "Electricity Demand and Fixed Import/Export" of EnergyPLAN, the first requirement is the total gross electricity demand, excluding electricity for transport, for biomass conversion, for heat pumps, for electric heating and electric cooling (that will be analyzed in the next tabs). This data is found starting from the total electricity produced given by the BEN [7]. For the electricity consumption EnergyPLAN also requires the hourly distribution of the load for all the year and the distribution is taken from TERNA for 2018 [9]. The next data requested is the net import that is taken from the BEN [7], its value is 43.89 TWh and its distribution is obtained by the TERNA [9] for 2018. The data are resumed in table 3.1

	2018 [TWh]	**Source**
Gross electricity demand (*)	290.95	BEN [7]
Import	43.89	BEN [7]

(*) excluding electricity for biomass conversion, transport, heat pumps, electric heating and electric cooling

Distribution	**Source**
Electricity demand distribution	TERNA [9]
Import distribution	TERNA [9]

Table 3.1: Tab "Electricity" demand EnergyPLAN - REM2018

Heating

The next tab is about the heating demand by buildings sector (residential and services), EnergyPLAN divides the demand into individual heating and district heating.

Starting from the individual heating, for the different energy sources the consumption is found thanks to the work of engineer Sara Bellocchi and professor Michele Manno [24]. They found for the year 2015 the percentage of energy consumption, for each energy sources, used for the individual heating with respect to the total consumption in buildings sector. Those percentages are then applied to the total buildings sector energy consumption in 2018 from the BEN for oil products, natural gas, electricity and biofuels. The heat from solar thermal and geothermal are directly taken from the BEN. Also for the efficiencies for the individual heating the reference is the work of Bellocchi and Manno [24]. During this work the heat pumps characterization has been modified, taking as source for the heat demand the BEN and for the global COP the "Heat Roadmap Europe 4" project (HRE4) [26]. This project will better analyzed in section 4.1, in its report a reference energy model is developed for EnergyPLAN, for the Italian case they use as base year the 2015.

The results are listed in table 3.2.

The heat demand from district heating in buildings sector is derived from the BEN, in particular from the derived heat final consumption for households and services, the results are shown in table 3.2.

The distributions required by EnergyPLAN in this tab are the one related to the individual heat demand, that is taken from Snam [28] for 2018 and the one related to the district heating demand, that is taken from the work done by Bellocchi and Manno [25], as the distribution of the district heating demand in Turin in 2010.

	2018		
	Fuel input [TWh]	**Efficiency/ COP [-]**	**Source**
Oil boiler	28.10	0.90	Elaboration from [7]/[25]
Ngas boiler	266.83	0.92	Elaboration from [7]/[25]
Biomass boiler	73.27	0.75	Elaboration from [7]/[25]
Electric heating	13.86	1	Elaboration from [7]/[25]
Heat pump	8.39	3.6	BEN [7] HRE4 [26]
District heating demand	23.11	-	BEN [7]

Distribution	**Source**
Individual heat demand distribution	Snam [28]
District heating demand distribution	Bellocchi [25]

Table 3.2: Tab "Heating" demand in residential and services EnergyPLAN - REM2018

Cooling

The cooling demand is divided in electric individual cooling and district cooling.

The individual cooling section has been re-elaborated during this work. The reference used is the project HRE4 [26]. The electric consumption by electric cooling given by HRE4 for 2015 is compared with the total electricity consumption in buildings sector from the BEN in 2015. The percentage found this way is used to estimated the electric consumption for individual cooling in 2018 using the BEN data for 2018. The COP for electric cooling is also taken from the HRE4 project.

The cooling production by district cooling is found in the AIRU report for 2018 [29].

The only distribution required by EnergyPLAN for the cooling sector is the cooling demand distribution and is taken from the work done by Bellocchi e Manno [24]. The data and the sources for the cooling sector are resume in table 3.3.

Industry and Other Fuel Consumption

In the tab "Industry and Other Fuel Consumption" EnergyPLAN requires the fuels consumption (excluding electricity and derived heat) for the industry sector and for the sectors that are not elsewhere specified in EnergyPLAN. These sectors are: the energy consumption of buildings sector (excluding the energy consumption for

	2018		
	Fuel/ Cooling [TWh]	**COP [-]**	**Source**
Electricity consumption for individual cooling	8.82	6.95	Elaboration from [7]/[26]
Cooling production by district cooling	0.133	-	AIRU [29]

Distribution	**Source**
Cooling demand distribution	Bellocchi [25]

Table 3.3: Tab "Cooling" demand EnergyPLAN - REM2018

heating and cooling), agriculture and forestry, fishing, and the energy consumption by the energy sector. The data for this tab are taken from the BEN. In the case of the industry sector they are directly taken from the BEN, while for the other sectors is the sum of their respective energy consumption.

The only distribution required in this tab is the natural gas demand distribution that is taken from Snam [28]. The data found are listed in table 3.4.

	2018		
EnergyPLAN data	**Industry [TWh]**	**Other [TWh]**	**Source**
Coal	11.79	0.87	BEN [7]
Oil	23.48	66.54	BEN [7]
Natural gas	100.57	31.72	BEN [7]
Biomass	4.58	0.84	BEN [7]

Distribution	**Source**
Natural gas demand distribution	Snam [28]

Table 3.4: Tab "Industry and Fuels" demand EnergyPLAN - REM2018

Transport

Transport sector includes: road, rail, domestic navigation, domestic navigation and other transport consumption. In EnergyPLAN the energy consumption is required aggregated for all these sub-sectors.

The fuel fluxes required by EnergyPLAN and useful for REM2018 are jet fuel, diesel, gasoline (and their biofuels), natural gas, LPG and electricity. The data are directly taken from the data related to transport sector in the BEN.

The only distribution useful in this sector is the one related to the electricity consumption and for this model it comes from the work of Bellocchi and Manno [24] as the distribution of the total transport in 2018. The data are listed in table 3.5.

	2018 fuel demand [TWh]	**Source**
Jet fuel	10.16	BEN [7]
Diesel	251.25	BEN [7]
Biodiesel	14.15	BEN [7]
Gasoline	88.84	BEN [7]
Biogasoline	0.38	BEN [7]
Natural gas	12.71	BEN [7]
LPG	20.62	BEN [7]
Electricity	11.54	BEN [7]

Distribution	**Source**
Electricity demand	Bellocchi [25]

Table 3.5: Tab "Transport" demand EnergyPLAN - REM2018

3.3.2 Supply

Heat and Electricity

The tab "Heat and Electricity" in EnergyPLAN is used to characterize the combined heat and power plants (CHP), the boiler plants and the heat demand by the industry sector.

For the boilers plants only the efficiency is requested in this tab. The fuels consumption, also for the CHP plants, will be analyzed in the next tabs. The efficiency is obtained from the BEN by comparing the fuels consumption (excluding the waste that will be analyzed individually in a specific tab) and the heat produced by these fuels.

For CHP plants are requested the efficiencies and the the electric capacity. The electric efficiency and the thermal efficiency are obtained as for the boilers plants, while the electric capacities are derived from the TERNA report for the electric generation in 2018 [30].

The heat consumption by the industry sector is obtained from the BEN its hourly distribution is also required by EnergyPLAN and is taken from the work of Bellocchi and Manna. The data are listed in table 3.6.

During this work the capacities and efficiencies of the plants have been remodelled to exclude the waste-to-energy plants. This analysis was done to exploit the potential of EnergyPLAN and to insert the waste-to-energy plants in the appropriate tab provided by the software.

	2018	**Source**
Boiler efficiency	0.880	BEN [7]
CHP electric capacity	26152.6 MW	TERNA [30]
CHP electric efficiency	0.392	BEN [7]
CHP thermal efficiency	0.217	BEN [7]
Heat demand by industry	39.97 TWh	BEN [7]

Distribution	**Source**
Heat demand by industry distribution	Bellocchi [25]

Table 3.6: Tab "Heat and Electricity" supply EnergyPLAN - REM2018

Central Power Production

In the tab "Central Power Production"he specification of the electricity production only plants is requested.

For the conventional thermal plants (PP) feed with coal, oil, natural gas and biomass, it is needed to specify the aggregated electric capacity and the electric efficiency. The total capacity is taken from TERNA for 2018 [30]. The electric efficiency is obtained as for boilers and CHP from the BEN data [7].

Also in this case the capacity and the efficiency of th PP has been remodelled to exclude the waste from their energy mix.

In this tab also the specification of geothermoelectric plants is required. The total capacity is taken from the TERNA report and the efficiency comes from the work done by Bellocchi and Manno [24]. The distribution for the electricity produced over the year for the geothermoelectric plants is obtained from TERNA for 2018 [9]. In table 3.7 the useful data are listed.

	2018	**Source**
PP efficiency	0.451	BEN [7]
PP electric capacity	37868.2 MW	TERNA [30]
Geothermal efficiency	0.1	Bellocchi [25]
Geothermal electricity production	813.1 MW	TERNA [30]

Distribution	**Source**
Electricity produced by geothermal plants	TERNA [9]

Table 3.7: Tab "Central Power Production" supply EnergyPLAN - REM2018

Variable Renewable Electricity

For the VRES (Variable Renewable Energy Sources) there is a specific tab in EnergyPLAN. For each renewable source are required the electric capacity and the distribution. The capacities are taken from the TERNA report about the electric generation in 2018 [30] and the distribution for 2018 are obtained from TERNA [9]. The useful data are shown in table 3.8.

	2018 RES capacity [MW]	**Source**
Wind	10264.7	TERNA [30]
Photo Voltaic	20107.6	TERNA [30]
Hydro	22910.5	TERNA [30]

Distribution	**Source**
Wind electricity production distribution	TERNA [9]
Photo Voltaic electricity production distribution	TERNA [9]
Hydro electricity production distribution	TERNA [9]

Table 3.8: Tab "Variable Renewable Electricity" supply EnergyPLAN - REM2018

Heat Only

In the heat only tab are required the specification for the central production of heat from renewable sources. This tab was completely rework during this thesis.

From the AIRU report [29] are obtained the values from the geothermal heat production and the industrial excess heat used in the district heating grid. The values are listed in table 3.9.

	2018 Central heat production [TWh]	**Source**
Geothermal	0.239	AIRU [29]
Industrial excess heat	0.051	AIRU [29]

Table 3.9: Tab "Heat Only" supply EnergyPLAN - REM2018

Fuel Distribution

EnergyPLAN requires in this tab the fuels consumption by the different energy plants (boilers, CHP and PP), these data are obtained from the BEN and are listed in table 3.10.

	2018 fuel consumption [TWh]				
EnergyPLAN data	**Coal**	**Oil**	**Ngas**	**Biomass**	**Source**
Boiler plants	0	0.05	3.19	1.19	BEN [7]
CHP plnats	8.21	43.92	179.78	29.29	BEN [7]
PP plants	73.84	3.79	88.96	21.69	BEN [7]

Table 3.10: Tab "Fuel Consumption" supply EnergyPLAN - REM2018

Waste

For the waste-to-energy sector a specific tab is dedicated by EnergyPLAN and for the year 2018 it was developed during this work.

The specification required by the software are the waste input in TWh and the electric and thermal efficiencies. These data are easily derivable from the BEN data. For the waste input are considered industrial and municipal waste both renewable and non-renewable, while the efficiencies are obtained comparing the waste energy input and the electricity and heat produced by it. The data found are listen in table 3.11.

	2018 waste data	Source
Waste input	20.09 TWh	BEN [7]
Electric efficiency	0.240	BEN [7]
Thermal efficiency	0.152	BEN [7]

Table 3.11: Tab "Waste" supply EnergyPLAN - REM2018

CO_2 emissions

To calculate the total emissions of CO_2 EnergyPLAN requires the specific emission factor for each fuel, these data are taken from ISPRA [31] and are reported in table 3.12.

	2018 CO_2 emissions [kg/GJ]	Source
Coal	93.89	ISPRA [31]
Oil products	76.69	ISPRA [31]
Ngas	57.62	ISPRA [31]
LPG	59.64	ISPRA [31]
Waste	32	ISPRA [31]

Table 3.12: Tab CO2 EnergyPLAN - REM2018

3.3.3 Model validation

In order to validate the REM2018 some of the results of the EnergyPLAN simulation of the model for 2018 have to be compared with the data from the official sources. To compare these data the deviation is calculated according the formula 3.1.

$$var\% = \frac{Model - Literature}{\frac{Model+Literature}{2}} \tag{3.1}$$

Table 3.13 reports the results achieved, showing how the deviations between model and statistics are lower than 3% for the different data analysed.

The deviation CO_2 production is slightly higher with respect to the works done by eng. Bembi [27] and eng. Bellocchi [24], while all the other deviations are near to be one order of magnitude more accurate. This is probably due to emissions associated to the waste, that are difficult to estimate.

	Model	**Official source**	**Deviation**	**Source**
CO2 emissions [Mton]	323.67	317.10	2.05%	IEA [8]
TPES [Mtoe]	139.57	139.20	0.27%	IEA [10]
FER electricity* [TWh]	96.96	96.97	-0.01%	BEN [7]
PP electricity [TWh]	87.23	87.21	0.02%	BEN [7]
CHP electricity [TWh]	105.47	104.92	0.52%	BEN [7]

*excluding bioenergies

Table 3.13: REM2018 validation

Chapter 4

2040: Base Scenario

According to the purposes of this work, the year 2040 is chosen to perform the long-term analysis. This choice was made because the 2040 is distant enough in time from Covid-19 crisis to assume that the economic effects will be negligible. At the same time, 2040 is not too far in time so that the effects on the behaviours, taken into account, will be potentially influential in the scenarios.

As seen in section 2.3, the European decarbonisation objectives for 2050 are contained in the European Green Deal. For now, these objectives are not specific for each sector or energy source, but they are mainly guidelines for the entire energy system. Instead, for 2030 the energy targets are well defined by PNIEC and by the European packages. So, the Italian energy system in 2030, both for generation and final use, can be deeply studied through these targets. This allows to have a solid base to construct the scenarios in 2040, as possible pathways towards the decarbonisation.

The Base Scenario for 2040 (BS2040) is constructed as a possible pathway towards the decarbonisation. The effects of the variable related to the change in behaviour, following Covid-19 pandemic, will be applied to the BS2040, in order to asses their impact on the Italian decarbonisation pathway.

The BS2040 assumes that there was no Covid-19 pandemic. It is constructed on the assumption that PNIEC targets will be met in 2030 and that full decarbonisation targets will be met in 2050.

The scenario was developed through the use of a model developed on Excel spreadsheets. This model was created starting from the REM2018 and then studying the evolution of each variable until 2040, using literature, equations and assumptions, that will be presented in this chapter.

In order to build the BS2040, several steps were implemented. A full 2030 scenario was constructed in the Excel model, based on PNIEC. The data from PNIEC are elaborated to fit the requirements of EnergyPLAN, using REM2018 and its assumption as starting model. For the sector not specified in PNIEC, different

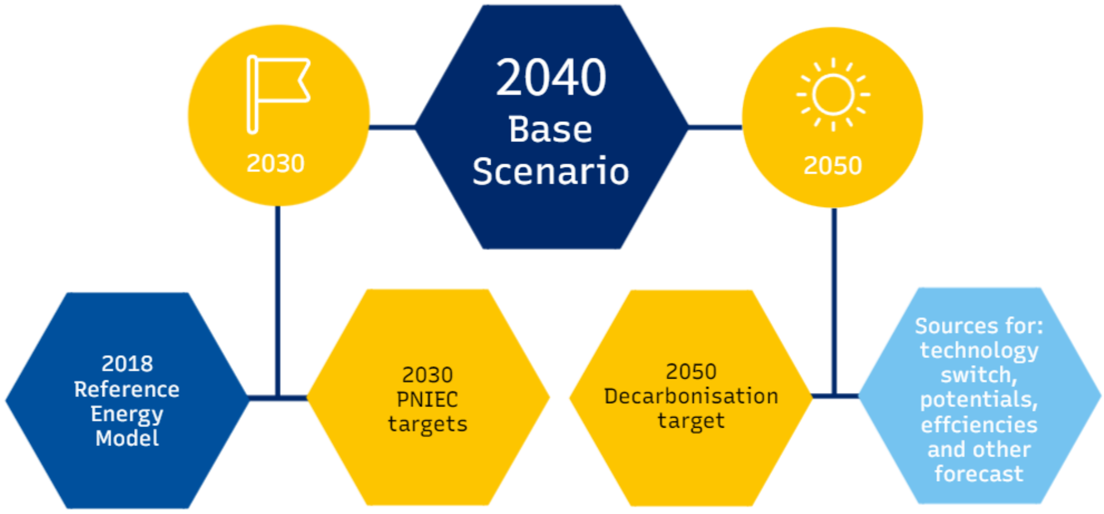


Figure 4.1: BS2040 construction

sources has been studied to met PNIEC general reduction targets of energy demand and emissions. Then, this scenario is implemented into EnergyPLAN to check the achievement of the targets. The general objectives from PNIEC for 2030 are reported in subsection 2.3.2 (table 2.1), while the specific targets for each sector will be presented in this chapter, at the beginning of the respective sections.

A partial scenario for 2050 is also developed in the model, but not implemented in EnergyPLAN. This scenario is useful to draw the trajectories from 2030 towards the decarbonisation. For the period between 2030 and 2050 several sources are studied for each sector, in order to find the most suitable pathway for the change in technologies and their potential, efficiencies improvement, and other useful forecasts.

The BS2040 is therefore developed as the evolution between the PNIEC2030 scenario and the 2050 decarbonisation scenario.

This reasoning is applied to all the different energy sectors, from the generation to the final use. A scheme of the reasoning behind the BS2040 construction is shown in figure 4.1 and for each sector a similar scheme will be presented more in detail.

In this work only technical simulation are carried out with EnergyPLAN; the economical effects are not taken into account.

4.1 Buildings sector

4.1.1 Objectives and construction

The 2030 PNIEC objectives for buildings sector are:

- Reduction of CO_2 emissions from 72 Mton $CO_{2\ eq}$ in 2020 to 52 Mton CO2eq in 2030 (-27.8%)
- Energy saving of 38.4 TWh for residential and 27.9 TWh for service sector between 2020 and 2030 (approximately -12.1% of total)
- 33.9% RES share in the heat generation

The final demand in the buildings sector was divided into **heating**, **cooling**, and **cooking and others electric consumption**, as shown in figure 4.2.

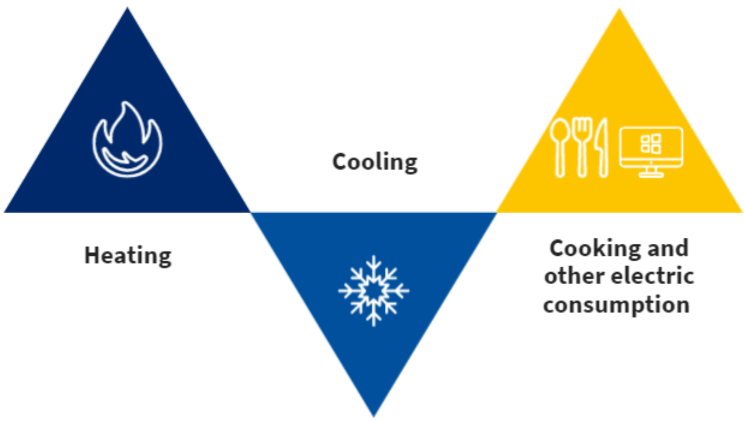


Figure 4.2: Final energy use in buildings sector

The Italian global trends for heating and cooling demand in the buildings sector are taken from the project "Heat Roadmap Europe 4" [26] [32]. The project focuses in particular on the heating and cooling sectors, but also considers the linkages to the entire energy system. It offers three different scenarios for 2050 for each European state: the *Baseline Scenario*, the *Decarbonization Scenario* and the *Heat Roadmap Europe 4 Scenario*. The *Baseline Scenario* shows a future trend under the assumption that the policies implemented before 2016 will be maintained, but not improved and the EU's 2030 targets are not included in this scenario. The *Decarbonization Scenario* and the *Heat Roadmap Europe 4 Scenario* explore two different pathways towards the decarbonisation. In the first there is not a substantial change in the technologies used: boilers are still the main technological solution in individual heating and the energy efficiency improvement in buildings is the same of the *Baseline Scenario*. In the second one there is a drastic change in the way heating and cooling are produced: a large use of heat pumps and major energy efficiency measures are taken to decrease the heat demand.

In all scenarios the heating demand decreases due to increasing buildings efficiency and climate changes, that will lead to higher temperature and so to less heating demand. In particular in the *Baseline Scenario* and in the *Decarbonization Scenario* the Italian heat demand decreases by 24.71% between 2018 and 2050, while in *Heat Roadmap Europe 4 Scenario* the heating demand decreases by 32.98% over the same period, due to major energy efficiency policies. To meet the energy saving PNIEC targets and the decarbonisation towards 2050, an average value between this two trends is chosen for this study to set the 2050 heating demand. The values for the heating demand for 2030 and 2040 are linearly interpolated between 2018 and 2050, so the final heat demand in the buildings sector will be 342.33 TWh in 2030 and 307.72 TWh in 2040, while in 2018 was 383.85 TWh (figure 4.3).

The Italian cooling demand in 2050 from HRE4 project is equal for all the scenarios and it is increasing due to people behaviors and to climate changes, that will led to higher temperatures. The increase in percentage is 224.06% between 2018 and 2050 and this value is also used in this work. The 2030 and 2040 values for cooling demand are linearly interpolated between 2018 and 2050. The results are that the final cooling demand in buildings sector will be 113.05 TWh in 2030 and 156.06 TWh in 2040, while in 2018 was 61.43 TWh. The values and the trends are shown in figure 4.3.

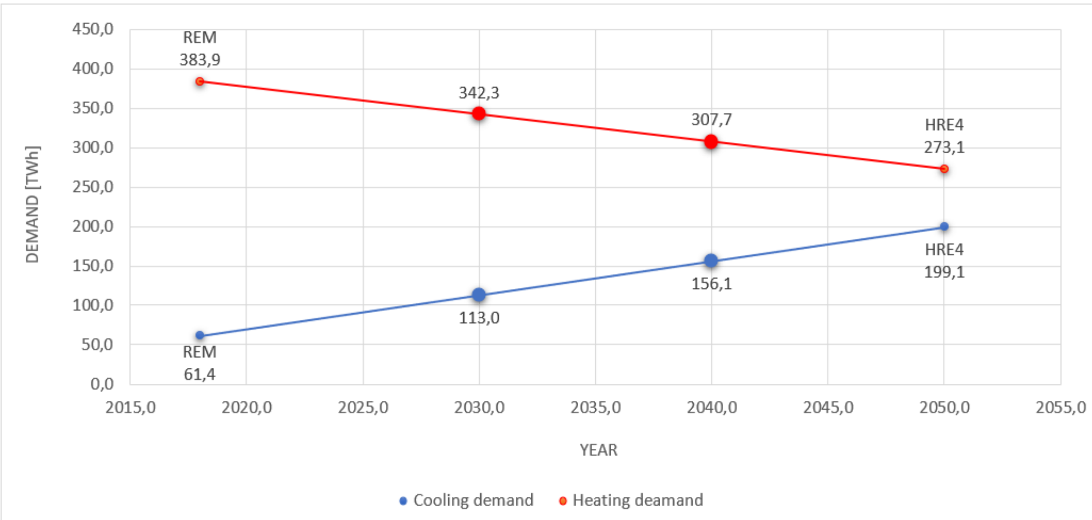


Figure 4.3: BS2040: total heat and cooling demand for buildings sector

Figure 4.4. shows the scheme of BS2040 construction in relation to heating production and demand for the building sector.

The different heating technologies to satisfy the global demand are modelled starting from data given by PNIEC. It provides the historical data for 2017 and the targets for 2030 for the final consumption of RES for heating: bioenergy, solar thermal, geothermal and ambient heat from heat pump. (Table 4.1)

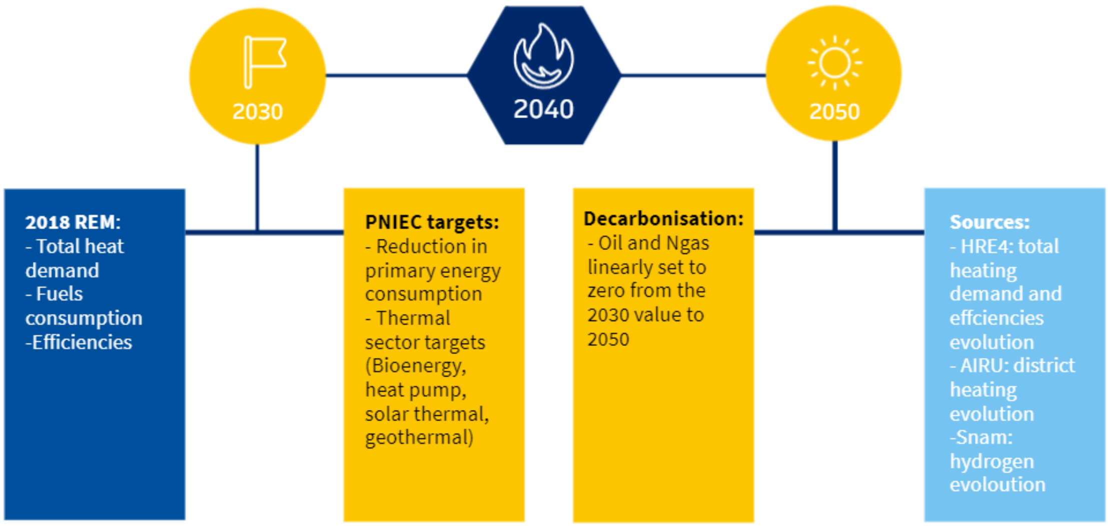


Figure 4.4: Heat demand in buildings sector construction

Source	2017	2030	Var %
Bioenergy	7,265	7,430	2.3 %
Solar	209	751	259.3 %
Geothermal	131	158	20.6 %
Ambient heat from heat pump	2,650	5,699	115.1 %
RES share (%)	20.1 %	33.9 %	68.7 %

Table 4.1: Final consumption of RES for heating by source from PNIEC (2017 values and 2030 targets) [ktoe]

The final consumption of RES for heating in table 4.1 represents the aggregated consumption for **buildings sector**, **district heating**, **industry sector** and **other sectors** (including agriculture, forestry, fishing and not elsewhere specified). To divide the 2030 targets of RES consumption in the different sectors, some consideration and hypotheses have been done and will be now presented.

First of all, the consumption of each RES for heating in 2017 given by PNIEC is divided in the different sectors using the literature data from the BEN [7], AIRU's report [29] and the REM2018 hypotheses. The division is shown in table 4.2.

Thermal RES	Sector	2017	
		TWh	Source
Ambient heat from heat pump	Buildings	30.82	BEN [7]
	District heating	0.06	AIRU [29]
	Industry	0	BEN [7]
	Other	0	BEN [7]
	TOTAL	30.88	-
	PNIEC	30.81	-
Solarthermal	Buildings	2.28	BEN [7]
	District heating	0.001	AIRU [29]
	Industry	0.12	BEN [7]
	Other	0.02	BEN [7]
	TOTAL	2.43	-
	PNIEC	2.33	-
Geothermal	Buildings	0.94	BEN [7]
	District heating	0.28	AIRU [29]
	Industry	0.03	BEN [7]
	Other	0.16	BEN [7]
	TOTAL	1.40	-
	PNIEC	1.45	-
Bioenergy	Buildings	79.12	BEN [7]
	District heating	2.04	AIRU [29]
	Industry	4.42	BEN [7]
	Other	0.41	BEN [7]
	TOTAL	85.99	-
	PNIEC	84.48	-

Table 4.2: Consumption of RES for heating: PNIEC 2017 data division by sector

The division of the 2030 heating targets starts from **district heating**. The cubic meters that will be heated by district heating in 2030 and 2040 are calculated projecting linearly the historical data from 2010 to 2019 given by AIRU [29] up to 2040; the evolution is reported in figure 4.5. The total energy demand, covered by district heating in the buildings sector, is then calculated starting from the 2018 value (10.8 TWh) and taking into account the increasing heated volume and the general decreasing in heating demand; the values obtained are 15.2 TWh in 2030 and 18.6 TWh in 2040.

In the study about the potential of district heating in Italy, edited by "Politecnico di Torino" and "Politecnico di Milano" commissioned by AIRU and UTILITAILA

[33], the district heating potential is studied. In the report a *"minimum cost scenario"* is developed, to understand what is the potential of the district heating under the hypothesis of economic competitiveness. In this scenario the potential of district heating is is about 38 TWh, so the values used in this study are economically feasible.

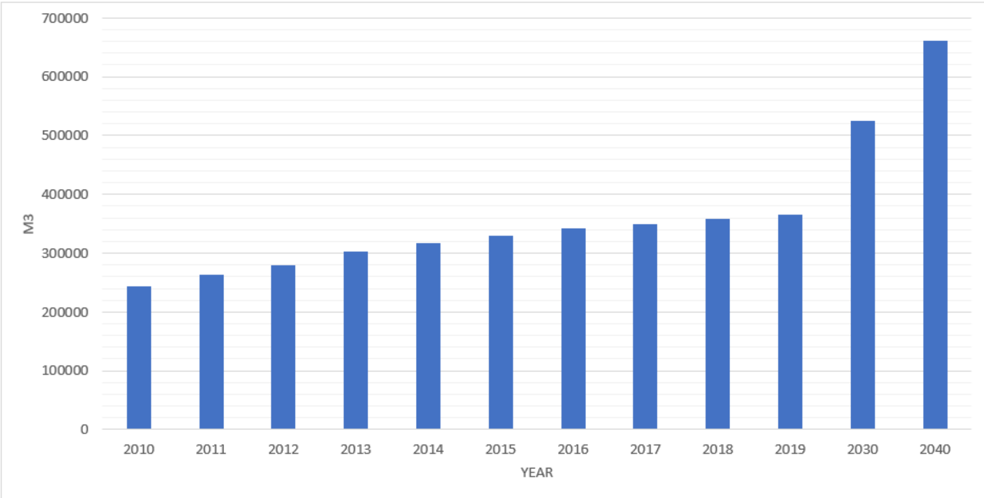


Figure 4.5: BS2040: Heated volume by district heating

To allocate the 2030 PNIEC thermal targets for the **district heating**, the portions for solar thermal, geothermal and heat from heat pump are derived starting from the 2018 values and than increased proportionally to the district heating energy demand, while the bioenergy is expected to increase more rapidly to replace the fossil fuels in the mix. These values will be shown more in detail in section 4.5 speaking about the generation sector and for now are resume in table 4.3.

For **other sectors** the fraction of consumption of RES for heating from the 2030 PNIEC targets for each RES is taken equal to the percentage in 2017 for the same commodity (table 4.3). These approximation is due to its small absolute consumption of thermal energy sources and under the hypothesis that these sectors will not go under drastic changes in their technologies.

In 2017 the ambient heat from heat pump in **industry** and **other sector** was negligible, so for the 2030 it was chosen to divide the thermal target for heat pump only between **district heating** and **buildings sector**. In this way the target is achieved and the use of heat pump in industry will be discusses when analysing the electrification of the industry sector in section 4.3.

Regarding bioenergies, solar thermal and geothermal, the 2030 target for **buildings sector** is calculated applying the same trend between 2017 and 2030 of PNIEC target for each commodity.

The PNIEC's targets division by sector for the consumption of RES for heating is listed in table 4.3.

Thermal RES	Sector	2030
		TWh
Ambient heat from heat pump	Buildings	66.10
	District heating	0.17
	Industry	0
	Other	0
	TOTAL	66.27
Solarthermal	Buildings	8.21
	District heating	0.001
	Industry	0.44
	Other	0.09
	TOTAL	8.73
Geothermal	Buildings	1.23
	District heating	0.40
	Industry	0.04
	Other	0.21
	TOTAL	1.88
Bioenergy	Buildings	80.92
	District heating	3.10
	Industry	5.16
	Other	0.41
	TOTAL	89.58

Table 4.3: Consumption of RES for heating: PNIEC 2030 targets division by sector

Now that the RES targets are found for the buildings sector in 2030, the fossil fuel consumption and the RES trend in buildings sector up to 2040 can be analyzed.

For the fossil fuel boilers, oil demand is set to zero from 2018 to 2050 and the values for 2030 and 2040 are linearly interpolated. Natural gas reduction is slower between 2018 and 2030 to meet the heat demand in 2030 and PNIEC targets, then it has a faster reduction towards 2040. The use of biomethane in the national grid in 2040 will be deepened in section 4.6, while in 2030 is not taken into account. According to PNIEC the potential Italian production of biogas is only used in the transport sector [23].

For renewable sources, solar thermal and geothermal linearly grow between 2018 and 2040, meeting the 2030 PNIEC targets. Heat pumps have a bigger growth between 2030 and 2040 with respect to the period among 2018 and 2030 to substitute the natural gas exiting from the energy mix, justified by a major technology maturity.

Electric heating slightly increases from 2018 and 2030 thanks to the shift from fossil fuels based boilers to electric technologies for hot water, then it decreases in 2040 due to the shift to more efficient technologies, like heat pumps and renewable options.

The use of hydrogen in the buildings sector is not covered in the PNIEC, so for 2030 its value is assumed to be zero. Instead for 2040 the report "H2 Italy 2050" from Snam [34] is taken as source for the hydrogen evolution. According to the report, the potential for hydrogen in 2040 for buildings sector is 38 TWh and 8 TWh in 2030; the average value between this two (23 TWh) is used in the model for 2040. This is justified by a slower diffusion in this sector with respect to the optimistic prevision given by Snam. Always according to the report, for urban buildings the hydrogen will be blended in the gas grid and used in the natural gas boilers, so assuming that this will not affect the efficiency of the boilers; the same efficiency of natural gas boilers is also used for hydrogen. The use of hydrogen in micro-CHP in rural areas is not taken into account in this work, under the hypothesis that this technology will have a sensible impact only after 2040.

The efficiency evolution of different technologies is taken form the EnergyPLAN files of the "Heat Roadmap Europe 4" project [26].

The hourly distributions for individual heating demand and district heating demand taken into account are equal to the REM2018. This choice is made under the hypothesis that the change in the technology mix for the heat generation in the buildings sector will not affect the hourly demand of energy sources for heating purposes.

The heat demands by fuels for the years 2018, 2030 and 2040 under the BS2040 hypotheses are shown in figure 4.6.

From figure 4.6 it is possible to see how the energy mix in the heating demand sector passes from strongly fossil-based in 2018 to a larger variety of sources in 2040. While the main source in 2018 was the natural gas, in 2040 it becomes the electricity, thanks to the high share of heat pumps in the technology mix.

As seen before, the Italian cooling demand by buildings sector will increase significantly over the studied period. As for 2018, also in 2030 and 2040 a small part of it will be satisfied by district cooling. These values are calculated starting from the cooling demand in 2018 from district cooling and then, taking in consideration the trend of the volume reached by district cooling and the increasing demand of cooling, the values for 2030 and 2040 are found. The remaining demand will be met by electric cooling units, mainly air conditioners and heat pumps.

The global COP of the electric cooling is taken from the Heat Roadmap project [26] and the hourly distribution for the cooling demand is taken equal to REM2018,

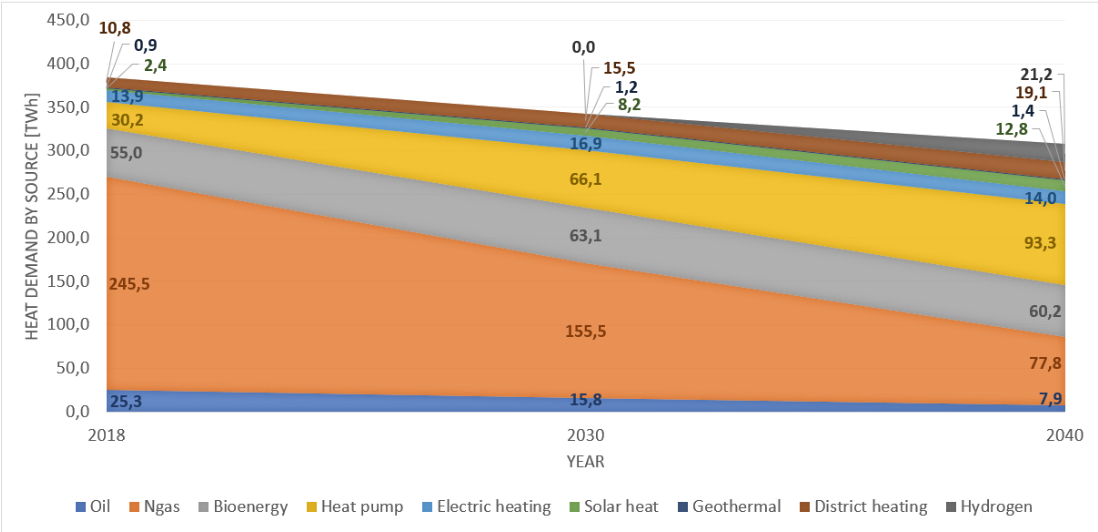


Figure 4.6: BS2040: Heat demand by source in buildings sector

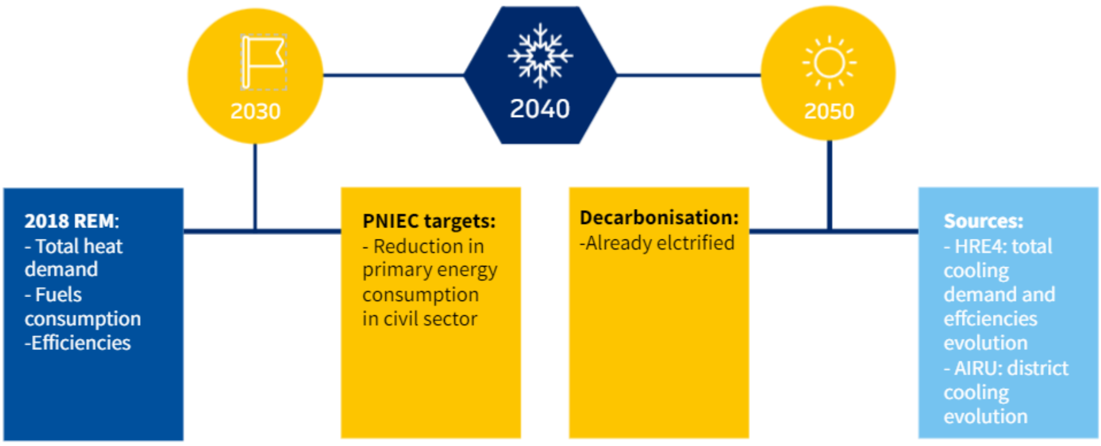


Figure 4.7: Cooling demand in buildings sector construction

under the same hypothesis made for heat demand by buildings sector.

The 2018 value from the reference model and the 2030 and 2040 forecast for the cooling of the buildings sector are shown figure 4.8.

The remaining energy demand for buildings sector is divided into cooking, lighting and others electric consumption (like household appliances and electronic devices). A scheme of the construction for this demand is shown in figure 4.9.

According to the ODYSSEE-MURE database, in Italy the electricity consumption per dwelling for electrical appliances and lighting varied from 2164 kWh/dwelling in 2000 to 2082 kWh/dwelling in 2018. Projecting linearly this trend

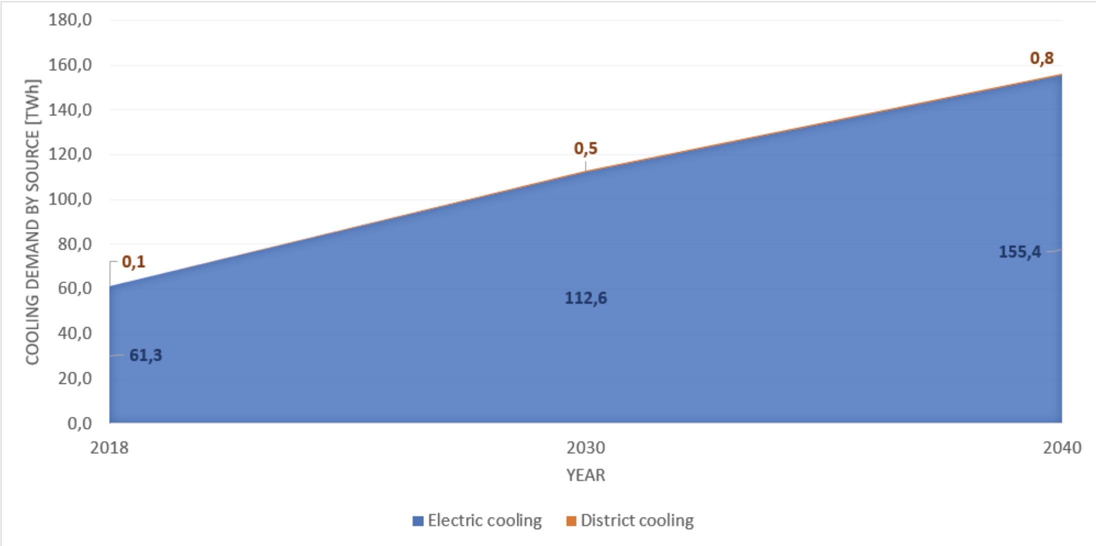


Figure 4.8: BS2040: Cooling demand by source in buildings sector

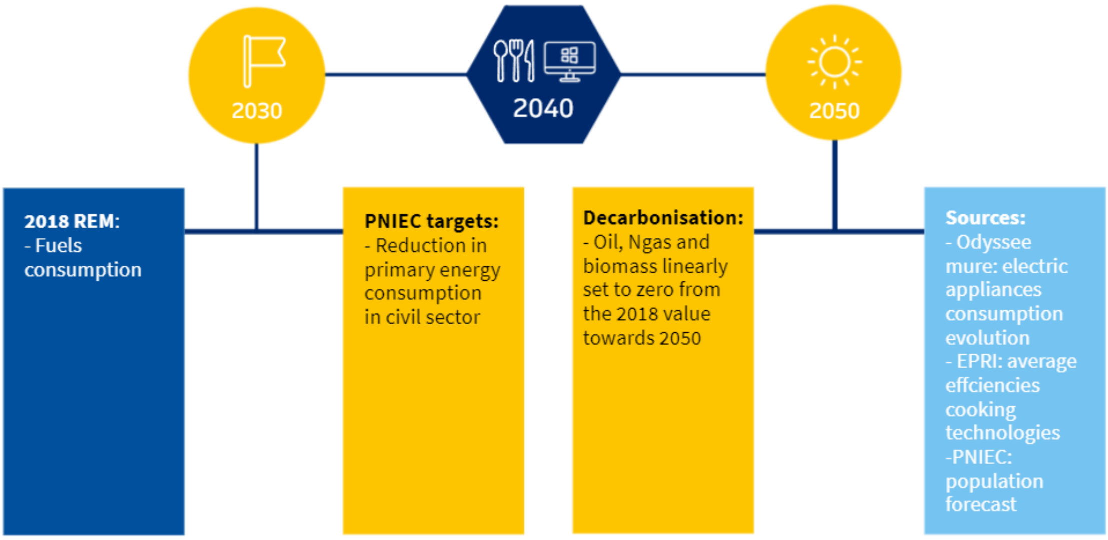


Figure 4.9: Cooking and other consumption in buildings sector

until 2040 and using the forecast for the Italian population from the PNIEC, it is achieved that the total demand of electricity for electrical appliances will increase by 1.9% from 2018 to 2030 and by 2.9% from 2018 and 2040, due to the increasing population. In the same database it is possible to find that, on average, in Europe the electricity demand in service sector increased by 1.1% from 2014 to 2018. For this study an overall increase for the buildings sector of 2% from 2018 to 2030 and

3% from 2018 to 2040 can be justified by the historical data and by an increasing legislation about energy efficiency. In 2018 electricity consumption for cooking can be considered negligible with respect to electrical appliances, so the previous percentages are applied directly to the 2018 value of total electricity for buildings sector (excluding electricity for heating and cooling)

To take into account the switch from fossil fuels and biomass to electric cooking, the values of oil consumption for cooking is linearly led to zero in 2040 and the same work is done for biomass and natural gas in 2050. The energy difference from the 2018 fossil fuels consumption is added to the electricity in 2030 and 2040 using an average efficacy of 35% for fossil fuels and biomass cooking and 76% for electric cooking [35].

The values for cooking and other electric consumption in buildings sector for 2018, 2030 and 2040 are shown in figure 4.10.

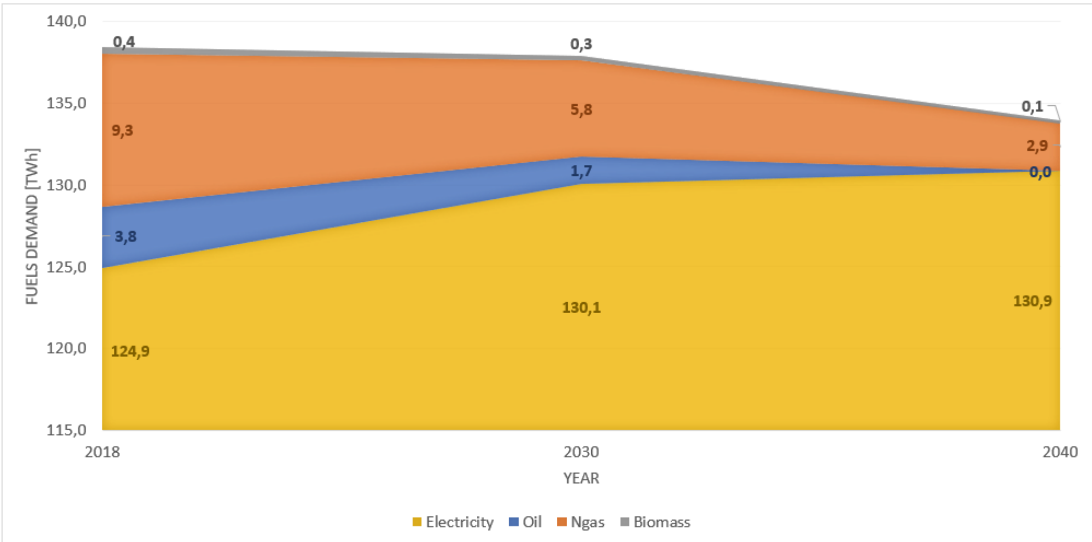


Figure 4.10: BS2040: Cooking and other consumption demand by source in buildings sector

The overall energy consumption in the buildings sector for 2018, 2030 and 2040 is shown in table 4.4

	2018	2030	2040
TOTAL energy consumption [TWh]	551.95	482.05	421.64

Table 4.4: BS2040: total energy demand buildings sector 2018 - 2030 - 2040

4.1.2 Strategies and technologies overview

The energy transition for the buildings sector must go through two essential elements:

- Decrease of total energy demand
- Recomposition of the energy mix

The major strategies that will lead the buildings sector to the decarbonisation are already underway and they are: the energy efficiency improvement, the electrification of the final demand and the switch to renewables and alternative fuels like bioenergies and hydrogen.

The most important step is decreasing the energy demand through energy efficiency policies: in Italy more than 50% of the residential buildings and 22% of the offices were built before the 70s [36]. Older buildings on average have high energy consumption and taking energy efficiency measures can have a major impact. As seen in section 2.3, the European Union has already implemented important mechanisms to help buildings renovation and to set high targets for new buildings. In the PNIEC the renovation rate expected for the period until 2030 is 0.9-1% per year, but it will have to be higher in the next period to meet the decarbonisation target.

The electrification will play a key role to reduce the energy demand and to allow the reduction of the GHG emissions. In particular, the heat generation has to go through a radical transformation from mainly fossil fuels boilers to heat pumps, that will become the major technology both for heating and cooling. In addition to the heat generation, electricity has to replace the natural gas also in cooking technologies.

Together with the energy efficiency improvement and the electrification, the direct use of RES will be indispensable. The increasing use of solar thermal energy and geothermal will be accompanied by the increasing share of biomethane and hydrogen in the national grid. These green commodities will have an important role where the electrification will be more difficult to be implemented due to economic or technological barriers.

The main technologies that will help the energy transition in this sector will be: heat pumps, bioenergies, solar thermal, geothermal and district heating.

The electric heat pumps are highly efficient (COP>3.5) thanks to the renewable heat, taken from the ambient, that can be used both for cooling and heating. The bioenergies systems are already an established technology and they can be carbon neutral thanks to the use of sustainable raw materials. Solar thermal and geothermal systems can be used for sanitary hot water and space heating. The district heating will have an increasing role in the heat demand and it will use different renewable sources in its generation mix like solar thermal, geothermal, heat pumps, sustainable biomass and industrial excess heat.

4.2 Transport sector

4.2.1 Objectives and construction

The 2030 PNIEC targets for transport sector are:

- Reduction of CO_2 emissions from 95 Mton $CO_{2\ eq}$ in 2020 to 79 Mton $CO_{2\ eq}$ in 2030 (approximately -16.8%)
- Energy saving of 30.2 TWh for transport sector between 2020 and 2030 (approximately -9.5%)
- 22% RES share in the final demand (calculating according the RED II method)
- Specific targets for each biofuels type and electricity (for road and rail only)

The PNIEC data for 2017 are slightly different from the BEN data (reference for the transport sector in REM2018) for the same year. For this reason, it was decided to group the fuels in three categories to compare the two different sources: biofuels, fossil fuels and electricity. The ratio between the BEN and the PNIEC data for 2017 is then performed and applied to each commodities for the 2030 PNIEC objectives. The 2017 values from BEN and PNIEC and their ratio are listed in table 4.5 and the targets for each fuel and electricity from the PNIEC and their normalized values with respect to the BEN are shown in table 4.6.

To study the transport sector evolution, it is divided in: road, rail, domestic aviation, domestic navigation and others, as shown in figure 4.11.

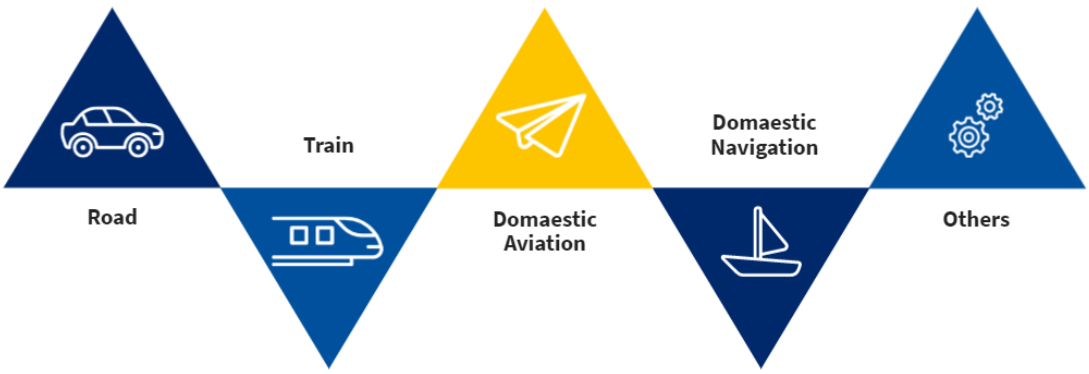


Figure 4.11: Final energy uses in transport sector

	2017
Total transport PNIEC [TWh]	352.93
Total transport BEN [TWh]	393.15
BEN/PNIEC [-]	1.114
Biofuels PNIEC [TWh]	11.16
Biofuels BEN [TWh]	12.35
BEN/PNIEC [-]	1.106
Electricity FER PNIEC [TWh]	1.87
Electricity FER BEN [TWh]	2.10
BEN/PNIEC [-]	1.124
Fossil fuels PNIEC [TWh]	335.26
Fossil fuels BEN [TWh]	375.21
BEN/PNIEC [-]	1.119

Table 4.5: 2017: PNIEC and BEN energy demand by transport sector

	2030 PNIEC TWh	**2030 PNIEC corrected * TWh**
Biomethane	9.22	10.20
Advanced biofules (excluded biomethane)	3.07	3.40
Double counting biofuels (excluded advanced)	6.63	7.33
Single counting biofuels	8.26	9.13
Road electricity from RES	4.70	5.28
Rail electricity from RES	3.64	4.09
Fossil fuels	277.11	310.13
Total energy demand	319.44	357.323

Table 4.6: 2030: PNIEC transport targets and PNIEC targets corrected*
* PNIEC data normalized with respect to the BEN

The PNIEC specified that the renewable energies targets (biofuels and electricity) are expected only for road and rail. Always according to the PNIEC, biofuels will also have a contribute in aviation and navigation sectors, but this aspect is not thoroughly explored, so these sectors will be studied separately.

Now will be studied the road and rail transport. A scheme for the scenario construction is shown in figure 4.12.

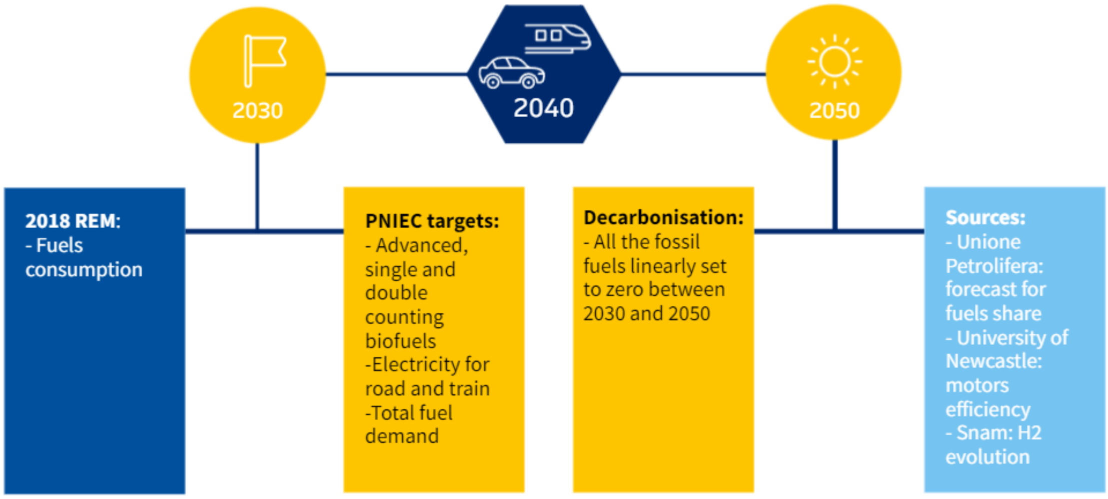


Figure 4.12: Road and rail in transport sector construction

The PNIEC targets for 2030 are given aggregated for fossil fuels and biofuels (table 4.6). For EnergyPLAN, the division in diesel, gasoline, natural gas, and LPG for fossil fuels, and in bio-diesel, bio-gasoline and bio-methane for biofuels is needed.

For road transport, the division of the targets for 2030 into different biofuels and fossil fuels is done starting from PNIEC targets and using the share for each fuel for road transport in 2030 given by the report "Previsioni domanda energetica e petrolifera 2019-2040" by Unione Petrolifera [37]. This report analyzes the energy demand in Italy until 2040, meeting PNIEC objectives in 2030. As a result of slight differences in the definitions of energy commodities, the global numbers from Unione Petrolifera are not taken in consideration. Therefore, using only the trends, the differences in 2030 between the Unione Petrolifera forecast and this model are less than 3%.

Now, the energy demand by road in 2030 is completely defined.

While in 2030 the Unione Petrolifera forecasts meet PNIEC targets, for 2040 they are too far from the trajectories towards a total decarbonisation in 2050. So, the data need an elaboration to met the BS2040 hypotheses. In this case, from Unione Petrolifera the trends of the fuels between 2030 and 2040 will be used as reference for the total travelled kilometers, considering the different engines efficiency for the technology shift.

All the fossil fuels are set to 0 in 2050 and the values for 2040 are linearly interpolated between 2030 and 2050. Bio-gasoline and bio-diesel can not be blended over a certain threshold, due to efficiency and other chemical proprieties. For that reason,for 2040 was chosen a share of bio-gasoline of 22%, that is the maximum blending level for ETBE according to the European Fuel Oxygenates Association, and 20% for bio-diesel, according to the research of the University of Castilla-La Mancha [38]. As regards bio-methane, the difference between the natural gas, that goes to zero towards 2050, and the trend in 2040 of Unione Petrolifera is added at the bio-methane trend of Unione Petrolifera.

The report about the hydrogen potential in Italy from Snam [34] is used for the values of hydrogen in 2030 and 2040, matching the PNIEC targets and the decarbonisation target of this scenario.

Instead, for electric vehicle, the difference between all the fuels consumption, found as described above, and the Unione Petrolifera trends are added to the electricity consumption. This operation is done using an average efficiency of 23.5% for gasoline internal combustion engine, 35.0% for diesel, 20.0% for natural gas and LPG, and 65.0% for electric engine, according to the research made by German Jordanian University [39]. In this way the forecasts for the global kilometres of travelling given by Unione Petrolifera for 2040 are maintained.

Regarding the rail sector, its total electrification is supposed by this work in 2040. For 2030 the electricity consumption is given by the PNIEC and for 2040 the increasing in electricity consumption maintains the same trend as between 2018 and 2030. In figure 4.13 are shown the fuels consumption for road and rail and in figure 4.14 is reported the breakdown for the different biofuels.

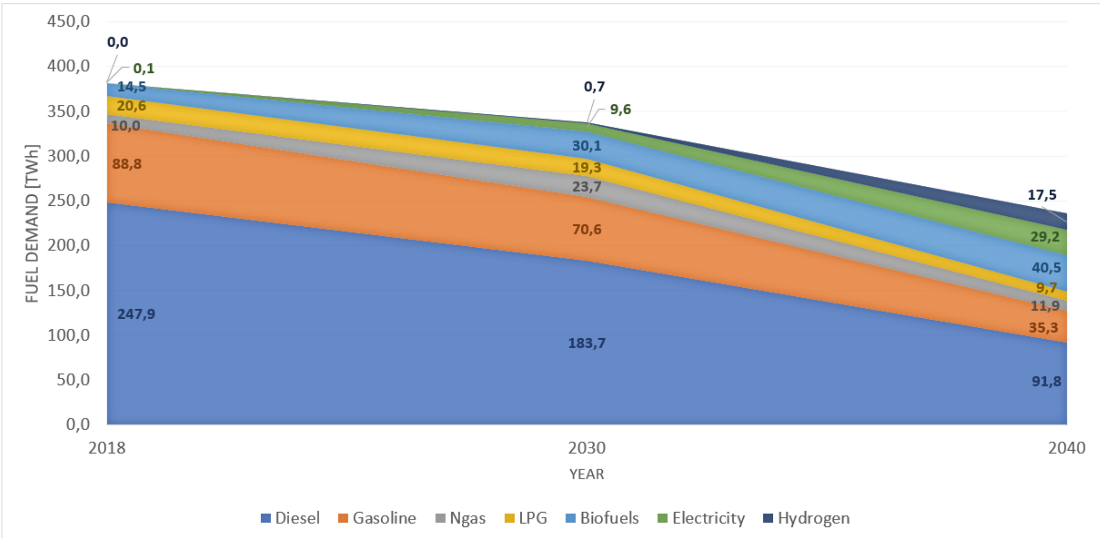


Figure 4.13: BS2040: Road and rail fuels demand

In figure 4.13 it is possible to see the change in the energy mix for road and rail transport. In 2018 the main charters were the fossil fuels. In 2040 they still play an important role, but the mix is far more heterogeneous. Biofuels, electricity and hydrogen becomes more and more important. The decreasing in energy is

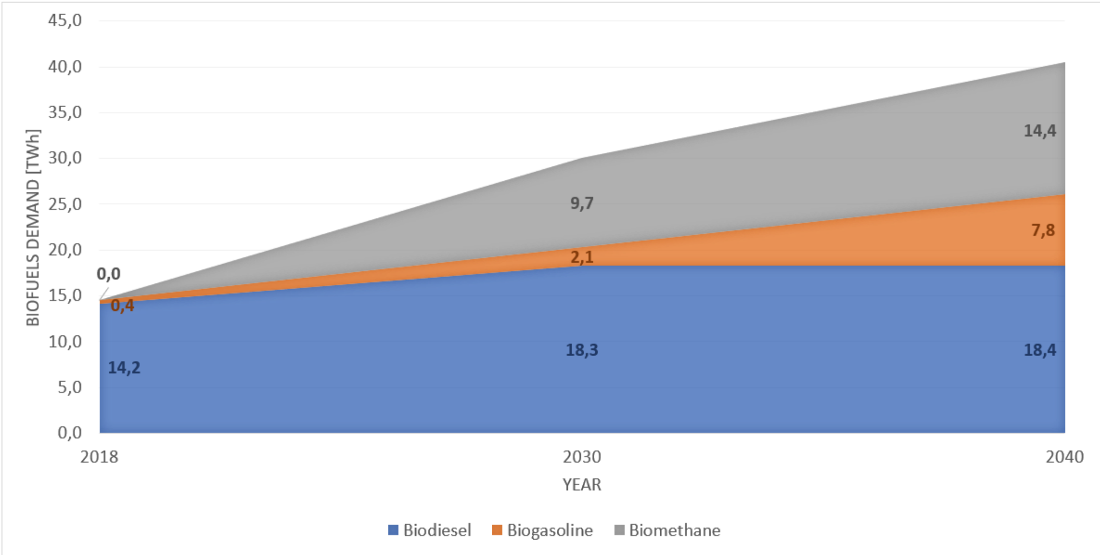


Figure 4.14: BS2040: Road biofuels demand

mainly due to the passage to more efficient technologies and secondary commodities (electricity and hydrogen), and thanks to the passage from private transport to public transport.

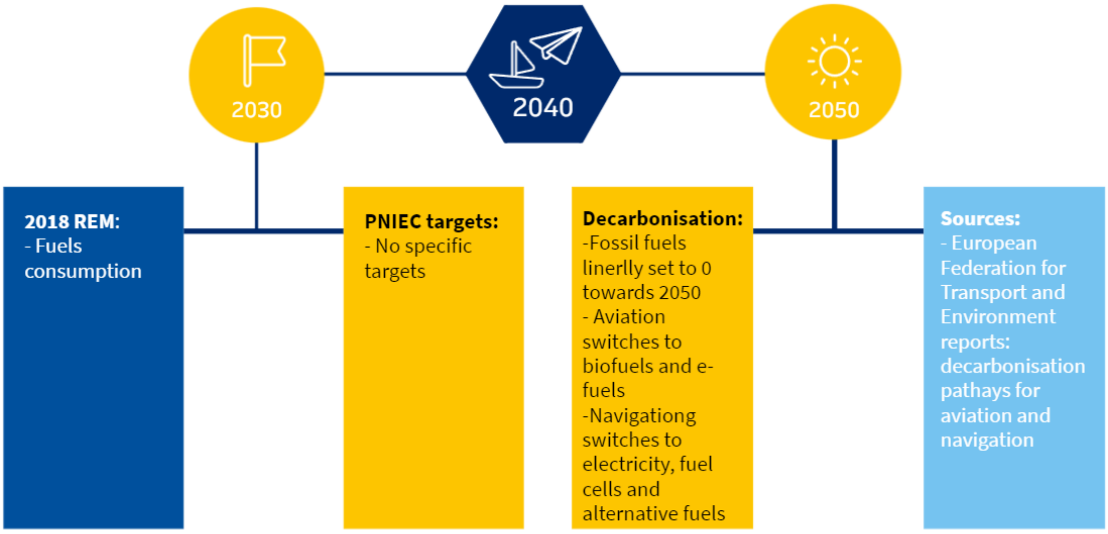


Figure 4.15: Domestic navigation and aviation construction

For domestic aviation and domestic navigation there are not specific targets contained in the PNIEC, so it was decided to study these sectors through specific reports edited by the European Federation for Transport and Environment (T&E): "Roadmap to decarbonising European aviation" [40] and "Roadmap to decarbonising European shipping" [41].

According to T&E, to decarbonise the aviation sector in 2050, the total fuel demand will have to be completely covered by bio-fuels and synthetic e-fuels. In particular, 11% of the fuel demand will be satisfied by biofuels. First of all, this low percentage is due to their wide use in other sectors,then to the limited availability of sustainable raw materials for their production and, finally, to the problems related to land use. E-fuels will cover the remaining demand (89%). The fuels demand will decrease by 0.9% per year due to more efficient aircrafts and engines and as a consequence of policies that encourage the land transport, that is easier to decarbonise [40]; this type of polices is also promoted in the PNIEC. The share of biofuels in this scenario will increase linearly starting from the 2018 value towards the 2050 share of 11%. The use of e-fuel will increase more slowly between 2018 and 2030, then rapidly between 2030 and 2050, when the technology will achieve a major maturity, up to reach the 89% share in 2050.

For the navigation, a combination of different technologies will help to decarbonise the sector: hydrogen and ammonia fuel cell, hydrogen in internal combustion engine, battery-powered ship, synthetic e-fuels and biofuels. Based on the T&E report the main technology for domestic navigation will be battery-powered ship. For the purpose of this study it was chosen to set this division for shipping technologies in 2050: 80% battery-powered ship, 10% hydrogen fuel cells, 5% biofuels and 5% e-fuels. The percentage of the technology share change linearly between 2018 and 2050. The global demand for shipping is maintained constant during the whole suited period and the switch between different energy sources is done considering the relationship between the different efficiency of each technology given by the T&E's report.

For the purpose of this work was made the same hypothesis of T&E, that is that e-fuels will only used in navigation and aviation. Due to their high prices and high electricity consumption for their production (CO_2 capture, H_2O electrolysis and e-fuels synthesis) their use will need to be limited to the sectors more difficult to decarbonise.

In figure 4.16 is shown the evolution of fuels demand in domestic navigation and aviation.

As for the road and rail transport, in figure 4.16 it is possible to see the passage from a complete fossil-based energy demand in 2018 to a wide variety of energy sources in 2040.

The last energy consumption in transport sector are associated to natural gas transport and the energy consumption for transport defined by the BEN as "not elsewhere specified". The energy consumption associated to the natural gas transport, in this model, will be changed proportionally to the total natural gas

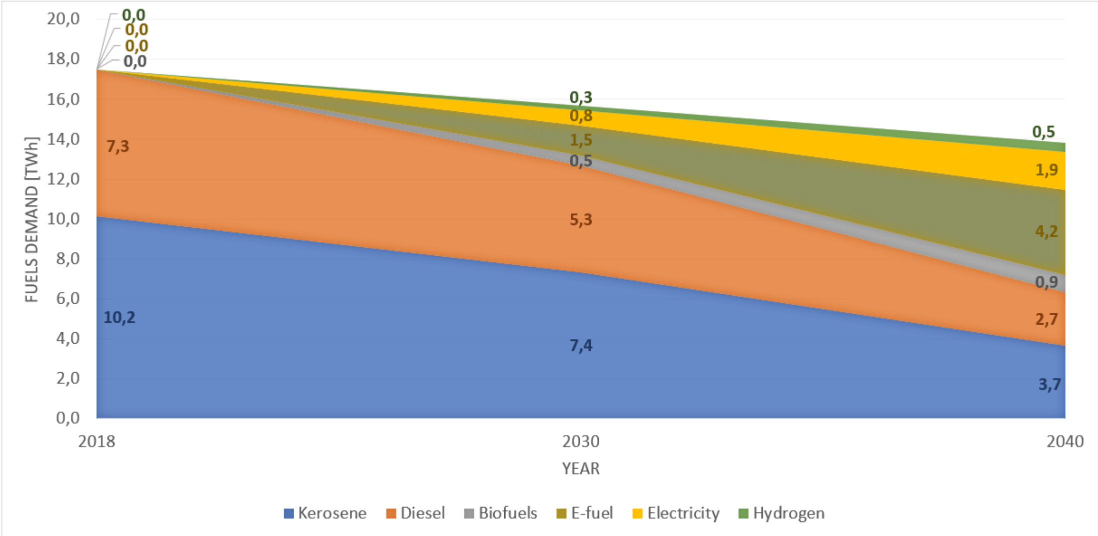


Figure 4.16: BS2040: Domestic navigation and domestic aviation fuels demand

consumption (fossil natural gas and biomethane) starting from the 2018 data. The consumption for transport "not elsewhere specified" includes transport activities like road vehicles in airports, fuels used in ports for ship and cranes. This demand is electricity only and it was quite constant during the period 2009-2019, so the average between these values is taken constant during the whole studied period.

In figure 4.17 the energy consumption by fuel for this last sectors is shown.

The hourly distributions required by EnergyPLAN in this case are the ones related to the electricity consumption. So, the electricity consumption in 2030 and 2040, when the electric vehicles becomes important in the mix, is divided in two groups: the electricity for road transport and the other electric consumption. For the road transport the distribution is taken from the work done by the University of Rome Tor Vergata about the interactions between vehicles and renewable energy sources in Italy [25]. This distribution is characterized by a curve that increases starting from 17 P.M., has its peak at 22 P.M. and decreases until 2 A.M., because the EV will be mainly recharged during the night when the people do not need their cars. The other electric consumption (mainly train and ship) maintain the same distribution of the Italian transport in 2018.

The total energy consumption by transport sector for 2018, 2030 and 2040, under hypotheses of BS2040 is shown in table 4.7.

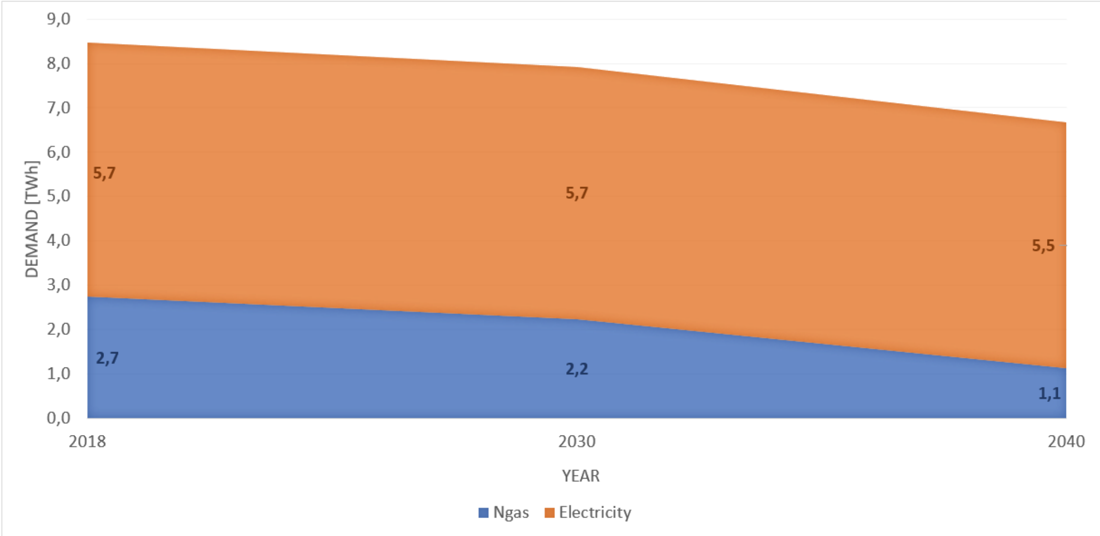


Figure 4.17: BS2040: Pipeline transport and other transport related sectors fuels demand

	2018	2030	2040
TOTAL energy consumption [TWh]	409.65	368.93	265.14

Table 4.7: BS2040: total energy demand transport sector 2018 - 2030 - 2040

4.2.2 Strategies and technologies overview

according to PNIEC principles about private passenger transport the priority is given to the policies related to the decrease in demand of transport, and the increase in sustainable mobility and collective transport, especially by rail. For goods transport the rail transport is preferred to road. In all the transport sector in addition to the energy efficiency policies, is encouraged the diffusion of biofuels (especially biomethane) and electric vehicles.

Towards the decarbonisation it is important to intervene on both quantity and quality of the demand of transport and on the technologies, changing fuels and engines. For the passenger sector, it will be important to reduce the need of mobility for private transport and to favorite the public one, in particular trains. It is also necessary to reduce the km/passenger for air travel, being one of the hardest sector to decarbonise. For private transport electrification of the car fleet and decrease in demand will lead the process, a increasing role from 2030 will be cover also by fuel cell cars with hydrogen as fuel. For goods the transport trains has to be preferred and the goods distribution optimized, the road transport will still be important. For light-commercial vehicles electrification and hydrogen will be the keys, while for heavy transport a more complex mix of technologies will be necessary, electricity can not cover all this sector due to higher power and autonomy requirements. Hydrogen-powered trucks will be useful together with biofuels, but with the limits due their production, the maximum bending and efficiencies. For aviation as seen in the previous section biofuels and synthetic e-fuels will be the main characters, joined to a reduction in demand. For navigation a mix of different technologies will be necessary: battery-powered ship, hydrogen and ammonia fuel cell, biofuels and synthetic electro-fuels. Energy efficiency improvement in the whole sector will continue to play a big role.

4.3 Industry sector

4.3.1 Objectives and construction

The main 2030 PNIEC targets for industry sector are:

- Reduction in CO_2 emissions from 42 Mton CO2eq in 2020 to 34 Mton CO2eq in 2030 (-19.05%)
- energy saving of 11.6 TWh in industry sector between 2020 and 2030 (approximately -4.2%)

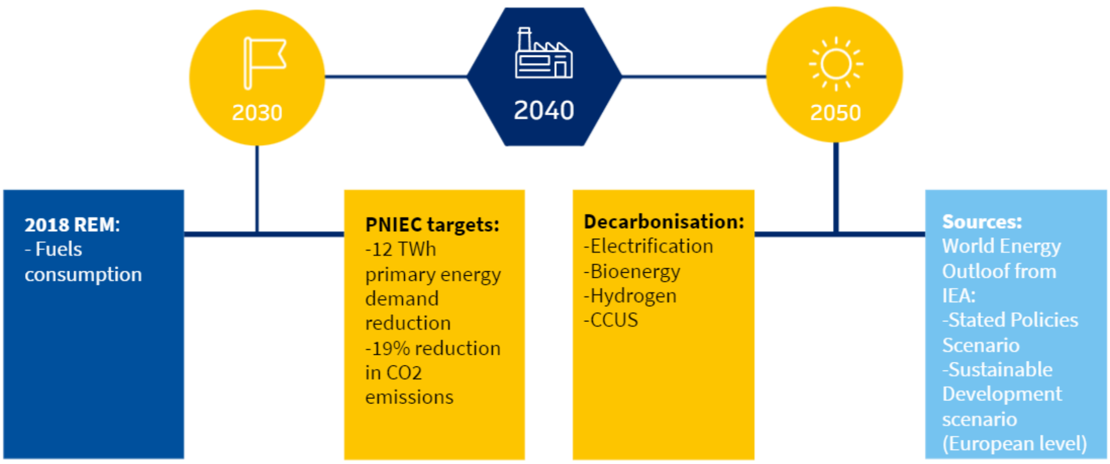


Figure 4.18: Industry sector construction

For the industry sector it was decided to use the World Energy Outlook (WEO) from the International Energy Agency (IEA) as reference [42]. The WEO scenarios are based on the World Energy Model [43]. This model divides the industry sector in six sub-sectors: aluminium, iron and steel, chemical and petrochemical, cement, pulp and paper, and other industry. The energy demand for these sub-sectors is driven by the demand for their products and by the added value. Each energy source is projected on the base of the previous year share, the price of fuels and the constrains of the scenario. Fuel switches are taken into account and in particular electrification.

In the period between 2018 and 2030, starting from the data of the Reference Energy Model, the European trends of the industry sector have been used for each energy commodity, in accordance with the Stated Policy Scenario (STS). The STS takes into account the energy policies and the targets set until mid-2020 and also the ones that have only been announced, this trends allow to meet the 2030 PNIEC targets.

The Stated Policies Scenario meets PNIEC targets in 2030, but in the period after 2030 it is distant from the decarbonisation target set to 2050 of BS2040 of this thesis. To take into account this target also the Sustainable Development Scenario (SDS) from the World Energy Outlook is analyzed. The SDS is the most ambitious scenario in the WEO, it is based on the UN Sustainable Development Goals (SDGs). In particular is developed under the assumption that the energy-related SDGs will be achieved: to reduce the health impact of air pollution, to guarantee energy access worldwide and to fight against climate change achieving as soon as possible the climate neutrality. These hypotheses are more consistent with the decarbonisation target of BS2040.

The trends from 2030 to 2040 are derived finding the average between the percentage variation, for each commodity, from the 2030 values in the STS and the 2040 values in the STS and in the SDS. Then this trends are used to derive the energy demand for the industry sector in 2040.

Regarding the hydrogen consumption for 2030 the value is taken equal to zero since in the STS is not taken into account and also in the PNIEC. For 2040 the sources for the hydrogen evolution used is the report about the potential of hydrogen edited by Snam [34]. The value used in this model is the average between the 2030 and 2040 values given by the report, justified by a slower diffusion in this sector with respect to the optimistic prevision given by Snam.

The hourly distribution for natural gas demand and heat demand by industry are taken equal to REM2018, under the hypothesis that the change in the technology mix will not affect the hourly energy demand.

The values of the different commodities consumption in the industry sector for 2018, 2030 and 2040 are listed in figure 4.19.

The total energy consumption by industry sector for 2018, 2030 and 2040, under hypotheses of BS2040 is shown in table 4.8.

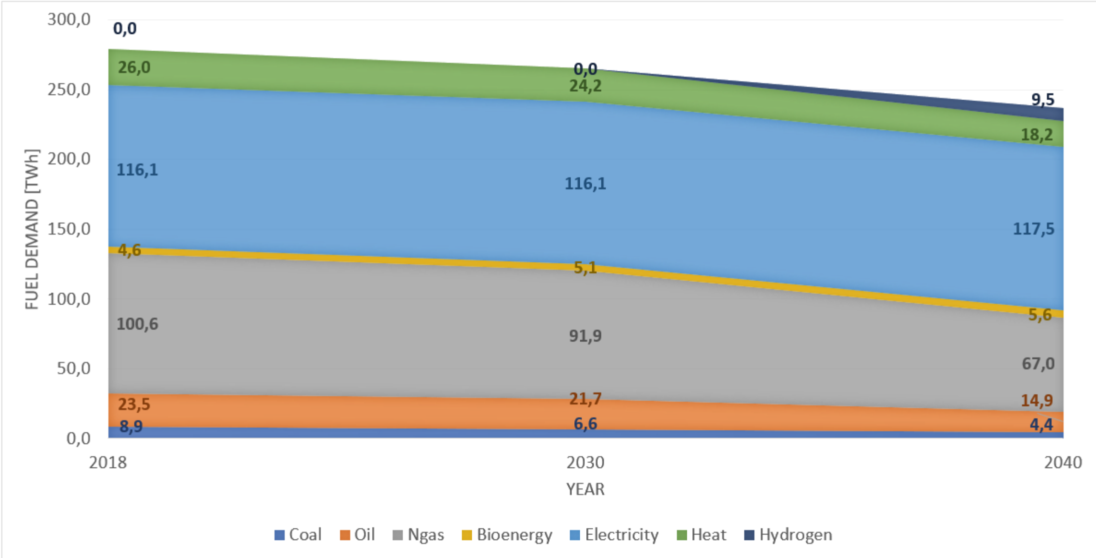


Figure 4.19: BS2040: industry sector fuels demand

	2018	2030	2040
TOTAL energy consumption [TWh]	279.51	265.58	237.13

Table 4.8: BS2040: total energy demand industry sector 2018 - 2030 - 2040

4.3.2 Strategies and technologies overview

The technologies and the strategies, on the basis of which the industry sector evolution is explored in the WEO scenarios, are analyzed in the report "Energy Technology Prospective 2020" [44] edited by IEA. The main decarbonisation strategies for the industry sector are: electrification, use of bioenergy, use of hydrogen and hydrogen based fuels, and carbon capture, utilization and storage (CCUS). Electrification will be important to substitute fossil fuels in chemicals and iron and steel sector. CCUS has large potential in the cement sector, but also in iron and steel and chemicals. Hydrogen technologies will have a large use only after 2050 and, together with bioenergies, they will be very useful where electrification will be more difficult. In industry an important role will be covered by the electrification of the heating sector. The main technologies will be heat pumps, microwave, induction and electric arc furnaces; infrared and plasma arcs will be used for high temperature heating.

Heavy industries are the most distant from the decarbonisation, in particular chemicals, steel and cement production. These three sectors represent half of the overall industry sector energy consumption and more than 70% of the GHG emissions. The major difficulties are the high-temperature heat requirements, the process emissions, the long-lived capital assets and trade consideration related to global market and competitiveness.

The major problem for chemical industry is the CO_2 emission from process reactions, in the short term efficiency improvements and fuels switching towards alternative fuels can provide a sensible emissions reduction. Electricity can be used for electrolysis in chemical production and to provide low and medium temperature heat. CCUS will be important, indeed it is expected that from 2030 all the new plant will be created with it. In this work the CCUS is not take into consideration, for the industry sector and this can be justified assuming that CCUS will be implemented for the emissions not energy-related (like process emissions), that are out of the boundaries of this study.

In steel production coal still has a major role in the energy mix. In the short to medium term, materials and technologies efficiency improvement and secondary products will lead the transition along with shifting from coal to natural gas and biomass. Also scarp-based input will have an important role.

In the cement industry, high levels of CO_2 are produced in the process reactions, in particular during the calcification. The energy transition will be lead by material efficiency, fuel switching form coal to renewable waste, biomass and natural gas and CCUS.

4.4 Other sectors

4.4.1 Objectives and construction

In other sectors are included: agriculture, forestry, fishing, the energy consumption not elsewhere specified and the energy sector (which is itself divided in electricity and heat generation, oil and gas extraction plants, and refineries).

Agriculture, forestry and fishing have not specific targets in the PNIEC and their energy consumption is small compared to the total demand. For that reason, it was decided to look at the trends of the last 15 years and linearly predict the future energy consumption starting from these data. In agriculture, the oil consumption is linearly set to zero towards 2050 from the 2018 level. The difference between the linear forecast and the found values are added to the natural gas consumption, in order to be covered by biomethane in the grid (the use of biomethane in the national grid will be deepened in the sub section 4.6).

As seen before the energy sector is divided in: *electricity and heat generation*, *oil and gas extraction plants*, and *refineries*.

For *electricity and heat generation* energy consumption, a linear prediction has been done starting from the data between 2004 and 2019. The total installed capacity of conventional plants (especially for natural gas, that is the main character)

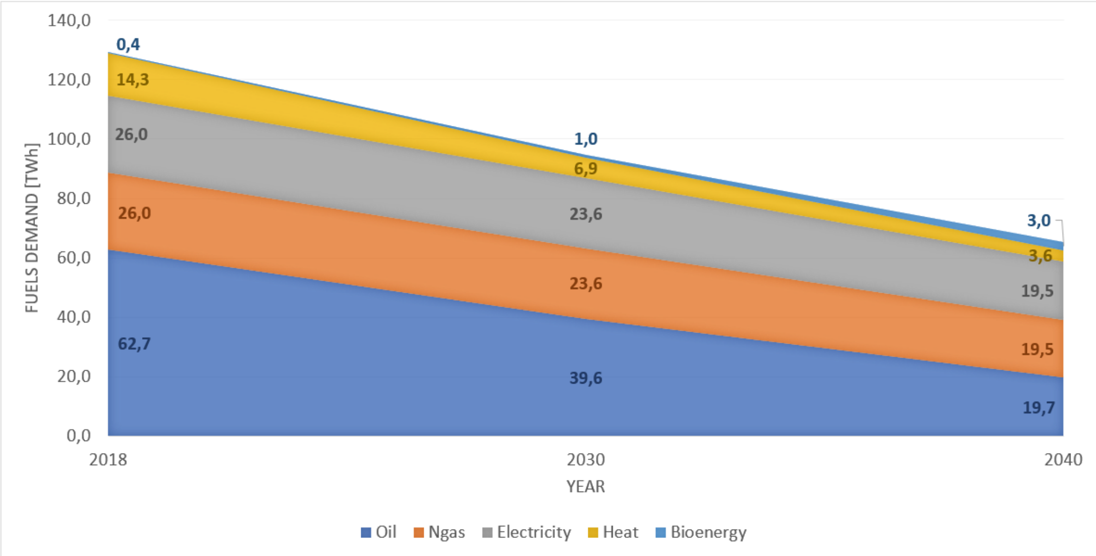


Figure 4.20: BS2040: Energy sector and other sectors fuel demand

will be quite constant during the studied period (see section 4.5 and figure 4.22), so this hypothesis can be justified.

For *oil & gas extraction plants*, and *refineries*, the energy consumption changes proportionally to the total oil and gas consumption in the model, starting from the 2018 values.

In 2018, the energy consumption by the bioenergy refineries and the gasification plants is not taken into account. To take in consideration these energy sectors, that in the future will have growing importance, an increasing bioenergy consumption is added to the one of the energy sector, proportionally to the total bioenergy consumption in the model.

In figure 4.20 is shown the energy demand divided by fuel for other sectors and energy sector.

The big decreasing in energy demand is due primarily to the exit from the Italian economy of the oil & gas industries that, in 2018, accounted for 76.6 TWh and, in 2040, only for 25.1 TWh. The remaining reduction is due to increasing policies of energy efficiency and the transition to more efficient technologies.

The total energy consumption by other sectors for 2018, 2030 and 2040 is shown in table 4.9.

	2018	2030	2040
Agriculture, forestry and fishing [TWh]	36.58	30.76	27.68
Energy sector [TWh]	86.48	60.03	30.02
TOTAL other sectors [TWh]	123.06	90.79	57.70

Table 4.9: BS2040: total energy demand other sectors 2018 - 2030 - 2040

4.5 Generation

4.5.1 Objectives and construction

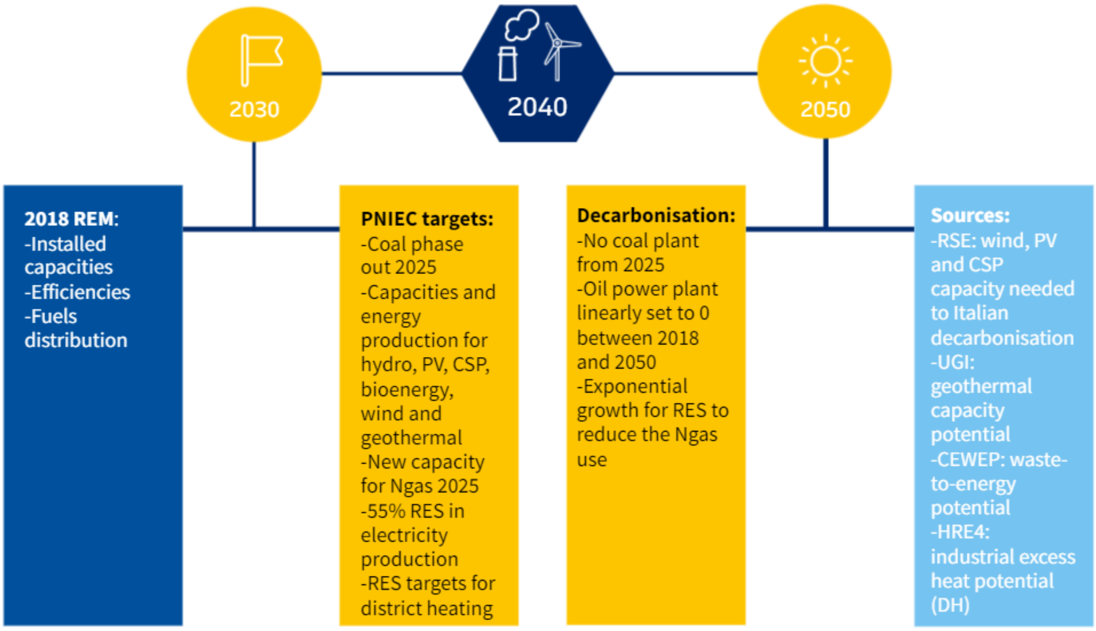


Figure 4.21: Generation sector construction

The PNIEC targets for the generation sector are:

- 187 TWh generation from RES in 2030
- 55% RES in electricity production in 2030
- Coal phase out 2025
- Natural gas new capacity of 3 GW by 2025 to replace coal power plant

The capacity and energy targets for each renewable energy source are listed in table 4.10 and table 4.11

Source	2017	2030
Hydro	18,863	19,200
Geothermal	813	950
Wind	9,766	19,300
Bioenergy	4,135	3,760
Photovoltaic	19,682	51,120
CSP	0	880
TOTAL	53,259	95,210

Table 4.10: PNIEC targets capacity RES 2017-2030 [MW]

Source	2017	2030
Hydro	46.0	49.3
Geothermal	6.2	7.1
Wind	17.2	41.5
Bioenergy	19.3	15.7
Solar	24.4	73.1
RES share	34.1%	55.0%

Table 4.11: PNIEC targets generation RES 2017-2030 [TWh]

For wind, photovoltaic, CSP and geothermal, the capacity values used in EnergyPLAN for 2030 are the same of PNIEC targets.

To study the evolution of these RES plants from 2030 to 2050, the data used come from the webinar "Scenari energetici: l'Italia, con l'Europa, alla sfida della decarbonizzazione" by RSE on the 10th of December 2020, in particular from the presentation shown by Alberto Gelmini about the 2050 scenario for Italian decarbonisation [45]. In this presentation, the installed capacity of each RES needed in 2050 for the decarbonisation scenario, developed by RSE, are indicated (275 GW PV, 3.3 GW CSP, 31 GW wind on shore, 16 GW wind off shore). These numbers are used as values in 2050 also in BS2040 and the values for 2040 are are found linearly between them and the 2030 PNIEC targets.

For hydro power plants, the value of the capacity is maintained constant during the whole time horizon of the study at 2018 level. The value used in REM2018, given by TERNA, is already higher than the 2030 PNIEC target. This approximation can be also justified by the hypothesis that in Italy most of potential hydro capacity is already exploited and the energy that will come from the new small possible plants will be covered by weather and climate factors that will lead to lower rainfall and less water available for the sector.

All the hourly distribution for the electricity renewable sources are taken equal to the REM2018, under the assumption that the weather and climate trend will not change so much the hourly distribution of the energy from sun and wind.

The fuel consumption of combined heat and power (CHP) and electricity only (PP) are derived for each energy sources proportionally to the evolution of the total installed capacity of each commodity.

The evolution is studied starting from the 2018 data from TERNA statistical yearbook [30] (that are given aggregated for CHP and PP) and under the simplified hypothesis that CHP and PP capacities will follow the same evolution for each commodity. Then, during the simulation, EnergyPLAN will choose the correct combination to meet the electricity and heat demand.

The total installed capacity for coal is set to zero from 2025 according to the PNIEC target for the coal phase-out. Oil total installed capacity is set to zero in 2050 and the value for 2030 and 2040 are linearly interpolated between the 2018 and 2050 values. For natural gas, a new capacity of 3 GW is added to the 2018 value in 2030 according to the PNIEC, and then it is taken constant in 2040 and the possibility to change the natural gas consumption to meet the demand will let to EnergyPLAN. Also for bioenergy total installed capacity the value at 2030 is set equal to PNIEC target and kept constant in 2040, with the possibility for EnergyPLAN to modify the value of fuel consumption.

The hourly distribution of the electricity demand is taken equal to REM2018, under the hypothesis that the electrification trend of the final uses will not change too much the distribution of the demand.

The total installed capacity for each technology for electricity production is shown in figure 4.22.

Regarding fuels consumption by boiler plants, the methodology is similar to the previous one. Coal is excluded from the energy mix in 2030, the same thing for oil in 2050. Natural gas and bioenergy consumption values are maintained constant and equal to the 2018 value, allowing EnergyPLAN to change these value according to the heat demand.

The methodology with which the renewable targets for district heating in 2030 and 2040 are obtained from PNIEC renewable targets in the thermal sector was previously described in section 4.1 and summarized in table 4.3.

An important role in district heating will be covered by the recovered heat from industrial process. The recovered heat from industry for the scenario is calculated starting from the 2050 value, taken from the "Heat Roadmap Europe Scenario" by the HRE4 project [26] (11.74 TWh). This value is also used to calculate the maximum district heating potential in the *minimum cost scenario* from "Politecnico di Torino" and "Politecnico di Milano" [33] used as source to the district heating sizing in BS2040. To obtain the 2050 value for this model, the heat recovery from industry is calculated as a fraction of the HRE4 value, taking in consideration

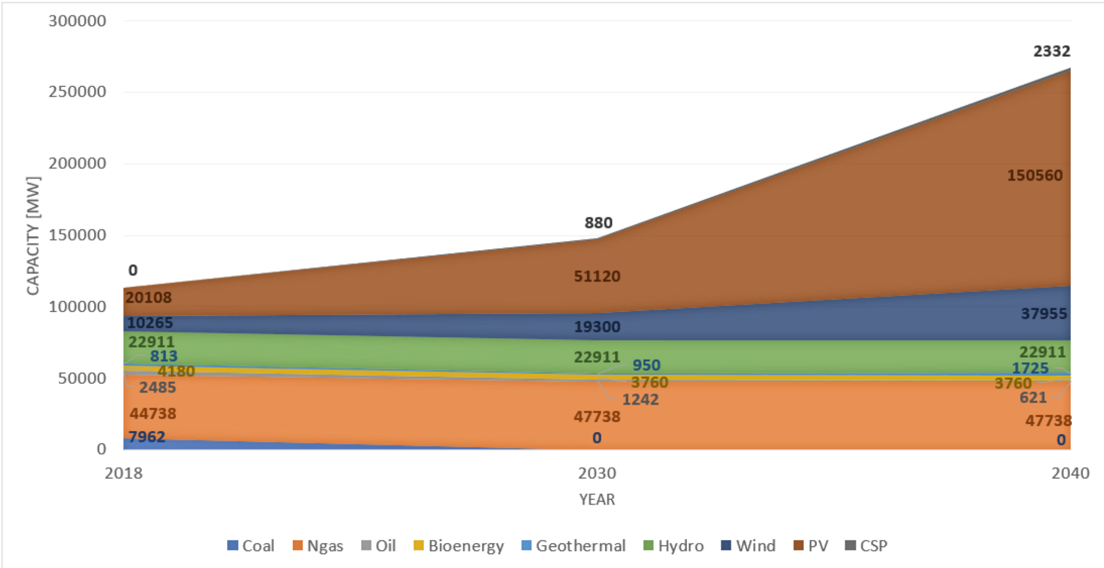


Figure 4.22: BS2040: electricity generation capacities

the research about the maximum potential and the model hypothesis. The values for 2030 and 2040 are linearly interpolated between the 2050 and 2018 data from REM2018. The COPs for district heating heat pump are also taken from Heat Roadmap Europe 4 project [26].

The results for each energy sources are shown in table 4.12. Bioenergy PNIEC targets for district heating are contained in the bioenergy consumption of heat only power plant.

	2018	2030	2040
Solar thermal heat	0.0010	0.0013	0.0017
Bioenergy	2.11	3.71	10.19
Geothermal heat	0.24	0.40	0.51
Heat pump COP [-]	0.06 2.63	0.17 3.14	0.28 3.57
Industrial excess heat	0.05	2.68	4.87

Table 4.12: BS2040: District heating RES 2018 - 2030 - 2040 [TWh]

The energy from waste sector is modelled in a different way because there are not specific targets contained in the PNIEC. In the "Waste-to-energy sustainability roadmap" report, published in 2019 by the Confederation of European Waste-to-Energy Plants [46], an ambitious scenario related to the European circular economy package is presented. In this scenario is shown an estimation of the European waste treatment capacity, ambitiously assuming that the 65% of the municipal waste and the 68% of non-hazardous waste from service and industry will be recycled. At the same time, it is assumed that the the landfilled waste will be as little as possible. The report comes with a paper with the calculations and hypothesis of the scenario [47], that will be now presented and applied to the Italian waste production.

The first hypothesis is that the waste production will remain constant during all the studied period; the increase in population and goods production will be covered by new policies on waste prevention. The data about the waste amount in megatonnes per year are taken from the EUROSTAT database. Municipal waste is directly taken from the database, while for industrial and commercial waste from the total waste stream are subtracted hazardous, mineral and municipal waste to avoid double counting. According to this hypotheses the municipal waste produced in 2018 in Italy was 30.17 Mton and the non-hazardous commercial and industry waste were 36.87 Mton. The percentages of municipal and industry waste intended to be recovered in the incineration plants are respectively 28% and 25%. The results for the Italian case is that the maximum amount of waste that can be used to produce energy, with an ambitious recycling strategy, is 17.81 Mton. By comparing it with the 2017 waste energy content (20.26 TWh) and mass (6.11 Mton) used to produce energy, this value corresponds to 59,04 TWh. Considering the climate neutrality target in 2050, this results is set for this year and the 2030 and 2040 values are linearly interpolated starting from the 2018 data; the results are shown in table 4.13.

	2018	**2030**	**2040**
Waste	20.09	34.69	46.87

Table 4.13: BS2040: Waste-to-energy input 2018 - 2030 - 2040 [TWh]

As hypothesis, all the efficiencies of the conventional plants will grown by 1% between 2018 and 2030 and then again between 2030 and 2040, due to improvement in generation technologies. The consumption of fuels and the energy production for all the plants will be presented in the results of the scenario in the section 4.7.

4.5.2 Strategies and technologies overview

The transformation of the power sector is central in the decarbonisation. The electrification of all end-use sectors will be possible and useful only if the generation will be as green as possible. The power generation capacity will be more than double between 2018 and 2040 under the BS2040 assumptions, due to the increasing electricity demand and the lower capacity factor of the RES, that will represent in 2040 82% of the total capacity.

In the light of the historical trends and PNIEC objectives in 2030, an important role by Ngas-produced electricity will be still required, despite the large increasing of RES power. In 2040 this trend will be still present because of the higher electricity demand caused by the electrification of the end-use sectors and by the intermittence of the RES. Part of the gas demand will be covered by biomethane, but the gas from fossil will remain a main actor in the electricity generation. In this work, until 2040, some innovative technologies that could substitute the use of fossil gas in the centralized electricity production are not taken in consideration. This choice is made assuming that their use will be widespread only after the time horizon of this study. These technologies are: the use of synthetic e-fuels in the generation sector, the fuel cells and the the use of natural gas coupled with CCUS systems. These possibilities could be studied in depth in more specific technological scenarios that fall outside the interest of this thesis.

The installation of new renewables plants for electricity production will be led by both the electrification trend of the final demand and the exit from the mix of the fossil fuels. These trends will require a huge efforts especially between 2030 and 2040, when the pathway towards the decarbonisation will be quicker. The solar energy will be the main character for this transition, as shown in the PNIEC and by RSE, along with wind energy and followed by hydro energy that will not see an drastic change in its energy production. Other possible RES not taken into account in this study could be tides and wave energy. The huge diffusion of this technologies will involve new objectives related to the environment to regulate the land use and to protect the landscapes. Another problem will be the disposal of the old plants: wind turbine are mainly made by composite materials that can not be recycled or burned, but only landfilled. In the same way, the production of photovoltaic panels is highly energy-intensive as well as their recycle. For these reasons, new policies about the life cycle of the plants will be necessary.

The electricity grid will also have to go under a exponential growth with the increasing electricity supply that will be mostly non-programmable. The gas grid will remain important during the decarbonisation as well, in particular for the transport of natural gas, biomethane and hydrogen in different concentration.

4.6 Storage, biofuels and Power-to-X

4.6.1 Objectives and construction

PNIEC targets for storage for 2030 are:

- 6,000 MW of pumped and electrochemical centralized storage
- 4,000 MW of distributed electrochemical storage

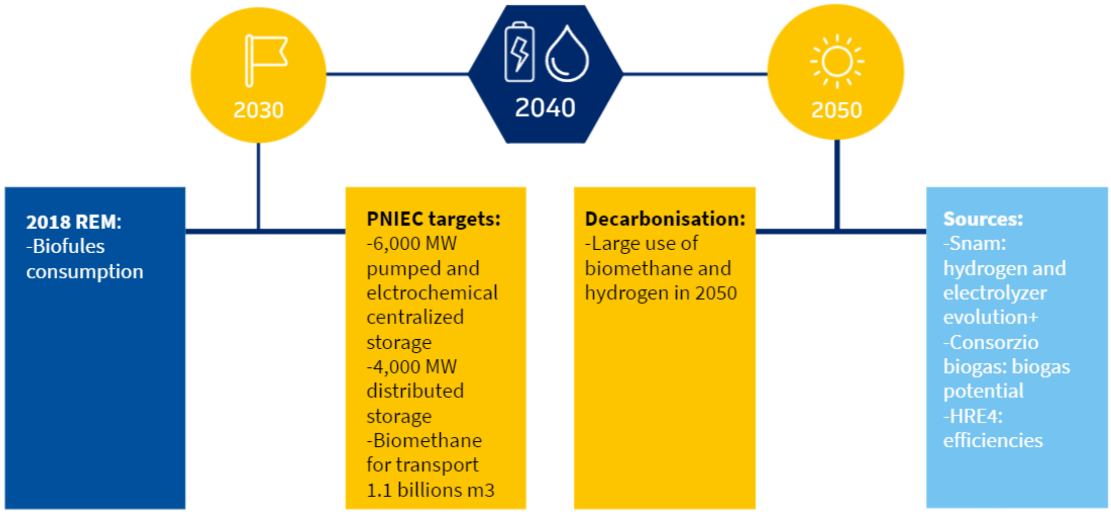


Figure 4.23: Storage, biofuels and Power-to-X construction

The values for storage in 2030 are taken from the PNIEC with the help of the ENIE's elaboration [48], that estimates the powers and the capacities at 2030. Instead, the values for 2040 are calculated starting from the 2030, proportionally to the RES capacity. The results are shown in table 4.14.

		2018	2030	2040
Pumped hydro	Power [MW]	7394	10394	19241
	Capacity [GWh]	3.41	4.80	8.88
Electrochemical centralized	Power [MW]	60	3060	11907
	Capacity [GWh]	0.25	24.25	94.36
Electrochemical distributed	Power [MW]	69	4000	16605
	Capacity [GWh]	0.11	15	62.27

Table 4.14: Base Scenario: power and capacity for storage 2018 - 2030 - 2040

Regarding the use of hydrogen, the source of information used is the report about the potential of hydrogen in Italy edited by Snam [34]. For transport the estimations done by Snam are taken equal for BS2040 (as seen in the sections 4.2), since they met the 2030 PNIEC targets and the 2050 decarbonisation goal. Instead, for the buildings and industry sectors the use of hydrogen is limited at the period after 2030, since no targets for this commodity in these sectors are taken into account by the PNIEC (section 4.1 and 4.3). The electrolizers capacity is then estimated starting from the value provided by Snam, proportionally to the variation of the hydrogen consumption in the report and in the BS2040 (taking into account also the use of hydrogen as feedstock). In table 4.15 are summarized the hydrogen consumption by sector and the electrolizers capacity.

	2018	**2030**	**2040**
Transport [TWh]	0	1	18
Buildings [TWh]	0	0	23
Industry [TWh]	0	0	9.5
Electrolizer capacity [GW]	0	7.62	30.99

Table 4.15: BS2040: Hydrogen use and electrolizers 2018 - 2030 - 2040

About biofuels in BS2040 the use of bio-gasoline, bio-diesel and bio-kerosene is limited to the transport sector, as seen in section 4.2.

The use of bio-methane in 2030 is related only with the transport sector (9.71 TWh), as described in the PNIEC, while in 2040 its use is supposed to be wider. The sources used to study the biogas potential is a report edited by CIB (Consorzio Italiano Biogas) [49]. According to this source, the potential for Italy in 2050 can be estimated between 300 and 350 TWh of total renewable biogas: 15 TWh by OMW (Olive Mill Wastewater), 185 TWh by agriculture and 150 TWh by renewable from gasification or biogenic. For BS2040 2040 a value of 156 TWh is found linearly between the 2030 value and an hypothetical value of 300 TWh in 2050. The division by sector of the biogas used in 2040 is the following: 27.4 TWh will be used to cover the transport demand (53% of the total gas demand in this sector), 76.6 TWh for electricity and heat generation (29% of the gas demand) and the remaining 49.6 TWh will be injected into the grid to satisfy the gas demand of civil, industry and other sectors (29% of the gas demand).

The use of synthetic electro-fuels is limited to the transport sector, in particular for aviation and navigation, due to their high cost and high electricity intensity, as described in section 4.2.

All the efficiencies needed by EnergyPLAN for the plants dedicated to the production of hydrogen, biofuels and e-fuels are taken from the Heat Roadmap Europe 4 project [26].

4.6.2 Strategies and technologies overview

One of the critical aspects related to the decarbonisation is the flexibility of the electrical system, which is the capacity to maintain balanced the supply and the demand. In a traditional energy system, this capacity is given by the thermoelectric plants and hydro power plants, while in the future scenarios this flexibility can only be given by electric storage. In BS2040 will be required two and a half times the capacity of pumped hydro storage with respect to the 2018 that correspond to

8.8 GWh, then will be also needed 94.4 GWh of electrochemical storage centralized and 62.3 GWh of electrochemical storage, distributed over the grid among the prosumers. Also the batteries of the electric vehicles could be used as energy storage; this process could be done sending part of the electricity when EV are connected and the grids need electricity. This strategy is not taken in consideration in this study and can be a starting point for a new analysis.

The possibility to have a large scale heat storage has not been deepened in this work, but it will be a possible strategy to help the decarbonisation of the civil sector, for example accumulating heat during the summer to use it through the district heating during the winter.

Part of the energy surplus during the hours of maximum production of the RES will be converted also in hydrogen and then in synthetic e-fuels. Alternative fuels like hydrogen, e-fuels and biofuels will have a key role in the future, especially in those sectors where electrification is more difficult. The existing national grid, used to distribute the fossil fuels today, will continue to be an important character for the distribution of the alternative fuels.

Biofuels from sustainable biomass will be necessary to reduce the emissions. Liquid biofuels will be useful especially in transport sector in short and medium term, when the electrification process will be slower. Biogas will have a wider use to satisfy the demand for transport, buildings, industry and generation sectors, blended in the gas grid in different concentration. The use of biofuels brings different problems related to the sustainability of the biomass used to produce them. The national and European policies are already promoting the use of advanced biofuels produced starting from residues and wastes from agriculture, forestry and food industries, or from non-food crops grown on marginal land as well [44].

Today the hydrogen is mainly blue hydrogen that is produced through steam reforming starting from natural gas. In BS2040 is only considered the green hydrogen produced by electrolysis using electricity from RES, under the hypothesis that by 2030 the price of green hydrogen will be competitive and there will be no more need of blue hydrogen. Hydrogen will be useful as energy carrier and as energy storage to save the surplus from renewables.

4.7 Results from EnergyPLAN

As seen in chapter 3, the software EnergyPLAN allows to explore different results; the main ones are listed down below: the fuel: the fuel balance for the conventional plants and their energy production, the energy produced by the renewable energy sources, the total CO_2 produced by the energy system, the total primary energy demand and the RES share in it, and the total consumption for the different energy sources.

In figure 4.24 is shown the electricity produced by each source from which is possible to see the increasing demand of electricity. This increment is due to the electrification of the various final sectors, in particular in the period between 2030 and 2040 when the path towards the decarbonisation will be quicker, passing from about 327 TWh in 2030 to 448 TWh in 2040, compared to the 2018 value of 290 TWh. Also the renewable energy sources have an increasing share, especially the electricity produced by photovoltaic panels. In 2030 the RES share in electricity production is 55.2% meeting the PNIEC target of 55%, in 2040 this value is 70.7%, while in 2018 was 34.8%.

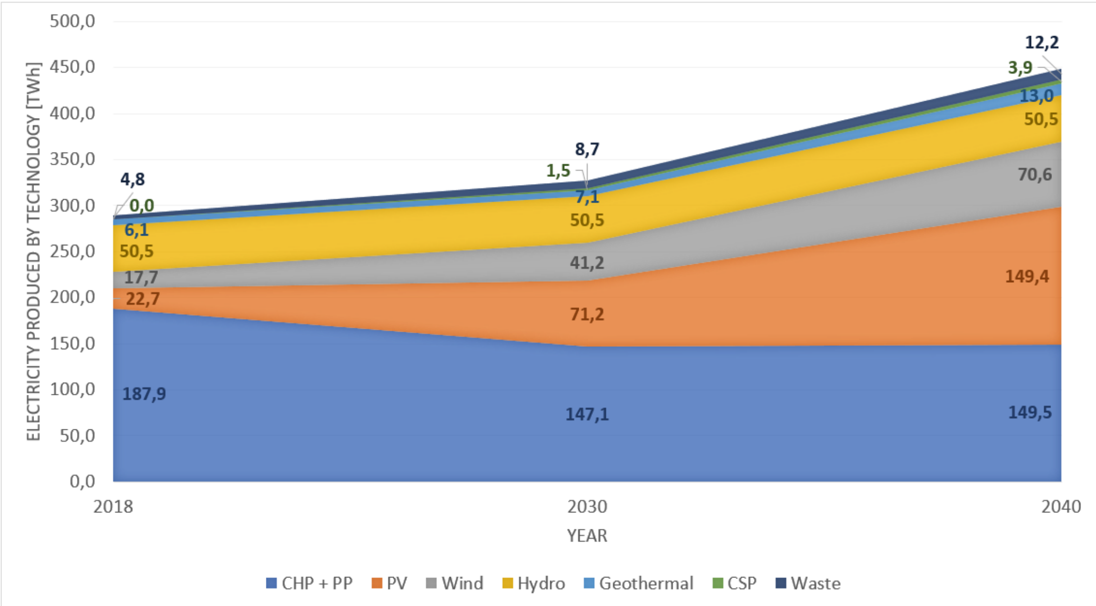


Figure 4.24: BS2040: electricity production by source

The conventional plants still play an important role over the whole studied period, with a decreasing production between 2018 and 2030 and, subsequently, remaining stable around the value of 147-149 TWh between 2030 and 2040. In figure 4.25 is reported the fuel consumption in CHP and PP. The coal exits the mix in 2025, while natural gas consumption remains quite constant in all the studied period, until 2030 where it is slowly substituted by renewable gas. Also the biomass consumption is almost constant, while the oil slowly exits the mix towards 2050.

The total primary energy supply evolution is shown in figure 4.26. According to the model, this evolution goes from 1623.0 TWh in 2018 to 1411.9 TWh in 2030 (reduction of 13.0%), with a reduction slightly more accentuated than the PNIEC target, and then a further decrease of 7.6% to 2040, to reach a value of 1304.0 TWh. The RES penetration in TPES goes from a value of 18.8% in 2018 to 32.1%

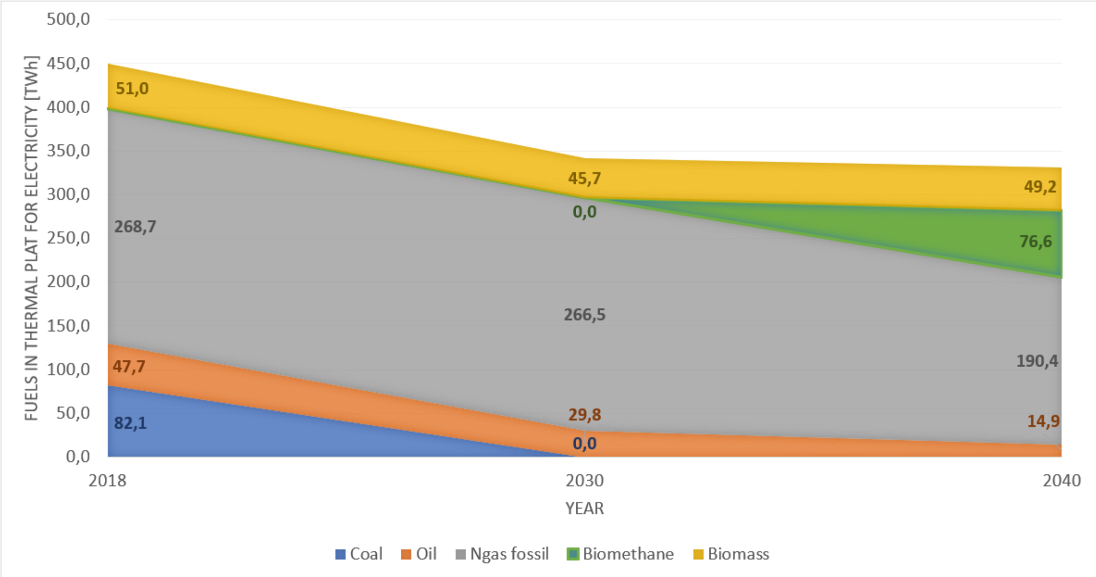


Figure 4.25: BS2040: CHP and PP fuel demand

in 2030 meeting the PNIEC target of 32% and then it goes to 62.7% in 2040

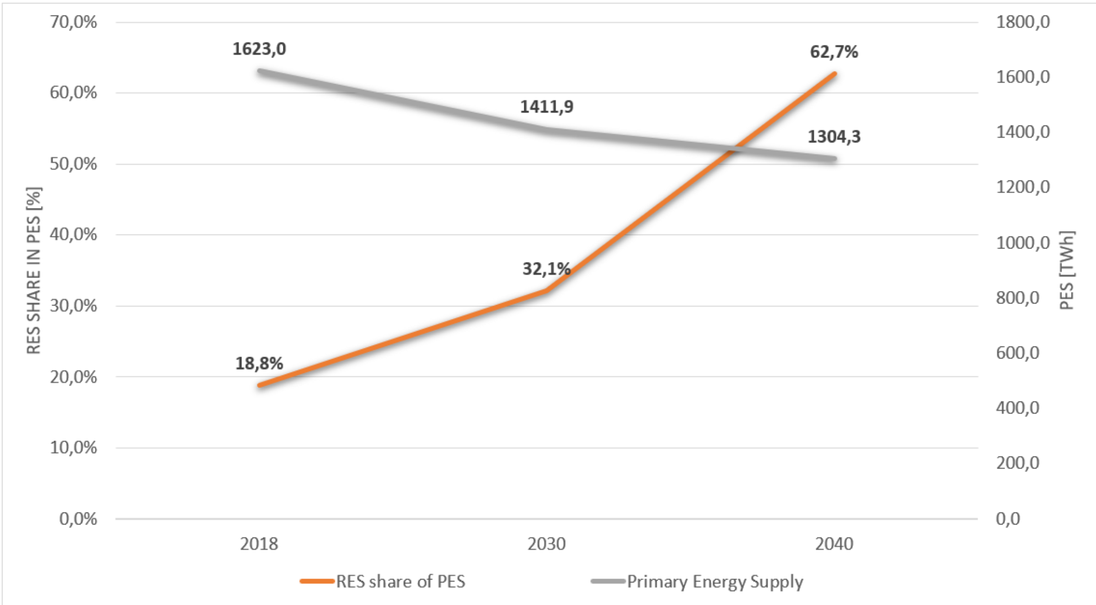


Figure 4.26: BS2040: Total Primary Energy Supply and RES share in PES

The total CO_2 generated by the Italian energy system is shown in figure 4.27. Its values, according to the model, is 327.9 Mton $CO_{2\ eq}$ in 2018, then it decreases to 233.8 Mton $CO_{2\ eq}$ in 2030 (reduction of 28.7%) and to 122.2 Mton $CO_{2\ eq}$ in 2040 (reduction of 47.7% between 2030 and 2040). In the same figure is also shown the linear trend between the 2018 CO_2 emissions from the Italian energy system and the 2050 decarbonisation objectives. While between 2018 and 2030 the CO_2 reduction is slower, in the period between 2030 and 2040 it accelerates to meet the decarbonisation goal in 2050.

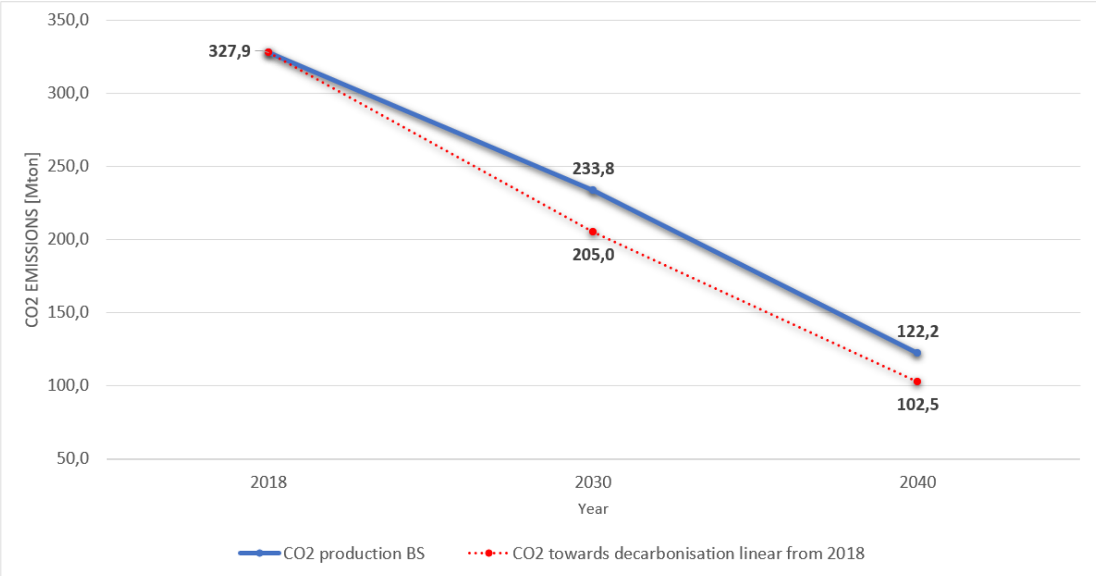


Figure 4.27: BS2040: CO_2 emission

Chapter 5

2040: Post-Pandemic Behaviour Scenarios

According to IEA [50] [42] the transformation of the energy systems cannot be achieved without the contribution of the changes in behaviour of the citizens. The people are the ones who drive the demand of energy related goods and services. In 2018, in Italy, the private mobility represents about 56% of gasoline and diesel consumption [37] in road transport and the residential sector accounted for 80% of the heating demand, 22% of the cooling demand and 47% of the demand for cooking and other electricity consumption in the buildings sector [7].

In this chapter the possible effects on the Italian decarbonisation pathway of the changes of the energy-related behaviours due to the pandemic will be numerically explored. The main ones taken into account can be grouped in two categories: the increasing share of remote workers over the total workforce and the effects of an increasing citizens' environmental and climate awareness.

Teleworking has become the new normality during the pandemic (section 2.2). This new way of working is expected to go through a radical change with respect to the one that we all have seen during the pandemic. In the future there will be a shift from working from home towards the remote working as organized and distributed ways to work, not only at home, in workplaces distributed throughout the territory (such as relocated company offices, private and public co-working spaces, etc.). In this thesis the analysis will be concentrated on the effects of the increasing share of remote workers on the private transport sector (section 5.1).

As seen in section 2.2 the pandemic has taught the importance of personal responsibility and social intervention in the global crisis. The pandemic has strengthened different aspects associated with personal norms: awareness of consequences, roles and responsibilities, efficacy beliefs and social factors [17]. There are different links between the pandemic crisis, and the climate and environmental crisis that may have strengthened citizens' environmental awareness and will be deepened in section 5.2.

The main effects of an increasing environmental and climate awareness taken into account in this study will be: reduction of heating demand into people's houses due to good energy practices and energy efficiency interventions, the personal transport mode switching towards "soft mobility" and the increase of EVs (Electric Vehicle) cars share over ICEs (Internal Combustion Engine) in the private transport.

To study the effects of remote working and citizens' awareness on the transport sector, the energy consumption for road transport in 2040 is divided between cars (private transport) and other road transport (that includes Light Duty Vehicles (LDV), Heavy Duty Vehicles (HDV) and public buses). The source to elaborate this division are the data from ISPRA [51] presented during the online event held on 16 April 2021 about the energy scenarios for the Italian transport sector and its possible evolution between 2019 and 2050. ISPRA more ambitious scenario meets the PNIEC targets in 2030, but it does not reach the decarbonisation in 2050. So, in 2040 the energy mix of transport sector in this scenario is slightly different from the BS2040 of this thesis. In 2040 the share of liquid fuels is almost the same, but, while the ISPRA scenario relies more on LPG and natural gas (and biomethane), the BS2040 has a higher share of hydrogen and electricity. Anyway, this source can be used to understand how the different energy sources will be divided by category of vehicle in the future.

The information contained in the ISPRA presentation are: the total energy consumption by vehicle category, the total energy consumption by fuel and the consumption by fuel for each vehicle category. From the elaboration of these data it is possible to find the energy consumption by vehicle category for each fuel.

It is obtained that in 2040 the cars share over the total energy for road transport will be 52.7% (consistent with the ISPRA scenario). The total energy consumption for road transport and the division between cars and other road transport are listed for each fuel in table 5.1.

To study the effects of citizens' awareness on the buildings sector, the total energy consumption for *heating demand*, *cooling demand*, and *cooking and other electrical consumption* in buildings sector from BS2040 is divided between residential, and public and services. The hypothesis of this division is that the percentages of energy consumption of residential, and public and services for the demands listed above will remain constant between 2018 and 2040. The source used to study this division is the BEN [7] for the year 2018 and the REM's assumption. The breakdowns between residential, and public and services for the different energy demands are listed in table 5.2.

	Road consumption [TWh]	Cars [%]	Other [%]
Diesel and Biodiesel	110.1	40.2%	59.8%
Gasoline and Biogasoline	43.1	84.4%	15.6%
Ngas and biogas	26.2	35.9%	64.1%
LPG	9.7	98.5%	1.5%
Electricity	29.2	60.9%	39.1%
Hydrogen	17.5	40.0%	60.0%
TOTAL energy consumption	**235.8**	**52.7%**	**47.3%**

Table 5.1: BS2040: fuels division for road transport between cars and other road transport

	Buildings energy demand [TWh]	Residential [%]	Public and services [%]
Heating demand	307.72	80.0%	20.0%
Cooling demand	156.05	22.2%	77.8%
Cooking and other electric consumption	133.93	47.5%	53.5%
TOTAL energy consumption	**421,64**	**64.9%**	**35.1%**

Table 5.2: BS2040: energy demand division for buildings sector between residential, and public and services

5.1 Remote working

The definition of remote working (also called teleworking, telecommuting or agile working) is not universal, but, among all of the different ways of interpreting it , the two most common criteria are the remote working location and the use of ICTs (Information Communication Technology), together with a work organisation based on autonomy, flexibility and collaboration. To make an example, the European Parliament defines remote working as "an approach to organising work through a combination of flexibility, autonomy and collaboration, which does not necessarily require the worker to be present in the workplace or in any pre-defined place enables them to manage their own working hours, while nevertheless ensuring consistency with the maximum daily and weekly working hours laid down by law and collective agreements" (2016/2017(INI)) [52].

The location from which the remote workers work can be of different types, like homes, satellite-offices or neighborhood offices, or they can also be mobile remote workers (like digital nomads) [53]. During the pandemic, remote workers have been working almost exclusively from their houses, often without adequate changes in the work organization. This phenomenon is due to the fact that remote working was an exceptional measure taken to tackle the pandemic crisis and the companies were not prepared to face it in a different way.

Along with the pandemic, in Europe, close to 40% of the citizens experienced to some extent remote working [54]. Before the pandemic, the percentage of those who had ever worked remotely was 14%. In 2019, 5.4% of employed in EU usually worked remotely, rather constant from 2009, and, in the same period of time, the share of people that worked at least sometimes remotely passed from 5.2% to 9% [54].

The people appreciation of remote working during the pandemic has gone through a particular development.

At the beginning of the Covid-19 crisis, people started forcibly to experiment the remote working and distance teaching. The companies and the workers were not ready, the spaces were inadequate, the houses were too full to find the right concentration and the distance from the co-workers has expanded a sense of loneliness. For those reasons and for the general stress caused by the pandemic, the workers have experienced discontent and fatigue related to working from home.

As time passes, the general organization of the remote working has gone under an improvement. With the reopening of schools and public spaces, remote workers have found their spaces and organization. The companies have started to offer training services and technological supports and in general, with the increasing experience, peoples have become more familiar with this way to work. According to several surveys done by companies and public institution, the workers has expressed a strong interest in finding a new flexibility in future, also for what concern the place from where to work.

According to a survey of 3,000 professionals in UK made by Rada Business [55], 45% of the workers say that "they are either extremely or very interested in making the shift to working remotely permanent".

Also the investments in technologies and training for remote working, done by the companies during the pandemic, will help its future diffusion [56].

Remote working has different potential across the different working sectors. The one with higher potential is the IT sector followed, in order, by the knowledge-intensive business services, education and publishing activities, telecommunications, and finance and insurance. There is a strong correlation between high-skill potential.ed workers and remote work potential [57].

As experienced during the pandemic, remote working can have both positive and negative effects on the workers. According to the study on remote working by ILO (International Labour Organization) and Eurofound [58] edited in 2017, in general, remote working has positive effects on performance and, under the right circumstances, it can improve personal organisation. Thanks to the reduction of commuting time and autonomy to organise the work, remote working can have positive impacts on the work-life balance, but with the risk of overlap working and family time. In Italy this particular aspect is more positive than the EU average [58], but, in general, there is the need to find a balance between work and personal life. The problems that come with the remote working are mainly related to isolation, stress, and less sense of belonging to the company. Remote workers tend to work more hours per day and during weekends with respect to full-office colleagues, due to the attempt to balance work-time, family needs and house works. In average, they tend to work more hours, but in a more "porous" way [58]. In general, the happiness and the satisfaction depends on the "degree of control over where and when they work" [57].

According to the OECD research about remote working [59] edited in 2020, there is an inverted "U-shaped correlation" between percentage of day of remote working and worker efficiency; the optimum time of work remotely is around 2 or 3 days per week (over the typical 5 working days), as shown in figure 5.1.

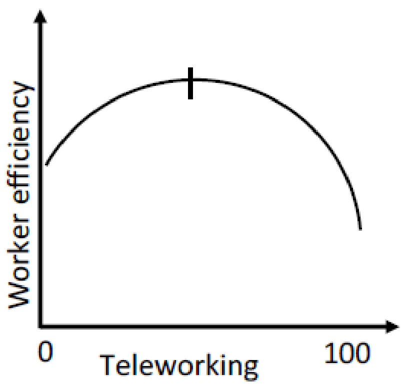


Figure 5.1: Remote work and worker efficiency relationship [59]

In Italy the workers that had ever work remotely before the pandemic was below EU average (about 7% in Italy against 14% in Europe over the total workforce). This is probably due to the relation between percentage of remote workers and the workers that are employed in knowledge and ICT-intensive services, that in Italy is about 24% and in Europe is in average 27%. The other motivations have to be find in cultural predisposition [54].

As seen in section 2.2, the report edited by Assotelematica [2] estimates that, during March 2020, 40% of the workers were working from home and in September 2020 they were still about the 30% of the total workforce. According to the same source [2], after the pandemic 5.35 millions workers will work remotely as a *new normality* and this number represents 35.7% of the possible remote workers or 21.0% of the total Italian workforce.

In Italy the remote work is better known as *lavoro agile* or *smart working*. Most of the legislation about remote working in Italy is related to the the public sector (since 1998) and only in 2017 it was expanded to the private sector. During the pandemic, the Italian state has encouraged the remote working with several directives.

In future, with this great diffusion of remote workers, there will be the need to implement new policies about public and private labour, from the moment that the current regulation is strongly based on the in-person work [56]. It will also be important for public administration to mitigate the negative effects for the sectors linked to the commuting, like shop, restaurant and transport [56]. The workers will also need the right training and technological equipment that will have to be provided by the companies.

In this work, the effects of the diffusion of remote working on the Italian energy system will be analyzed for the year 2040.

To study the effects of remote working some hypotheses and simplification have to be done. In this study, it is assumed that in 2040 the remote work will be fully developed and different from the one that we have known during the pandemic. Most of remote workers will not work at home, but in specific locations, provided by the companies, or in co-working spaces around the city near the workers' homes.

The remote working can affect different areas of the energy demand: especially offices, residential sector and transport sector. People working from home can increase the residential energy consumption, while the redistribution of the working spaces can affect the energy consumption of the offices and of the new working spaces. In the same way, the energy policies of the companies can influence their energy consumption, and, finally, the change in the commuting behaviour of the workers and the rebound effects, due to more free time and more flexibility, can affect the transport sector.

Under the hypotheses described above, it is assumed that the energy consumption related to offices, new working spaces and residential sector in his total will be not affected by the increase in remote workers. This assumption can be justified by the fact that the energy consumption by the offices in BS2040 will be redistributed along the new working spaces. This can be true only if the companies will implement optimal energy strategies. The increasing energy consumption by residential sector due to the workers who decide to work from home will be negligible and included in the redistribution of the working spaces. These hypotheses are valid under the assumption that remote working will follow a correct path towards its optimization. The possible energy effects excluded by this assumption can be a starting point for future researches.

So, the only effect taken into account in this study will be the lower energy consumption by private transport due to less commuting, that will be now numerically explored.

As seen above, according to the report from Assotelematica [2], the "new normality" after the Covid-19 pandemic will see 21.0% of the total Italian workforce as remote workers (or 35.7% of the possible remote workers), using the 2019 data from ISTAT. Processing the data from ISTAT database and the report from Assotelematica, it is obtained that the total possible remote workers correspond to 58.8% of the total Italian workers.

In 2019 the Italian population was 59,64 millions and the workers were 25,47 millions. According to the PNIEC forecast (also used in BS2040), the Italian population in 2040 will be 65.40 millions, and, under the hypothesis that during the studied period the share of the workers and of the share of potential remote workers will remain constant, the Italian workforce in 2040 will be about 28 millions units and the potential remote workers about 10 millions.

The effects of the wide diffusion of Italian remote workers in 2040 will be studied through three different level of penetration of remote workers over the total workforce:

- **Base**: as in BS2040
- **New normality**: 21% of remote workers over the total workforce (according to the definition of "new normality" from Assotelematica)
- **High**: 50% of remote workers over the total workforce (consistent with the the total potential remote workers from the report edited by Assotelematica)

As seen above, according to the OECD study [59], the maximum efficiency of remote workers is reached when they work remotely half of the working time (figure 5.1). In these scenarios, under the hypothesis of fully developed and optimized remote working, it is assumed that remote workers will work in average 2.5 working days remotely over the 5 working days. It is also assumed that the public transport will not be affected by the increase share of remote workers. The decreasing in demand of public transport, due to the less commuting, will be covered by the general increase of the sector taken into account by the sources used to develop BS2040 [23] [37].

One important rebound effect related to remote working for the transport sector is the increase in travels not work-related, due mainly to more free time and more flexibility [60]. To take into account this rebound effects and other business travels, it is assumed that the private transport saving, due to the remote working location, will be in average -90% with respect to an average working day for each remote worker.

According to the 17th report on the Italian mobility edited by ISFORT [61] the 47% of the passenger*km of the Italian private transport is for work purposes. Taking into consideration this data, the average remotely working days for each remote worker, the rebound effects and the percentage of remote workers in the different level of penetration, it is achieved that in the case of *high* penetration of remote workers the energy saving in the private transport sector will be -10.2% and in the conditions of *"new normality"* will be -5.3%. The results are summarized in figure 5.2.

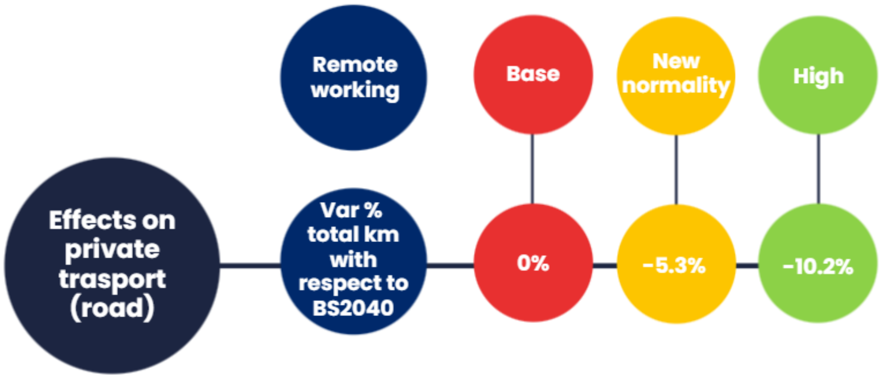


Figure 5.2: Effects of the remote workers in the scenarios on private transport

5.2 Citizens' awareness

As seen in section 2.2 the pandemic has shown how the people's behaviors can influence the environment. Clearer skies, more breathable air and wildlife spread into the cities have left their mark into people.

The pandemic has also taught the importance of personal responsibility to fight global crisis. Millions of people, led by politicians and public information, have drastically changed their lifestyle to reach a common goal.

Covid-19 and climate change are very different challenges, but there are some links between the two. Both are global and, in both, personal actions have to play a big role to mitigate their effects. Beyond the clear differences, there is surely something that people may have learned from the Covid-19 pandemic that can be applied to the mitigation of climate changes, the main ones are shown in figure 5.3 and explained below.

Awareness of consequences: the consequences of Covid-19 have been clear since the earliest days, also thanks to a wide media coverage of the event that has communicated every day the number of people infected and died from Covid-19. The consequences of climate change are more difficult to be seen and communicated and they are often distant in time or too slow to be clearly seen. After the pandemic, people are probably more ready to understand the consequences of climate changes and the public information more ready to communicate such information [17].

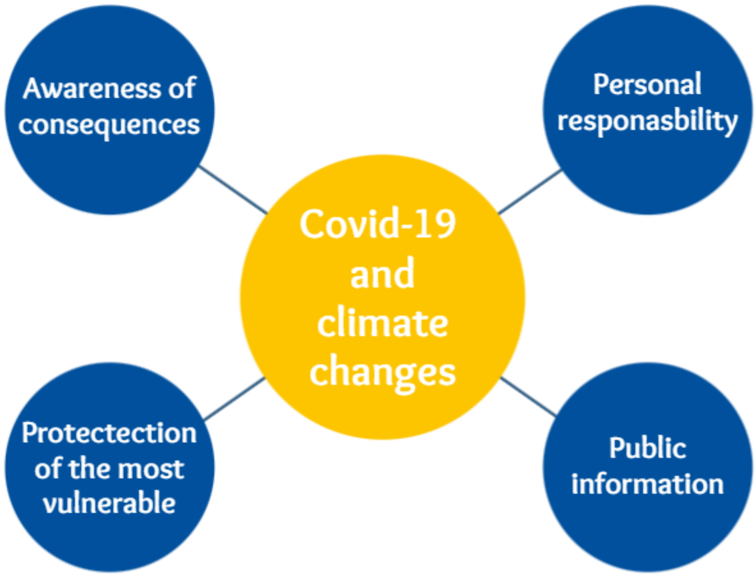


Figure 5.3: Main field that Covid-19 pandemic may have strengthened that can help with the climate crisis

Personal responsibility: during the pandemic a lot of efforts have been requested to citizens to mitigate the virus spread. The personal responsibility has been crucial during this difficult period, each individual had the responsibility to protect the people around him. This new sense of responsibility, if it will be maintained independently from the pandemic, will be able to play an important role in the mitigation of climate change [17].

Protection of the most vulnerable: in most cases, people who have been subjected to the restrictions were not the ones most at risks for the virus consequences, but they still did what needed for the the weaker members. This is another important lesson that can be applied to climate change, where, in most cases, the richest regions are the ones that will less suffer the effects of the environmental crisis, while the poorer countries with the weak health and adaptation infrastructure will be the least prepared to the effects of the climate change [62].

Public information: one key role to help people to understand the importance of personal and social actions and encourage sustainable practices has to come from public campaigns. As for the pandemic, the media have to widely and more constantly communicate which are the good personal norms and to help the people to understand the consequences of climate change. In general also the public information and education have a lot to learn from the pandemic. "If properly designed, targeted awareness-raising campaigns and education will encourage attitudes and practices that will lead to fair and green public procurement and to circular economy approaches that will bring about a better use of materials and a reduction in wastage and emissions" [63].

In the early stages, Italy was one of the nations hardest hit by the pandemic and where the personal restrictions were first implemented. This could have had a major impact on the people awareness of global crisis with respect to other countries. In a poll conducted by the survey agency Ipsos [62], in March 2020, 72% of the Italian interviewed agree that "in the long term, climate change is as serious a crisis as Covid-19 is" and in another poll, made in June 2020, more than 80% of the interviewed agree that "the government should make environment protection a priority in recovery from Covid-19". These values are higher than the world average and EU average and this can represent the personal intention for the Italian citizens to better tackle the climate crisis.

In this part of the thesis, the possible change in behaviour that can come from a higher citizens environmental awareness after the pandemic and that can have an effects on the Italian decarbonisation pathway will be analysed. For each change in behaviour, different sources will be used to numerically explore the possible impact on the Italian energy system.

The main effects of the increase environmental awareness that will be studied in this work are: personal transport switch from cars to "soft mobility", increase in EV share over ICE cars in personal transport and general improvement in energy efficiency in residential sector (figure 5.4).

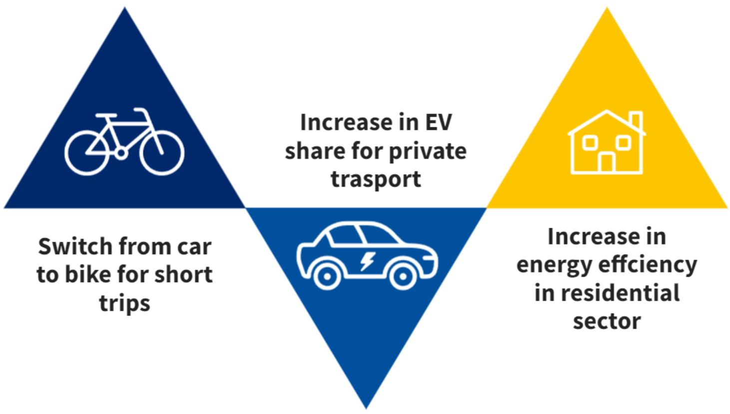


Figure 5.4: Main effects of citizens awareness in the post-pandemic behaviour scenarios

There are other possible changes in energy-related behaviour that in this work are not taken into account, but that can be interesting for future studies. One of these can be the lower use of single-use plastic and higher rate of recycling: ambitious targets of recycling are already present in the BS2040 (section 4.5), so this aspect is not further explored. Also the less citizen purchasing power due to a slower economic recovery is not taken into account, because no economical effects are present in this thesis, going out of the intention of this work. Another interesting effect can be the switch from air to rail travels, but this trend is already widely explored in the BS2040, both for rail and domestic aviation (section 4.2). Other possible effects not addressed in this thesis can be the pressure from citizens on politics to encourage energy transition and more green energy from prosumers and energy communities.

To explore the possible impacts of the behaviour in the scenario will be considered three level of effects of the post-pandemic awareness on the different behaviour:

- **No effects**: as in the BS2040
- **Medium effects**: slight variation with respect to the BS2040
- **High effects**: strong variation with respect to the BS2040

People have spent long time in their home during the pandemic and they had to deal with more expensive bills and to find a new comfort in their homes. These experiences, plus the new environmental awareness, may lead to more effective saving energy practices and push towards the implementation of new energy efficiency measures in the future.

Some hypotheses have been done to numerically explore the possible effects on the residential sector. The effect of the increasing efficiency in residential sector is take into account only for the heating demand. Cooling demand will follow the same path in all the scenarios. Also the demand for cooking and other electric consumption will not go under any changes, the increase in efficiency for these sectors is already widely explored in the BS2040 (section 4.1).

As seen in the introduction of this chapter, the residential sector is responsible for 80% of the heating demand of the buildings sector (see table 5.2). Under the BS2040 hypotheses the heat demand decreases of -19.8% between 2018 and 2040. This trend was taken from HRE4 project [26] as an average between the *Baseline Scenario* and the *Heat RoadMap Scenario* to meet linearly the 2030 PNIEC energy reduction target. It is important to remember that, for the buildings sector, in the HRE4's analysis there is a noticeable difference between the heat demand in the two different scenarios. In the *Heat RoadMap Scenario* more ambitious energy efficiency targets in the buildings sector are implemented with respect to the *Baseline Scenario*. In order to explore the increasing energy efficiency of citizens' homes, the trend of the heat demand of the *Heat RoadMap Scenario* is used to find the residential heat demand in 2040 in the case of *high effects* of awareness in the scenarios. While for the *medium effects* case of the residential heat demand is used an average between BS2040 and the *high effects*. In the HRE4 project the cooling demand is the same for all the scenarios, so the same hypothesis is made in this work. In figure 5.5, the effects on residential heating demand are summarized for the different levels of citizens' awareness.

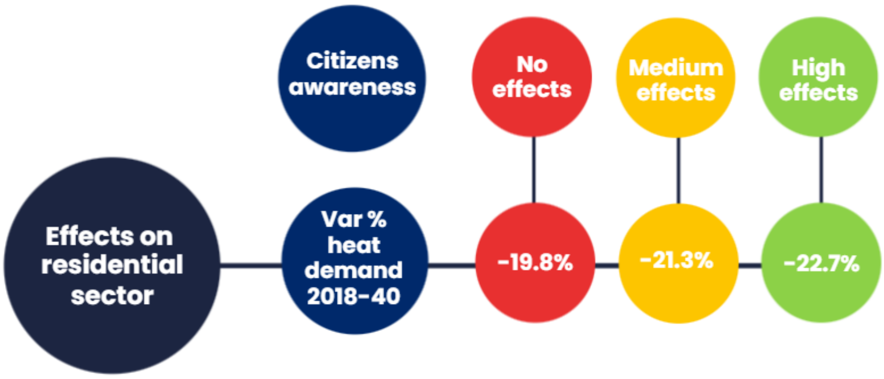


Figure 5.5: Effects of the citizens' awareness in the scenarios on residential sector

Moving to the transport sector, a big role in the reduction of cities pollution during the quarantine was due to the less road traffic (see section 2.2). People have experienced clearer skies and more breathable air especially in major and typically more polluted cities. These experiences can have left a mark into people and, united with a increased climate and environmental awareness, may lead them to a more sustainable way of travel.

As seen in the introduction of this chapter, according to ISPRA forecast BS2040, the private transport by car accounts for 52.7% of the total energy consumption by road transport sector (see table 5.1 for the division for each fuel).

The effects considered in this section are: the switch from cars to bikes for short travel and the increase in EV share over ICE in the private transport.

For the switch from cars to bikes for short travel it is taken as source of information the WEO 2020 edited by IEA [42]. According to this source, 7% of the emissions from private road transport comes from travel that could be done in 10 minutes by bike (similarly, 10% of the emissions can be avoided by 15 minutes travel by bike). So for *high level* of citizens' awareness, an average of -7% energy demand by private transport cars is taken as energy saving, while for *medium level*, an energy saving of -3.5% is used for the private cars road transport, assumed as the half of the *high level*. These data are summarized in figure 5.6.

Combining the data from BS2040 and ISPRA about the fuels division by vehicle category, it is obtained that the share in BS2040 of EV over the total cars for private transport is 36.7%. It was decided to increase this share by 10% for each level of citizens' awareness. So, it is obtained that for *high level* of citizens' awareness the share of EV in private transport will be 56.6%, that is an ambitious share with respect to the studied sources [31] [37] [42]. While, in the case of *medium level*, it will be 46.6%. These results are summarized in figure 5.6.

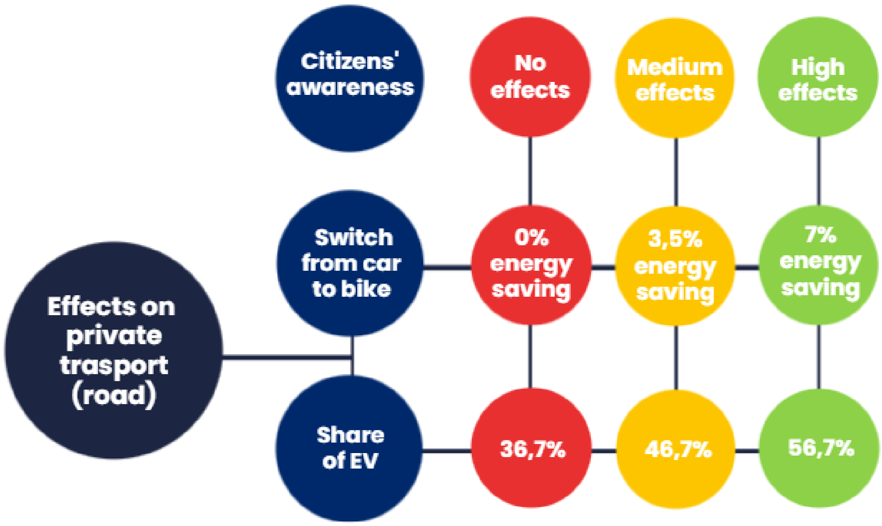


Figure 5.6: Effects of the citizens' awareness in the scenarios on private transport

5.3 Scenarios construction

In order to explore the different possible impacts of the changes in behaviour on the Italian decarbonisation pathway, it has been decided to carry out six different scenarios, called Post-Pandemic Behaviour Scenarios (PPBS), numbered from 1 to 6.

PPBS 1, 2, and 3 consider a medium penetration of remote workers over the total workforce (*"new normality"* level, see section 5.1 and figure 5.2), while the effects of citizens' environmental awareness will be increased from PPBS 1 to 3 starting from *"no effects"* to *"high effects"* (see section 5.2, and figures 5.5 and 5.6). Furthermore, PPBS 4, 5 and 6 consider a high penetration of remote workers (*"high"*), with increasing effects of citizens' awareness from PPBS 4 to 6.

It is important to remember that in BS2040 it is not taken into account the increased citizens' awareness (*"no effects"*) and neither the increasing share of remote workers (*"base"*).

The decision to set at least a medium penetration of smart workers in all the PPBSs is due to the fact that it is highly probable that in the future this trend will continue. While in PPBS 1 and 4, the effects of the increased citizens' awareness about the climate crisis is not included because it is more difficult to forecast.

The scenarios construction is summarized in figure 5.7.

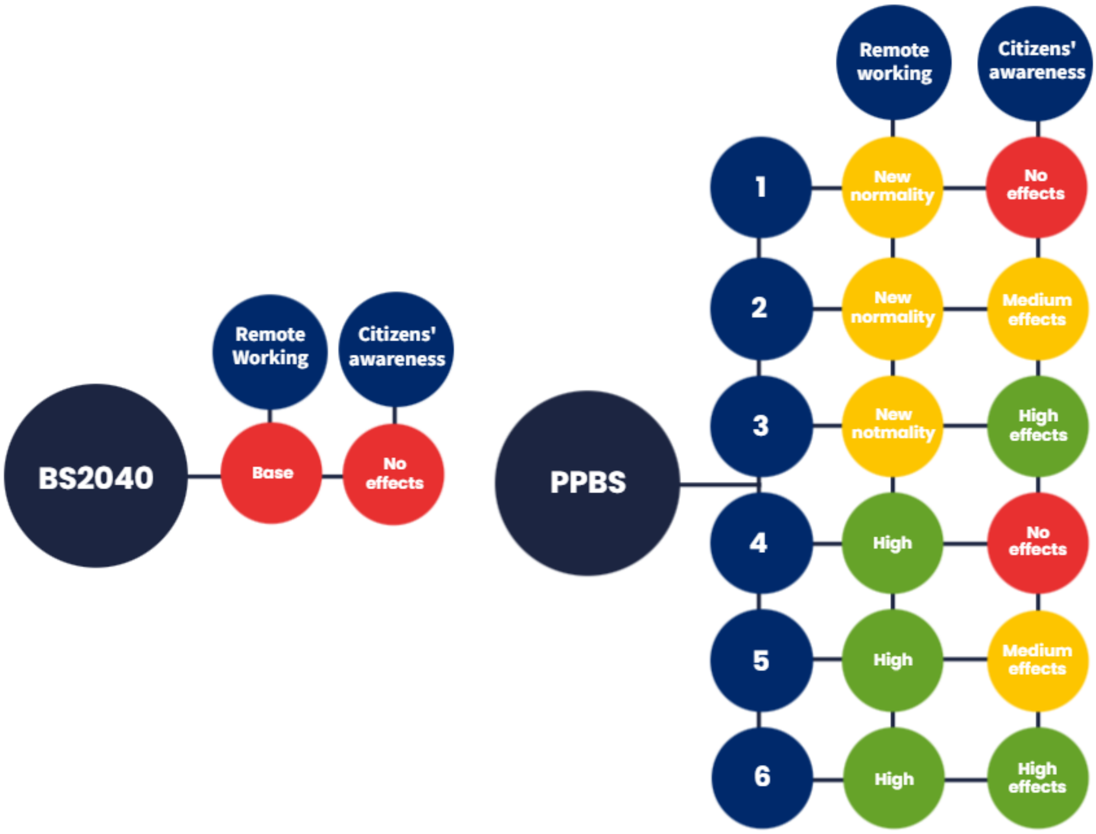


Figure 5.7: Scenarios resume

5.4 Results and discussion

The results of the scenarios are all given in the same form. The results of the PPBSs are presented as percentage variation with respect to the BS2040. In each graph, the columns of the histogram are the variation between PPBSs and BS2040. To have a benchmark, a table containing the variation of the same quantity with respect to BS2040 for REM2018 and the 2030 PNIEC scenario is also included in the results.

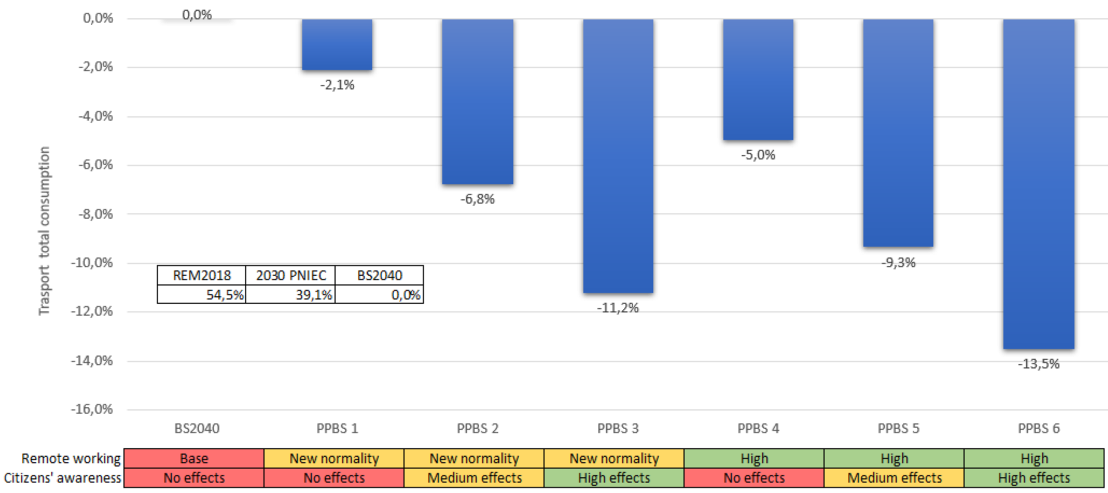


Figure 5.8: Scenarios: Transport sector energy consumption percentage variation with respect to BS2040

In figure 5.8 the effects of PPBSs on the transport sector final energy demand are shown. Transport sector is the sector most affected by the changes in behaviour. In PPBS 1 and 4, it is possible to see the effects of the increasing share of remote workers only. In these scenarios, the work travels decrease by 9% and 23%, respectively in the PPBS 1 and 4 with respect to the BS2040. The change in the total transport demand is -2.1% with respect to the BS2040, when the share of remote workers is 21% over the total workforce (PPBS 1, *"new normality"* remote working) and -5% when the remote workers are 50% (PPBS 4, *"high"* remote working).

Under the assumptions illustrated in this chapter, the effects of citizens' awareness has a slight larger impact on the transport sector with respect to the remote working. The energy savings from the reduced mobility due to the switch from cars to "soft mobility" are very similar to the ones due to the increasing share of remote workers. The higher reduction in energy transport demand is due to the passage from ICE to EV, that involves a general increase of the efficiency in the private transport sector.

In the PPBS 6 (*high* penetration of remote workers and *high effects* of citizens' awareness), the global effect on the energy use in transport sector is a reduction of -13.5% in the final demand. Comparing this data with the variation between the BS2040 and the 2030 PNIEC scenario (39.1%), it is possible to understand that the behaviours analyzed have a big potential to help the decarbonisation of the transport sector. Energy saving and energy efficiency from the citizens can play a key role in this sector.

The reduction in transport demand and the shift towards more efficient transport technologies involves, not only the reduction in energy demand, but also a general improvement in the living standards of urban areas. Minor road traffic and an increased air quality allow to make cities more livable. As seen during the pandemic, the road the changes in the mobility can have a huge impact on the urban environment.

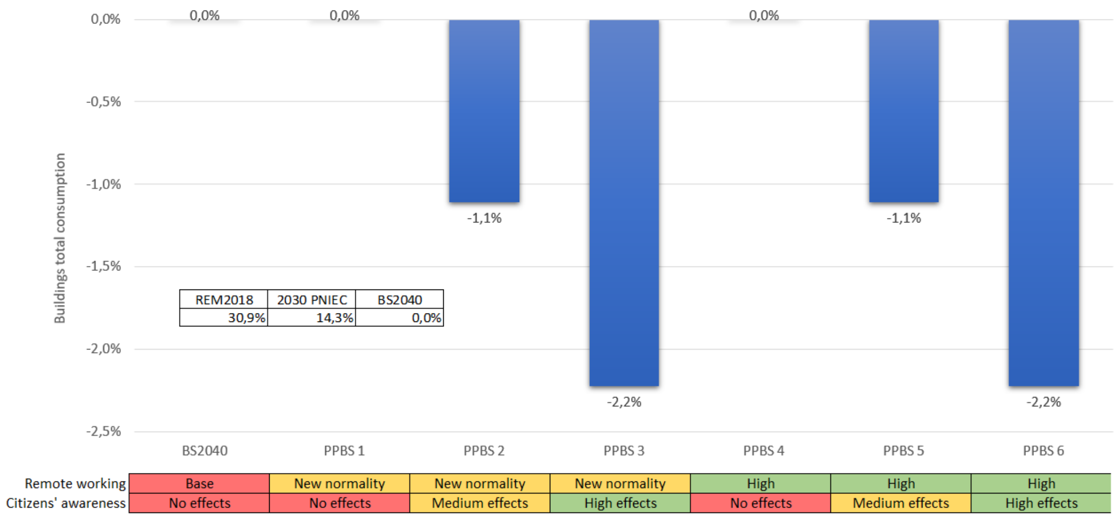


Figure 5.9: Scenarios: Buildings sector energy consumption, percentage variation with respect to BS2040

In figure 5.9 is shown the impact of the different PPBSs on buildings sector. Under the hypotheses made during the construction of the scenarios, remote working has no effects on this sector. So the variation in the total energy demand can be only appreciated in PPBS 2, 3, 5 and 6.

The overall impact of citizens' awareness on buildings sector is smaller than the one on transport sector. The reduction in the total energy demand is -1.1% in the case of *medium effects* of citizens' awareness and -2.2% in the case of *high effects*. This is related to the general decrease in heat demand already present in the BS2040, with high energy efficiency targets that leave little space to further efficiency measures. The decrease between 2018 and 2040 is lower than the reduction in the same period in transport sector and this shows how, in buildings sector, high energy saving targets are more difficult to reach.

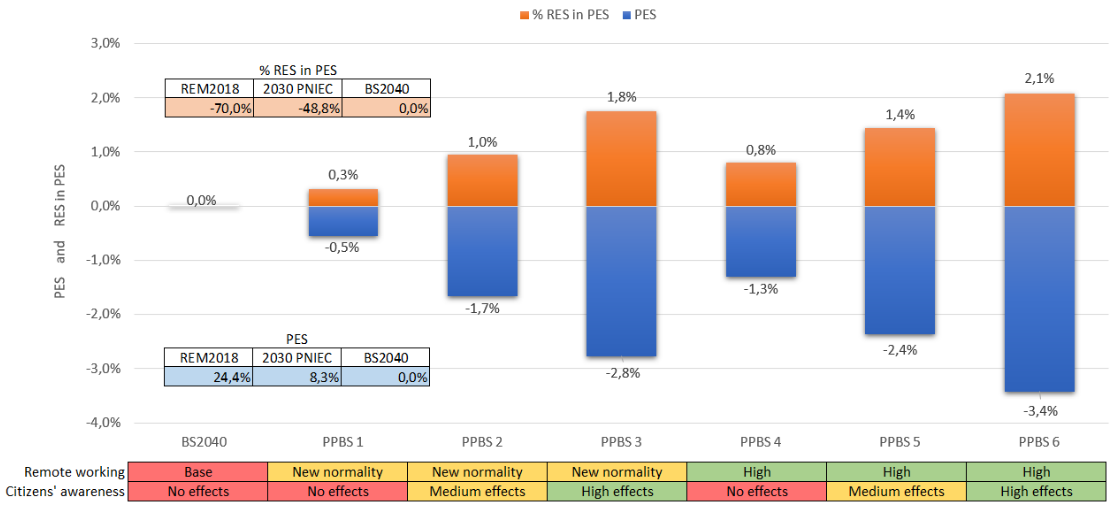


Figure 5.10: Scenarios: Primary Energy Supply and RES share in PES, percentage variation with respect to BS2040

The PES (Primary Energy Supply) evolution in the scenarios is mainly driven by the change in demand of the transport sector. The decrease in transport alone have a small impact on the the PES, but, if coupled with an increase of EV share and residential sector efficiency, it becomes significant.

In PPBS 6, (*high* penetration of remote workers and *high effects* of citizens' awareness) the global effects on the PES is a reduction of -3.4% with respect to the BS2040, while in PPBS 4 (*high* penetration of remote workers only) the reduction is -1.3%. The variation between the 2030 PNIEC scenarios and BS2040 is in the order of 8%. This indicates how the changes in behaviour can have an important impact on the global energy saving targets.

The share of RES in the PES has a smaller variation through the scenarios, especially if compared to the variations between REM2018, 2030 PNIEC scenario and BS2040. The increase in RES share is mainly due to the reduction of fossil fuels consumption due to the less mobility in the scenarios.

The variations of oil and natural gas consumption in the scenarios are shown in figure 5.11. The impacts are similar to the one related to the transport sector, but more contained. Also here, it is possible to see that the changes in behaviour have a sensible potential, especially when the reduction in transport demand is joined with an increasing share of EV and a reduction of heat demand.

The effects on the total electricity production and the share of RES in it have a

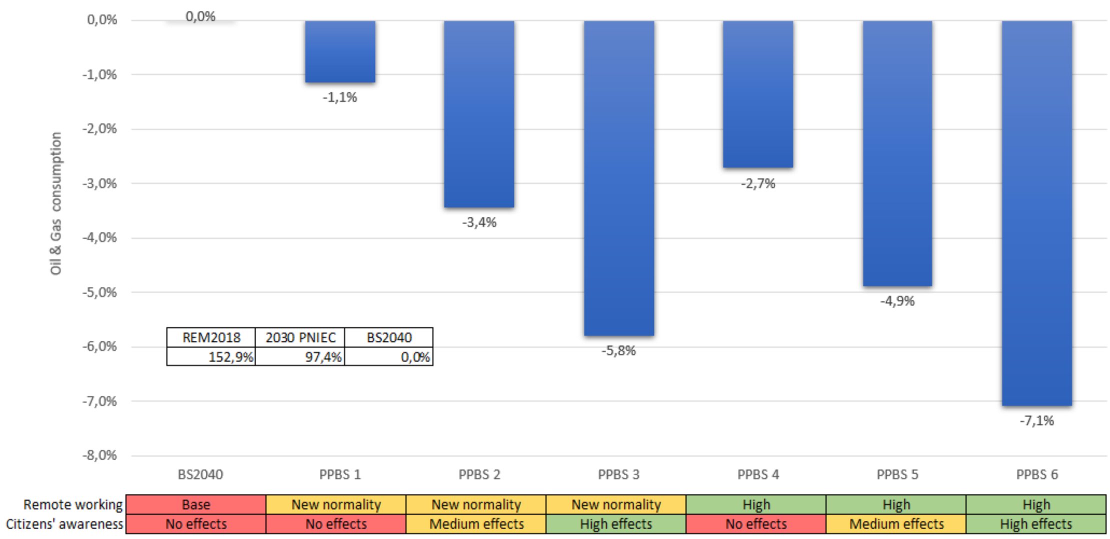


Figure 5.11: Scenarios: Oil & Gas consumption, percentage variation with respect to BS2040

particular behaviour in the scenarios (figure 5.12).

In PPBS 1 and 4, where only the effects of remote working are taken into account, the reduction in transport demand generates a decrease in the total electricity produced and also an increase in the RES share in the electricity mix.

In PPBS 2, 3, 5 and 6, where also the citizens' awareness is taken into account, the increasing share of EV causes a growth in the electricity production and, in parallel, the RES share proportionally decreases. This behaviour is more pronounced in PPBS 3, where the maximum share of EV is coupled with a smaller decrease in mobility demand.

The motivation of this trend can be find in two main reasons. The first one is that the capacity of the RES plant for electricity production is the same in all the scenarios and EnergyPLAN already fully exploits the renewable sources in BS2040. In fact, the variation of the electricity produced by RES (absolute value) to respect with BS2040 is lower than 0.6% in all the PPBSs.

The second one is that the EV, under the BS2040 hypotheses, are mainly recharged at night, when the PV (main electric RES) cannot work; in this situation the electrical storage system may not completely met the electricity demand by the EV. The electric storage capacity was not changed between the scenarios; the improvement of the energy storage, in the scenarios with higher share of EV, could help to increase the share of RES in the produced electricity. This analysis was left out of the boundaries of this work, but can be a starting point for future analysis.

In the last graph is shown the variation with respect to the BS2040 of the CO_2

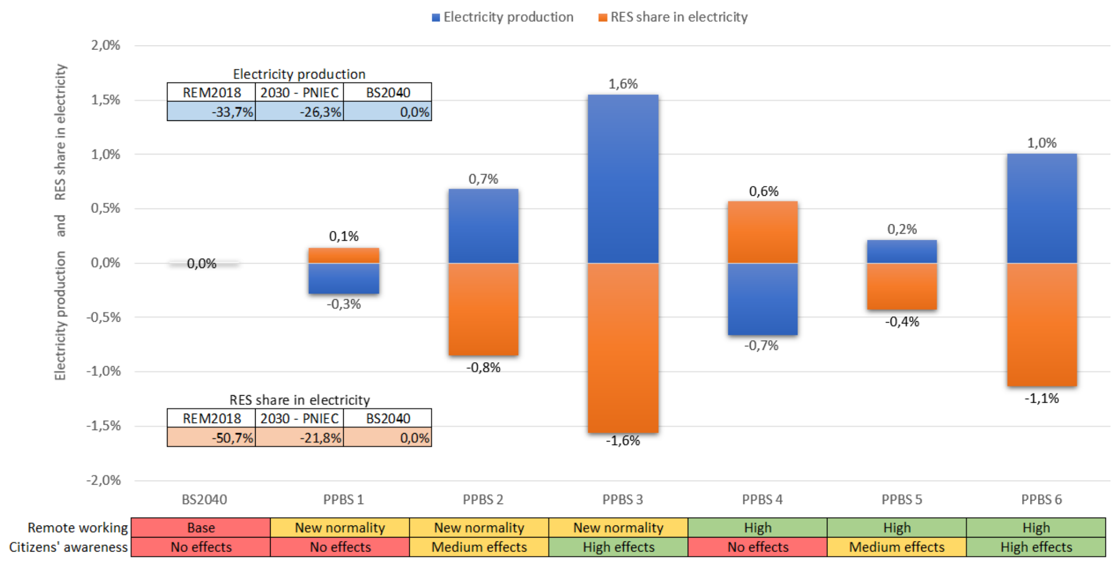


Figure 5.12: Scenarios: Electricity production and RES share in electricity, percentage variation with respect to BS2040

emissions for each scenario (figure 5.13). The main causes of the CO_2 reduction in the scenarios are the decrease in oil and gas consumption, the electrification of the private transport sector and the general decrease due to energy saving behaviour.

In PPBS 6 the CO_2 reduction is 8.1% with respect to the BS2040. Comparing this value with the variation of the same quantity between the 2030 PNIEC scenario and the BS2040 (91%), it can be said that the behaviours taken into consideration in thesis have large potential on the pathways towards the Italian decarbonisation.

Figure 5.13: Scenarios: CO_2 emissions, percentage variation with respect to BS2040

Chapter 6

Conclusion

From chapter 2 it is seen how in all the sectors, in the last years, the processes that involve a reduction in GHG emissions are already under way. Energy efficiency measures, electrification and increase in RES share are trends that are already influencing the evolution of the Italian energy system. The targets set by the European and Italian policies aims to accelerate these processes in the coming decades.

The effects of the pandemic on the energy system during the crisis have been severe, reduction in demand and people's habits has strongly influenced the energy sector in 2020. In this work only the changes in the citizens' energy-related behaviour are taken into account for the long-term study. The effects due to the economical crisis are not considered, under the hypothesis that in 2040 they will be negligible. This is a strong assumption, that excludes the possibility to study the long-term effects of a slower or a quicker economic recovery; this analysis can be a starting point for future studies.

In chapter 4, in order to have a solid stage between the historical data and the BS2040, also a scenario for 2030 has been developed based on the PNIEC. Then, the BS2040 has been found as a linear pathway from the 2030 scenario to a decarbonisation scenario in 2050.

The results from the analysis of the model show that PNIEC targets for 2030 for the energy final use are almost in line with a linear decarbonisation towards 2050. Only for the transport sector a greater effort will be required in the period after the 2030 to met the BS2040 hypotheses. Instead, regarding the generation sector, PNIEC targets for the RES capacity are far away from a linear pathway towards the decarbonisation in 2050. A huge effort for the installation of RES plants will be required between 2030 and 2040 to put the BS2040 in line with the decarbonisation objective, especially for the PV plants. This means that the Italian energy system in 2030 will still relies strongly on the thermal plants and in particular on the natural gas. The trend of the CO_2 emissions in the model highlights this gap between PNIEC targets and the European decarbonisation objectives.

In general, the BS2040 shows that the end-use sectors will have to go under changes. The energy saving measures will have to lead a decrease in energy demand, together with the transition towards more efficient technologies. If the final energy demand today is strongly fossil-based, the future energy demand will have to be more varied, with different energy solutions according to the necessity. The generation sector will strongly relies on variable energy sources and this would require a strong increase in energy storage capacity and in the energy transmission system. Despite the big increase in RES capacity, natural gas will still play an important role, due mainly to the increase in electricity demand as results of the rapid electrification on the end-use sector.

In this thesis the technological choices are all limited at the BS2040. In the other scenarios only the energy demand and the share of EV in private transport has been changed, all other technologies, on which the BS2040 relies, have been left unchanged. The study of these variations on different technology-based scenarios could be a starting point for future researches.

In conclusion, in chapter 5, this work tries to answer to the main objective of the thesis, developing 6 different Post-Pandemic Behaviour Scenarios. The main objective was to understand the possible impacts of the citizens' changes in behaviour, as a consequence of the pandemic, on the Italian decarbonisation pathways. The main energy-related behaviour taken into account in the Post-Pandemic Behaviour Scenario were the increasing share of remote workers and the increasing citizens' awareness about climate issues. In particular, the effect of remote working considered in the scenario is the reduction in private transport demand due to less commuting. The effects led by the citizens' awareness are the increasing share of EV over ICE in the private mobility, the switch from car to "soft mobility" for short travels and a general increase in the residential sector.

From the results of the different scenarios and under the hypothesis used to build them, it is possible to say that the impact of remote working alone is limited on the energy system. Also considering an ambitious share of 50% of remote workers over the total Italian workforce, the impact on the transport sector is only a 5.0% decrease in the energy demand. Moreover, the reduced mobility causes a reduction of 2.8% in the global CO_2 production, that is a small value with compared to the efforts already required by the BS2040. Although remote working can have a small impact on the energy sector, it still represents one step closer to the decarbonisation. In addition, the increasing share of remote workers is a social transformation that comes with zero costs and that responds to the will of the workers, asking for more flexibility. The remote working advantages are not only related to the reduction in energy commodities, but the decrease in urban road traffic have a general positive impact in urban areas. The possible improvement are related to air quality, road accidents, noise, livable cities and green urban planning.

When increasing share of remote workers is coupled with the increase in citizens' awareness about climate issues, the effects on the energy system are far more visible. The case of high share of remote workers and high citizens' awareness is ambitious, but it is a benchmark for the potential of these effects. For this scenario the main effects are a reduction of 13.5% in the energy demand by transport sector, a reduction of 3.4% in the primary energy supply and a reduction of 8.1% in GHG emissions. This results demonstrate that the effects of the pandemic on people habits, taken into account in thesis, have a large potential to help the Italian decarbonisation pathway, in particular on transport sector. As seen for remote working, also the social transformation related to citizens' awareness comes with low economic costs for the population. They are mainly personal choices. While for remote working are the workers themselves to ask for more flexibility, in this case could be more difficult to spread the "green" behaviours. In this context the public information will have to play an important role leading the citizens' on the correct pathway, as seen during the pandemic.

During the construction of the Post-Pandemic Behaviour Scenarios, several simplifications and assumptions has been made. For the effects of the increasing share of remote working, only the impacts on the transport sector have been considered, while the possible influences on the offices and the residential sector have been excluded, under the hypothesis of an optimal way to organize the remote working. The possible effects of the increasing citizens' awareness about climate issues are several, in this thesis some of them have been excluded from the analysis because they have already been taken into account in the construction of the BS2040 or because beyond the borders of interest of this work. These simplifications and assumption can be a starting point for feature studies.

Appendix A

EnergyPLAN simulation results

In this appendix are shown the EnergyPLAN's simulation results for all the scenarios seen in the thesis:

- REM2018 (figure A.1)
- 2030 PNIEC Scenario (figure A.2)
- BS2040 (figure A.3)
- PPBS 1 (figure A.4)
- PPBS 2 (figure A.5)
- PPBS 3 (figure A.6)
- PPBS 4 (figure A.7)
- PPBS 5 (figure A.8)
- PPBS 6 (figure A.9)

Input 2018_REM.txt — The EnergyPLAN model 15.0

Electricity demand (TWh/year):			
Fixed demand	290,96	Flexible demand	0,00
Electric heating + HP	22,24	Fixed imp/exp.	-43,89
Electric cooling	8,82	Transportation	11,54
		Total	289,67

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	4,14	18,97	0,00	23,11
Solar Thermal	0,00	0,00	0,00	0,00
Industrial CHP (CSHP)	0,00	-39,97	0,00	-39,97
Demand after solar and CSHP	4,14	58,93	0,00	63,08

Wind	10265	MW	17,71	TWh/year	0,00	Grid
Photo Voltaic	20108	MW	22,65	TWh/year	0,00	stabili-
Wave Power	0	MW	0	TWh/year	0,00	sation
River Hydro	22910	MW	50,5	TWh/year	0,00	share
Hydro Power	0	MW	0	TWh/year		
Geothermal/Nuclear	813	MW	6,1	TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	26153	14446	0,39	0,22	
Heat Pump	0	0			3,00
Boiler		0		0,88	
Group 3:					
CHP	0	0	0,00	0,00	
Heat Pump	0	0			3,00
Boiler		0		0,88	
Condensing	0		0,00		

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

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,00	4,82
Gr.3:	0,00	0,00

Regulation Strategy:	Technical regulation no. 2	
CEEP regulation	000000000	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	0	MW
Distr. Name :	Hour_nordpool.txt	
Addition factor	0,00	EUR/MWh
Multiplication factor	2,00	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	227	EUR/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level:

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

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	350,25	12,71	0,00
Household	0,00	28,10	266,83	73,27
Industry	11,79	23,48	100,57	4,58
Various	0,87	66,54	31,72	0,84

Output

District Heating

	Demand: Distr. heating MW	Production: Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba- lance MW
January	6294	0	-4158	1095	9340	0	0	0	0	18
February	5628	0	-4158	975	8809	0	0	0	0	2
March	4094	0	-4158	700	7519	0	0	0	0	33
April	1934	0	-4158	313	5632	0	0	0	0	147
May	699	0	-4158	91	4724	0	0	0	0	42
June	299	0	-4158	18	4424	0	0	0	0	15
July	250	0	-4158	9	4410	0	0	0	0	-10
August	274	0	-4158	13	4430	0	0	0	0	-11
September	536	0	-4158	62	4644	0	0	0	0	-12
October	2127	0	-4158	347	5927	0	0	0	0	11
November	3901	0	-4158	666	7375	0	0	0	0	19
December	5694	0	-4158	987	8778	0	0	0	0	86
Average	2638	0	-4158	439	6330	0	0	0	0	28
Maximum	11631	0	-4158	2051	13746	0	0	0	0	5379
Minimum	4	0	-4158	0	1845	0	0	0	0	-12
TWh/year	23,18	0,00	-36,53	3,85	55,60	0,00	0,00	0,00	0,00	0,25

Electricity / Exchange

	Consumption: Elec. demand MW	Flex.& Transp. MW	HP MW	Elec- trolyser MW	EH MW	Hydro Pump MW	Production: Tur- bine MW	RES MW	Hy- dro MW	Geo- thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Balance: Stab- Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Exchange: Payment Imp (Million EUR)	Exp
January	33924	1288	2326	0	3844	0	0	7500	0	708	549	16908	9579	100	0	0	0	0	0	0
February	35772	1325	1731	0	2861	0	0	7394	0	706	549	15948	10539	100	0	0	0	0	0	0
March	33784	1339	1072	0	1772	0	0	9458	0	706	549	13611	7738	100	0	0	0	0	0	0
April	31270	1280	681	0	1125	0	0	12764	0	705	549	10195	5054	100	0	0	0	0	0	0
May	33242	1339	547	0	904	0	0	15149	0	696	549	8551	6508	100	0	0	0	0	0	0
June	35210	1331	391	0	646	0	0	15380	0	690	549	8009	8293	100	0	0	0	0	0	0
July	39339	1286	316	0	521	0	0	12635	0	673	549	7983	13806	100	0	0	0	0	0	0
August	33573	1339	264	0	437	0	0	10144	0	676	549	8020	12560	100	0	0	0	0	0	0
September	34843	1304	356	0	589	0	0	8877	0	689	549	8407	14350	100	0	0	0	0	0	0
October	32681	1313	582	0	961	0	0	7126	0	691	549	10730	11274	100	0	0	0	0	0	0
November	33523	1331	1283	0	2119	0	0	9282	0	691	549	13351	10874	100	0	0	0	0	0	0
December	32425	1287	1922	0	3175	0	0	8386	0	708	549	15892	8588	100	0	0	0	0	0	0
Average	34128	1314	955	0	1578	0	0	10344	0	695	549	11459	9930	100	0	0	0	0	Average price	
Maximum	56197	3994	3540	0	5850	0	0	29191	0	736	549	24884	27010	100	0	0	0	0	(EUR/MWh)	
Minimum	17572	0	0	0	0	0	0	1119	0	565	549	3340	0	100	0	0	0	0	237	231
TWh/year	299,78	11,54	8,39	0,00	13,86	0,00	0,00	90,86	0,00	6,10	4,82	100,65	87,23		0,00	0,00	0,00	0,00	0	0

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon- version	Electro- Fuel	Wind	PV and CSP	Wind off Wave	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (Mt): Total	Net
Coal	-	8,07	0,00	-	-	75,89	-	-	-	-	-	-	-	-	-	-	-	-	-	12,66	96,62	0,00	96,62	32,66	32,66
Oil	0,05	43,17	0,00	-	-	3,90	-	-	-	-	-	-	-	-	-	-	-	350,25	28,10	90,02	515,48	0,00	515,48	142,32	142,32
N.Gas	3,15	176,71	0,00	-	-	91,43	-	-	-	-	-	-	-	-	-	-	-	33,33	264,23	136,10	704,96	0,00	704,96	146,38	150,66
Biomass	1,18	28,79	0,00	-	-	22,29	-	-	20,09	-	0,57	-	-	-	-	-	-	-	73,27	5,42	151,61	0,00	151,61	2,31	2,31
Renewable	-	-	-	-	-	-	61,04	-	-	-	-	-	17,71	22,65	-	50,50	2,39	-	-	-	154,29	0,00	154,29	0,00	0,00
H2 etc.	-	-	0,00	-	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-14,53	-	-	-	-	-	-	14,53	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	4,38	256,74	0,00	-	-	193,51	61,04	-	20,09	-	-13,96	-	17,71	22,65	-	50,50	2,39	398,11	365,60	244,20	1622,96	0,00	1622,96	323,67	327,95

18-novembre-2021 [14:20]

Figure A.1: EnergyPLAN simulation: REM2018

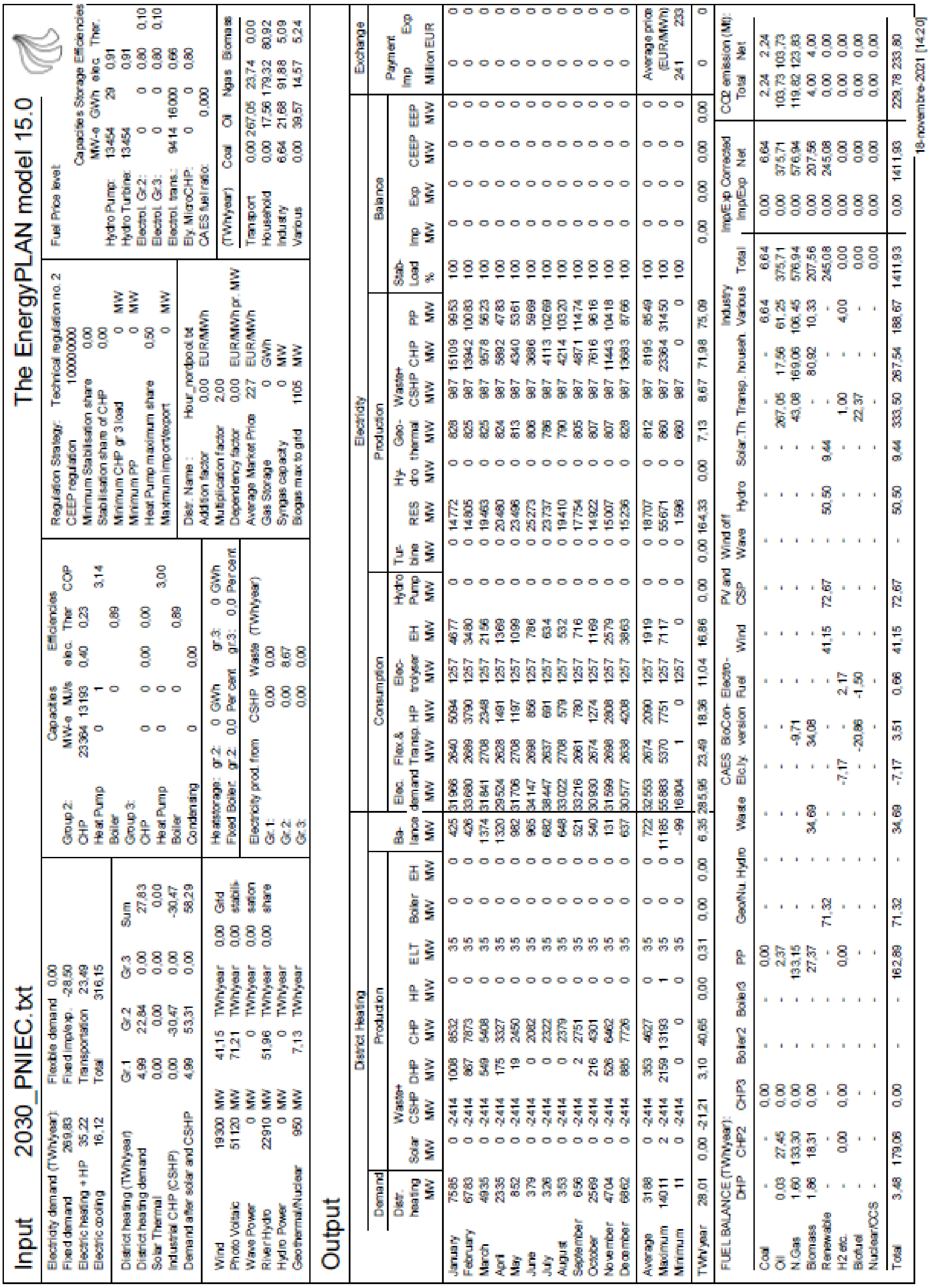


Figure A.2: EnergyPLAN simulation: 2030 PNIEC scenario

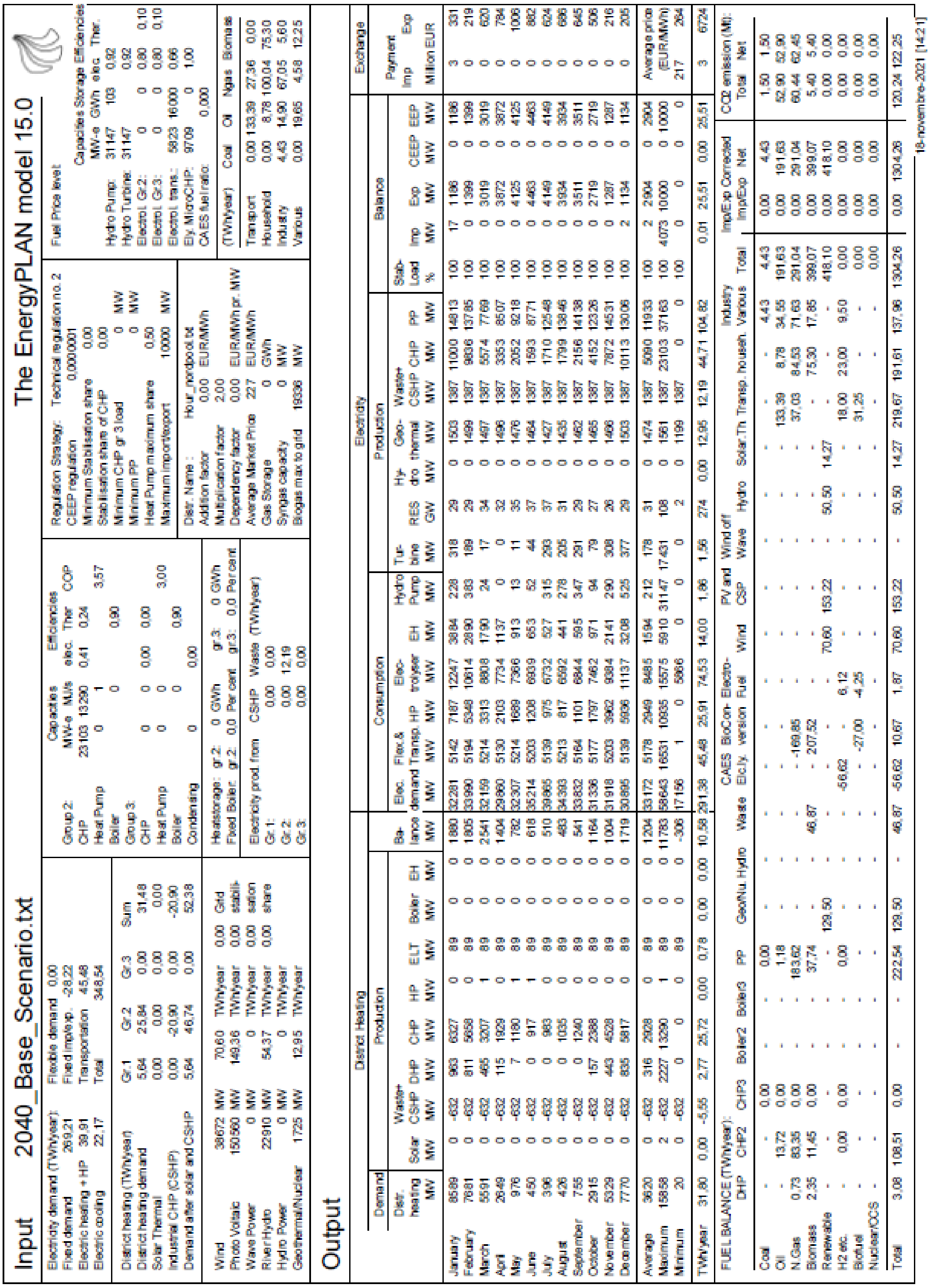


Figure A.3: EnergyPLAN simulation: BS2040

Input 2040_Scenario_1.txt — **The EnergyPLAN model 15.0**

Electricity demand (TWh/year):		Flexible demand	0,00
Fixed demand	269,21	Fixed imp/exp.	-28,22
Electric heating + HP	39,91	Transportation	44,69
Electric cooling	22,17	Total	347,75

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	5,64	25,84	0,00	31,48
Solar Thermal	0,00	0,00	0,00	0,00
Industrial CHP (CSHP)	0,00	-20,90	0,00	-20,90
Demand after solar and CSHP	5,64	46,74	0,00	52,38

Wind	38672 MW	70,50	TWh/year	0,00	Grid
Photo Voltaic	150560 MW	149,15	TWh/year	0,00	stabili-
Wave Power	0 MW	0	TWh/year	0,00	sation
River Hydro	22910 MW	54,37	TWh/year	0,00	share
Hydro Power	0 MW	0	TWh/year		
Geothermal/Nuclear	1725 MW	12,95	TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	23103	13290	0,41	0,24	
Heat Pump	0	1			3,57
Boiler		0		0,90	
Group 3:					
CHP	0	0	0,00	0,00	
Heat Pump	0	0			3,00
Boiler		0		0,90	
Condensing	0		0,00		

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

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,00	12,19
Gr.3:	0,00	0,00

Regulation Strategy:	Technical regulation no. 2	
CEEP regulation	0,0000001	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	10000	MW
Distr. Name :	Hour_nordpool.txt	
Addition factor	0,00	EUR/MWh
Multiplication factor	2,00	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	227	EUR/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	19336	MW

Fuel Price level:

	Capacities MW-e	Storage GWh	Efficiencies elec.	Efficiencies Ther.
Hydro Pump:	31147	103	0,92	
Hydro Turbine:	31147		0,92	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	5823	16000	0,66	
Ely. MicroCHP:	9709	0	1,00	
CAES fuel ratio:		0,000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	130,43	26,94	0,00
Household	0,00	8,78	100,04	75,30
Industry	4,43	14,90	67,05	5,60
Various	0,00	19,65	4,58	12,25

Output

District Heating:

	Demand: Distr. heating MW	Production: Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba-lance MW
January	8589	0	-639	963	6322	0	89	0	0	1893
February	7681	0	-639	811	5653	0	89	0	0	1817
March	5591	0	-639	465	3201	1	89	0	0	2553
April	2649	0	-639	115	1927	0	89	0	0	1413
May	976	0	-639	7	1179	1	89	0	0	791
June	450	0	-639	0	916	1	89	0	0	627
July	396	0	-639	0	983	0	89	0	0	518
August	426	0	-639	0	1035	0	89	0	0	491
September	755	0	-639	0	1239	0	89	0	0	549
October	2915	0	-639	157	2386	0	89	0	0	1174
November	5329	0	-639	443	4524	0	89	0	0	1016
December	7770	0	-639	835	5810	0	89	0	0	1733
Average	3620	0	-639	316	2925	0	89	0	0	1215
Maximum	15858	2	-639	2227	13290	1	89	0	0	11790
Minimum	20	0	-639	0	0	0	89	0	0	-299
TWh/year	31,80	0,00	-5,62	2,77	25,69	0,00	0,78	0,00	0,00	10,67

Electricity:

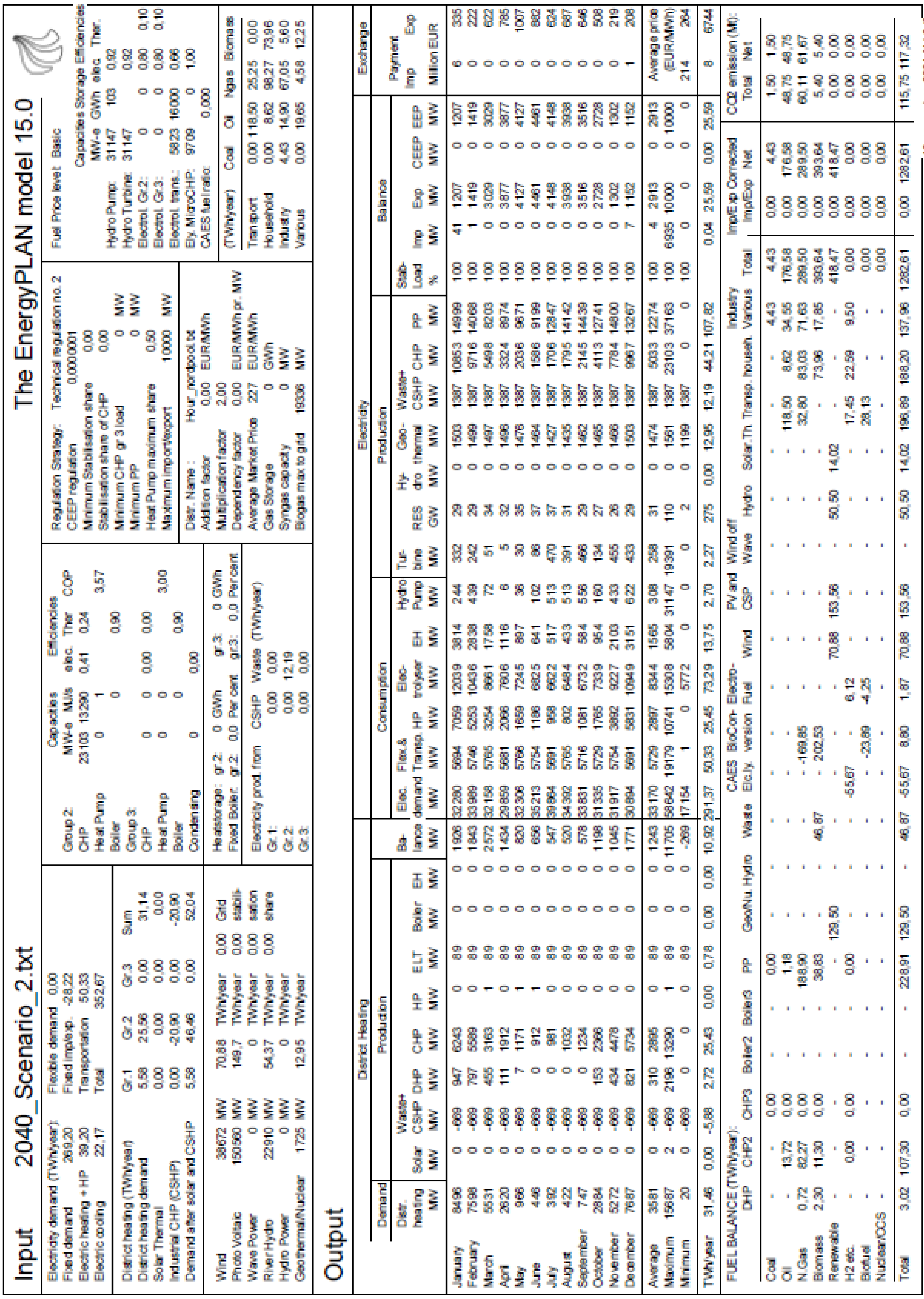
	Consumption: Elec. demand MW	Flex.& Transp. MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Production: Tur-bine MW	RES GW	Hy-dro MW	Geo-thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Balance: Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Exchange Payment Imp Million EUR	Exp Million EUR
January	32281	5052	7187	12193	3884	213	306	29	0	1503	1387	10990	14721	100	0	1189	0	1189	0	331
February	33990	5104	5348	10560	2890	373	179	29	0	1499	1387	9828	13680	100	0	1402	0	1402	0	219
March	32159	5124	3313	8754	1790	17	12	34	0	1497	1387	5565	7657	100	0	3022	0	3022	0	621
April	29860	5040	2103	7680	1137	0	0	32	0	1496	1387	3350	8389	100	0	3874	0	3874	0	785
May	32307	5124	1689	7312	913	9	8	35	0	1476	1387	2049	9104	100	0	4127	0	4127	0	1007
June	35214	5113	1208	6885	653	47	39	37	0	1464	1387	1592	8661	100	0	4467	0	4467	0	883
July	39865	5049	975	6678	527	281	262	37	0	1427	1387	1709	12460	100	0	4151	0	4151	0	624
August	34393	5124	817	6538	441	241	175	31	0	1435	1387	1798	13755	100	0	3936	0	3936	0	687
September	33832	5075	1101	6790	595	310	260	29	0	1462	1387	2154	14046	100	0	3512	0	3512	0	645
October	31335	5088	1797	7408	971	84	71	27	0	1465	1387	4148	12210	100	0	2722	0	2722	0	507
November	31918	5113	3962	9330	2141	265	282	26	0	1466	1387	7865	14428	100	0	1290	0	1290	0	217
December	30895	5050	5936	11083	3208	500	361	29	0	1503	1387	10100	12908	100	1	1137	0	1137	0	206
Average	33171	5088	2949	8431	1594	194	163	31	0	1474	1387	5085	11830	100	0	2906	0	2906	Average price	
Maximum	58642	16100	10935	15521	5910	31147	16946	106	0	1561	1387	23103	37163	100	965	10000	0	10000	(EUR/MWh)	
Minimum	17155	1	0	5813	0	0	0	2	0	1199	1387	0	0	100	0	0	0	0	230	264
TWh/year	291,38	44,69	25,91	74,06	14,00	1,71	1,43	274	0,00	12,95	12,19	44,66	103,91		0,00	25,53	0,00	25,53	0	6730

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Electro-Fuel	Wind	PV and CSP	Wind off Wave	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (Mt): Total	Net
Coal	-	-	0,00	-	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-	4,43	4,43	0,00	4,43	1,50	1,50
Oil	-	13,72	0,00	-	-	1,18	-	-	-	-	-	-	-	-	-	-	-	130,43	8,78	34,55	188,67	0,00	188,67	52,09	52,09
N.Gas	0,73	83,25	0,00	-	-	182,03	-	-	-	-	-169,85	-	-	-	-	-	-	36,19	84,53	71,63	288,51	0,00	288,51	59,91	61,83
Biomass	2,35	11,44	0,00	-	-	37,41	-	-	46,87	-	206,53	-	-	-	-	-	-	-	75,30	17,85	397,74	0,00	397,74	5,40	5,40
Renewable	-	-	-	-	-	-	129,50	-	-	-	-	-	70,50	153,01	-	50,50	14,27	-	-	-	417,79	0,00	417,79	0,00	0,00
H2 etc.	-	0,00	0,00	-	-	0,00	-	-	-	-56,31	-	6,12	-	-	-	-	-	17,69	23,00	9,50	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-26,38	-4,25	-	-	-	-	-	30,63	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	3,08	108,41	0,00	-	-	220,62	129,50	-	46,87	-56,31	10,30	1,87	70,50	153,01	-	50,50	14,27	214,94	191,61	137,96	1297,14	0,00	1297,14	118,90	120,82

18-novembre-2021 [14:21]

Figure A.4: EnergyPLAN simulation: PPBS 1



Input 2040_Scenario_2.txt

The EnergyPLAN model 15.0

Electricity demand (TWh/year):		Flexible demand	0,00
Fixed demand	269,20	Fixed imp/exp.	-28,22
Electric heating + HP	39,20	Transportation	50,33
Electric cooling	22,17	Total	352,67

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	5,58	25,56	0,00	31,14
Solar Thermal	0,00	0,00	0,00	0,00
Industrial CHP (CSHP)	0,00	-20,90	0,00	-20,90
Demand after solar and CSHP	5,58	46,46	0,00	52,04

Wind	38672	MW	70,88	TWh/year	0,00	Grid
Photo Voltaic	150560	MW	149,7	TWh/year	0,00	stabili-
Wave Power	0	MW	0	TWh/year	0,00	sation
River Hydro	22910	MW	54,37	TWh/year	0,00	share
Hydro Power	0	MW	0	TWh/year		
Geothermal/Nuclear	1725	MW	12,95	TWh/year		

	Capacities		Efficiencies		
Group 2:	MW-e	MJ/s	elec.	Ther	COP
CHP	23103	13290	0,41	0,24	
Heat Pump	0	1			3,57
Boiler		0		0,90	
Group 3:					
CHP	0	0	0,00	0,00	
Heat Pump	0	0			3,00
Boiler		0		0,90	
Condensing	0		0,00		

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

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,00	12,19
Gr.3:	0,00	0,00

Regulation Strategy:	Technical regulation no. 2	
CEEP regulation	0,0000001	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	10000	MW

Distr. Name :	Hour_nordpool.txt	
Addition factor	0,00	EUR/MWh
Multiplication factor	2,00	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	227	EUR/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	19336	MW

Fuel Price level: Basic

	Capacities	Storage	Efficiencies	
	MW-e	GWh	elec.	Ther.
Hydro Pump:	31147	103	0,92	
Hydro Turbine:	31147		0,92	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	5823	16000	0,66	
Ely. MicroCHP:	9709	0	1,00	
CAES fuel ratio:		0,000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	118,50	25,25	0,00
Household	0,00	8,62	98,27	73,96
Industry	4,43	14,90	67,05	5,60
Various	0,00	19,65	4,58	12,25

Output

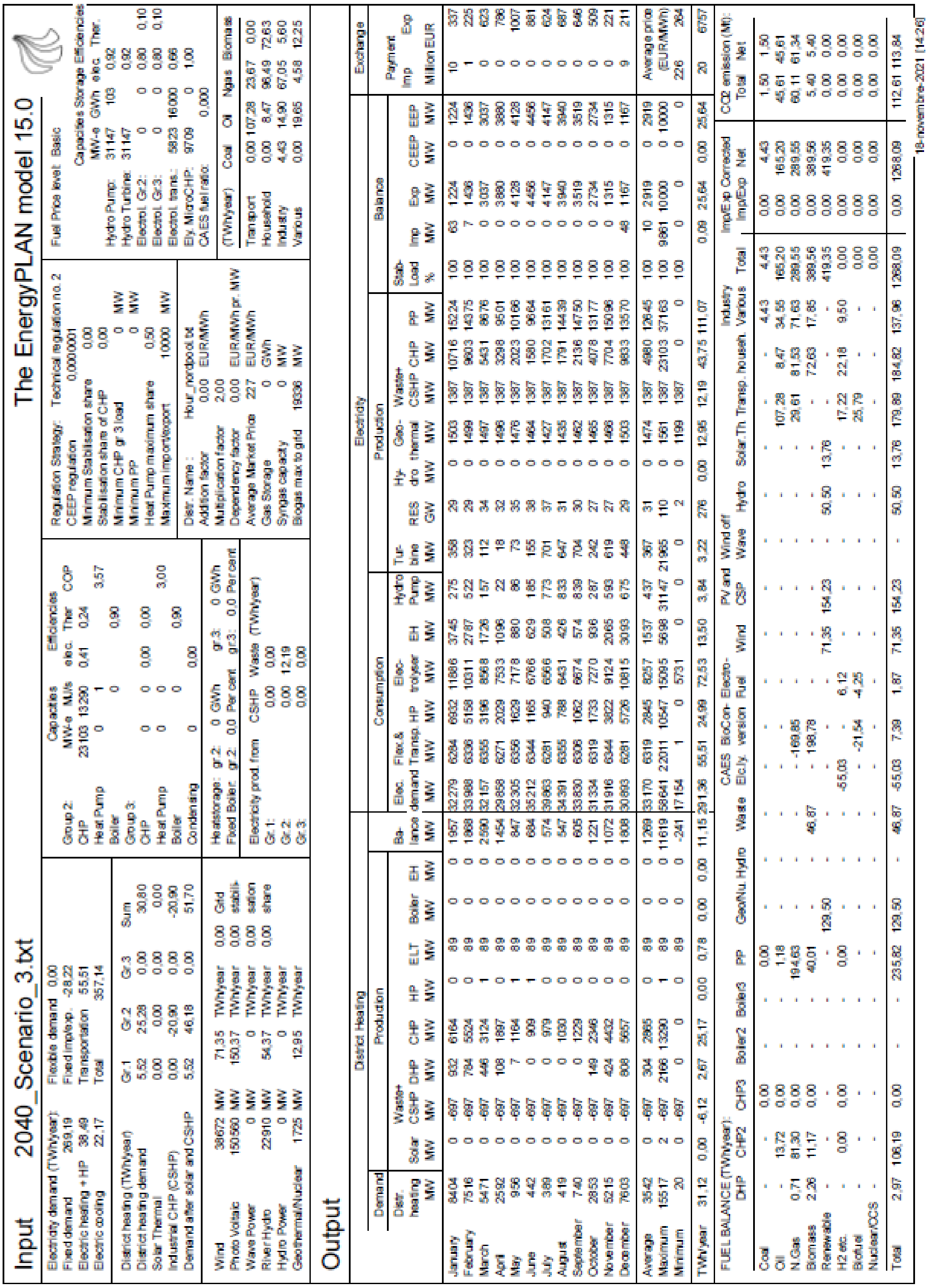
	District Heating: Demand	Production									Electricity: Consumption						Production							Balance					Exchange: Payment	
	Distr. heating	Solar	Waste+ CSHP	DHP	CHP	HP	ELT	Boiler	EH	Ba- lance	Elec. demand	Flex.& Transp.	HP	Elec- trolyser	EH	Hydro Pump	Tur- bine	RES	Hy- dro	Geo- thermal	Waste+ CSHP	CHP	PP	Stab- Load	Imp	Exp	CEEP	EEP	Imp	Exp
	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	GW	MW	MW	MW	MW	MW	%	MW	MW	MW	MW	Million EUR	
January	8496	0	-669	947	6243	0	89	0	0	1926	32280	5694	7059	12039	3814	244	332	29	0	1503	1387	10853	14999	100	41	1207	0	1207	6	335
February	7598	0	-669	797	5589	0	89	0	0	1843	33989	5746	5253	10436	2838	439	242	29	0	1499	1387	9716	14068	100	1	1419	0	1419	0	222
March	5531	0	-669	455	3163	1	89	0	0	2572	32158	5765	3254	8661	1758	72	51	34	0	1497	1387	5498	8203	100	0	3029	0	3029	0	622
April	2620	0	-669	111	1912	0	89	0	0	1434	29859	5681	2066	7606	1116	6	5	32	0	1496	1387	3324	8974	100	0	3877	0	3877	0	785
May	966	0	-669	7	1171	1	89	0	0	820	32306	5786	1659	7245	897	36	30	35	0	1476	1387	2036	9671	100	0	4127	0	4127	0	1007
June	446	0	-669	0	912	1	89	0	0	656	35213	5754	1186	6825	641	102	86	37	0	1464	1387	1586	9199	100	0	4461	0	4461	0	882
July	392	0	-669	0	981	0	89	0	0	547	39864	5691	958	6622	517	513	470	37	0	1427	1387	1706	12847	100	0	4148	0	4148	0	624
August	422	0	-669	0	1032	0	89	0	0	520	34392	5765	802	6484	433	513	391	31	0	1435	1387	1795	14142	100	0	3938	0	3938	0	687
September	747	0	-669	0	1234	0	89	0	0	578	33831	5716	1081	6732	584	556	466	29	0	1462	1387	2145	14439	100	0	3516	0	3516	0	646
October	2884	0	-669	153	2366	0	89	0	0	1198	31335	5729	1765	7339	954	160	134	27	0	1465	1387	4113	12741	100	0	2728	0	2728	0	508
November	5272	0	-669	434	4478	0	89	0	0	1045	31917	5754	3892	9227	2103	433	455	26	0	1466	1387	7784	14800	100	0	1302	0	1302	0	219
December	7687	0	-669	821	5734	0	89	0	0	1771	30894	5691	5831	10949	3151	622	433	29	0	1503	1387	9967	13267	100	7	1152	0	1152	1	208
Average	3581	0	-669	310	2895	0	89	0	0	1243	33170	5729	2897	8344	1565	308	258	31	0	1474	1387	5033	12274	100	4	2913	0	2913	Average price	
Maximum	15687	2	-669	2196	13290	1	89	0	0	11705	58642	19179	10741	15308	5804	31147	19391	110	0	1561	1387	23103	37163	100	6935	10000	0	10000	(EUR/MWh)	
Minimum	20	0	-669	0	0	0	89	0	0	-269	17154	1	0	5772	0	0	0	2	0	1199	1387	0	0	100	0	0	0	0	214	264
TWh/year	31,46	0,00	-5,88	2,72	25,43	0,00	0,78	0,00	0,00	10,92	291,37	50,33	25,45	73,29	13,75	2,70	2,27	275	0,00	12,95	12,19	44,21	107,82		0,04	25,59	0,00	25,59	8	6744

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon- version	Electro- Fuel	Wind	PV and CSP	Wind off Wave	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (Mt): Total	Net
Coal	-	-	0,00	-	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-	4,43	4,43	0,00	4,43	1,50	1,50
Oil	-	13,72	0,00	-	-	1,18	-	-	-	-	-	-	-	-	-	-	-	118,50	8,62	34,55	176,58	0,00	176,58	48,75	48,75
N.Gas	0,72	82,27	0,00	-	-	188,90	-	-	-	-	-169,85	-	-	-	-	-	-	32,80	83,03	71,63	289,50	0,00	289,50	60,11	61,67
Biomass	2,30	11,30	0,00	-	-	38,83	-	-	46,87	-	202,53	-	-	-	-	-	-	-	73,96	17,85	393,64	0,00	393,64	5,40	5,40
Renewable	-	-	-	-	-	-	129,50	-	-	-	-	-	70,88	153,56	-	50,50	14,02	-	-	-	418,47	0,00	418,47	0,00	0,00
H2 etc.	-	0,00	0,00	-	-	0,00	-	-	-	-55,67	-	6,12	-	-	-	-	-	17,45	22,59	9,50	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-23,89	-4,25	-	-	-	-	-	28,13	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	3,02	107,30	0,00	-	-	228,91	129,50	-	46,87	-55,67	8,80	1,87	70,88	153,56	-	50,50	14,02	196,89	188,20	137,96	1282,61	0,00	1282,61	115,75	117,32

18-novembre-2021 [14:24]

Figure A.5: EnergyPLAN simulation: PPBS 2



Input 2040_Scenario_3.txt — The EnergyPLAN model 15.0

Electricity demand (TWh/year):		Flexible demand	0,00
Fixed demand	269,19	Fixed imp/exp.	-28,22
Electric heating + HP	38,49	Transportation	55,51
Electric cooling	22,17	Total	357,14

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	5,52	25,28	0,00	30,80
Solar Thermal	0,00	0,00	0,00	0,00
Industrial CHP (CSHP)	0,00	-20,90	0,00	-20,90
Demand after solar and CSHP	5,52	46,18	0,00	51,70

Wind	38672 MW	71,35 TWh/year	0,00	Grid
Photo Voltaic	150560 MW	150,37 TWh/year	0,00	stabili-
Wave Power	0 MW	0 TWh/year	0,00	sation
River Hydro	22910 MW	54,37 TWh/year	0,00	share
Hydro Power	0 MW	0 TWh/year		
Geothermal/Nuclear	1725 MW	12,95 TWh/year		

	Capacities MW-e	MJ/s	Efficiencies elec.	Ther	COP
Group 2:					
CHP	23103	13290	0,41	0,24	
Heat Pump	0	1			3,57
Boiler		0		0,90	
Group 3:					
CHP	0	0	0,00	0,00	
Heat Pump	0	0			3,00
Boiler		0		0,90	
Condensing	0		0,00		

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

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,00	12,19
Gr.3:	0,00	0,00

Regulation Strategy:	Technical regulation no. 2
CEEP regulation	0,0000001
Minimum Stabilisation share	0,00
Stabilisation share of CHP	0,00
Minimum CHP gr 3 load	0 MW
Minimum PP	0 MW
Heat Pump maximum share	0,50
Maximum import/export	10000 MW
Distr. Name :	Hour_nordpool.txt
Addition factor	0,00 EUR/MWh
Multiplication factor	2,00
Dependency factor	0,00 EUR/MWh pr. MW
Average Market Price	227 EUR/MWh
Gas Storage	0 GWh
Syngas capacity	0 MW
Biogas max to grid	19336 MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Ther.
Hydro Pump:	31147	103	0,92	
Hydro Turbine:	31147		0,92	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	5823	16000	0,66	
Ely. MicroCHP:	9709	0	1,00	
CAES fuel ratio:		0,000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	107,28	23,67	0,00
Household	0,00	8,47	96,49	72,63
Industry	4,43	14,90	67,05	5,60
Various	0,00	19,65	4,58	12,25

Output

	District Heating Demand Distr. heating MW	Production Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba-lance MW	Electricity Consumption Elec. demand MW	Flex.& Transp. MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Production Tur-bine MW	RES GW	Hy-dro MW	Geo-thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Balance Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Exchange Payment Imp Million EUR	Exp Million EUR
January	8404	0	-697	932	6164	0	89	0	0	1957	32279	6284	6932	11886	3745	275	358	29	0	1503	1387	10716	15224	100	63	1224	0	1224	10	337
February	7516	0	-697	784	5524	0	89	0	0	1868	33988	6336	5158	10311	2787	522	323	29	0	1499	1387	9603	14375	100	7	1436	0	1436	1	225
March	5471	0	-697	446	3124	1	89	0	0	2590	32157	6355	3196	8568	1726	157	112	34	0	1497	1387	5431	8676	100	0	3037	0	3037	0	623
April	2592	0	-697	108	1897	0	89	0	0	1454	29858	6271	2029	7533	1096	22	18	32	0	1496	1387	3298	9501	100	0	3880	0	3880	0	786
May	956	0	-697	7	1164	1	89	0	0	847	32305	6356	1629	7178	880	86	73	35	0	1476	1387	2023	10166	100	0	4128	0	4128	0	1007
June	442	0	-697	0	909	1	89	0	0	684	35212	6344	1165	6766	629	185	155	38	0	1464	1387	1580	9664	100	0	4456	0	4456	0	881
July	389	0	-697	0	979	0	89	0	0	574	39863	6281	940	6566	508	773	701	37	0	1427	1387	1702	13161	100	0	4147	0	4147	0	624
August	419	0	-697	0	1030	0	89	0	0	547	34391	6355	788	6431	426	833	647	31	0	1435	1387	1791	14439	100	0	3940	0	3940	0	687
September	740	0	-697	0	1229	0	89	0	0	605	33830	6306	1062	6674	574	839	704	30	0	1462	1387	2136	14750	100	0	3519	0	3519	0	646
October	2853	0	-697	149	2346	0	89	0	0	1221	31334	6319	1733	7270	936	287	242	27	0	1465	1387	4078	13177	100	0	2734	0	2734	0	509
November	5215	0	-697	424	4432	0	89	0	0	1072	31916	6344	3822	9124	2065	593	619	27	0	1466	1387	7704	15096	100	0	1315	0	1315	0	221
December	7603	0	-697	808	5657	0	89	0	0	1808	30893	6281	5726	10815	3093	675	448	29	0	1503	1387	9833	13570	100	48	1167	0	1167	9	211
Average	3542	0	-697	304	2865	0	89	0	0	1269	33170	6319	2845	8257	1537	437	367	31	0	1474	1387	4980	12645	100	10	2919	0	2919	Average price (EUR/MWh)	
Maximum	15517	2	-697	2166	13290	1	89	0	0	11619	58641	22011	10547	15095	5698	31147	21965	110	0	1561	1387	23103	37163	100	9861	10000	0	10000		
Minimum	20	0	-697	0	0	0	89	0	0	-241	17154	1	0	5731	0	0	0	2	0	1199	1387	0	0	100	0	0	0	0	226	264
TWh/year	31,12	0,00	-6,12	2,67	25,17	0,00	0,78	0,00	0,00	11,15	291,36	55,51	24,99	72,53	13,50	3,84	3,22	276	0,00	12,95	12,19	43,75	111,07		0,09	25,64	0,00	25,64	20	6757

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Electro-Fuel	Wind	PV and CSP	Wind off Wave	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (Mt): Total	Net
Coal	-	-	0,00	-	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-	4,43	4,43	0,00	4,43	1,50	1,50
Oil	-	13,72	0,00	-	-	1,18	-	-	-	-	-	-	-	-	-	-	-	107,28	8,47	34,55	165,20	0,00	165,20	45,61	45,61
N.Gas	0,71	81,30	0,00	-	-	194,63	-	-	-	-	-169,85	-	-	-	-	-	-	29,61	81,53	71,63	289,55	0,00	289,55	60,11	61,34
Biomass	2,26	11,17	0,00	-	-	40,01	-	-	46,87	-	198,78	-	-	-	-	-	-	-	72,63	17,85	389,56	0,00	389,56	5,40	5,40
Renewable	-	-	-	-	-	-	129,50	-	-	-	-	-	71,35	154,23	-	50,50	13,76	-	-	-	419,35	0,00	419,35	0,00	0,00
H2 etc.	-	0,00	0,00	-	-	0,00	-	-	-	-55,03	-	6,12	-	-	-	-	-	17,22	22,18	9,50	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-21,54	-4,25	-	-	-	-	-	25,79	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	2,97	106,19	0,00	-	-	235,82	129,50	-	46,87	-55,03	7,39	1,87	71,35	154,23	-	50,50	13,76	179,89	184,82	137,96	1268,09	0,00	1268,09	112,61	113,84

18-novembre-2021 [14:26]

Figure A.6: EnergyPLAN simulation: PPBS 3

Input 2040_Scenario_4.txt

The EnergyPLAN model 15.0

Electricity demand (TWh/year):		Flexible demand	0,00
Fixed demand	269,20	Fixed imp/exp.	-28,22
Electric heating + HP	39,91	Transportation	43,60
Electric cooling	22,17	Total	346,66

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	5,64	25,84	0,00	31,48
Solar Thermal	0,00	0,00	0,00	0,00
Industrial CHP (CSHP)	0,00	-20,90	0,00	-20,90
Demand after solar and CSHP	5,64	46,74	0,00	52,38

Wind	38672	MW	70,37	TWh/year	0,00	Grid
Photo Voltaic	150560	MW	148,86	TWh/year	0,00	stabili-
Wave Power	0	MW	0	TWh/year	0,00	sation
River Hydro	22910	MW	54,37	TWh/year	0,00	share
Hydro Power	0	MW	0	TWh/year		
Geothermal/Nuclear	1725	MW	12,95	TWh/year		

	Capacities		Efficiencies		
Group 2:	MW-e	MJ/s	elec.	Ther	COP
CHP	23103	13290	0,41	0,24	
Heat Pump	0	1			3,57
Boiler		0		0,90	
Group 3:					
CHP	0	0	0,00	0,00	
Heat Pump	0	0			3,00
Boiler		0		0,90	
Condensing	0		0,00		

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

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,00	12,19
Gr.3:	0,00	0,00

Regulation Strategy:	Technical regulation no. 2	
CEEP regulation	0,0000001	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	10000	MW

Distr. Name :	Hour_nordpool.txt	
Addition factor	0,00	EUR/MWh
Multiplication factor	2,00	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	227	EUR/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	19336	MW

Fuel Price level: Basic

	Capacities	Storage	Efficiencies	
	MW-e	GWh	elec.	Ther.
Hydro Pump:	31147	103	0,92	
Hydro Turbine:	31147		0,92	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	5823	16000	0,66	
Ely. MicroCHP:	9709	0	1,00	
CAES fuel ratio:		0,000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	126,34	26,36	0,00
Household	0,00	8,78	100,04	75,30
Industry	4,43	14,90	67,05	5,60
Various	0,00	19,65	4,58	12,25

Output

	District Heating										Electricity																		Exchange	
	Demand	Production									Consumption						Production								Balance				Payment	
	Distr. heating MW	Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba- lance MW	Elec. demand MW	Flex.& Transp. MW	HP MW	Elec- trolyser MW	EH MW	Hydro Pump MW	Tur- bine MW	RES GW	Hy- dro MW	Geo- thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Stab- Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Imp Million EUR	Exp
January	8589	0	-650	963	6315	0	89	0	0	1911	32281	4928	7187	12119	3884	191	287	29	0	1503	1387	10977	14592	100	0	1192	0	1192	0	332
February	7681	0	-650	811	5647	0	89	0	0	1833	33990	4980	5348	10486	2890	360	167	29	0	1499	1387	9817	13534	100	0	1407	0	1407	0	220
March	5591	0	-650	465	3194	1	89	0	0	2571	32158	5000	3313	8680	1790	8	6	34	0	1497	1387	5552	7503	100	0	3026	0	3026	0	621
April	2649	0	-650	115	1925	0	89	0	0	1426	29859	4916	2103	7606	1137	0	0	32	0	1496	1387	3346	8225	100	0	3877	0	3877	0	785
May	976	0	-650	7	1176	1	89	0	0	804	32307	5000	1689	7238	913	5	4	34	0	1476	1387	2045	8947	100	0	4131	0	4131	0	1007
June	450	0	-650	0	914	1	89	0	0	638	35214	4989	1208	6810	653	41	34	37	0	1464	1387	1589	8509	100	0	4473	0	4473	0	883
July	396	0	-650	0	983	0	89	0	0	529	39864	4925	975	6604	527	237	222	36	0	1427	1387	1708	12336	100	0	4155	0	4155	0	625
August	426	0	-650	0	1034	0	89	0	0	502	34392	5000	817	6463	441	194	140	31	0	1435	1387	1798	13625	100	0	3940	0	3940	0	687
September	755	0	-650	0	1238	0	89	0	0	561	33832	4951	1101	6715	595	263	221	29	0	1462	1387	2151	13918	100	0	3515	0	3515	0	645
October	2915	0	-650	157	2383	0	89	0	0	1187	31335	4964	1797	7333	971	71	60	27	0	1465	1387	4142	12051	100	0	2726	0	2726	0	508
November	5329	0	-650	443	4519	0	89	0	0	1031	31918	4989	3962	9256	2141	233	248	26	0	1466	1387	7856	14284	100	0	1294	0	1294	0	217
December	7770	0	-650	835	5800	0	89	0	0	1753	30894	4926	5936	11009	3208	467	341	28	0	1503	1387	10083	12771	100	0	1140	0	1140	0	206
Average	3620	0	-650	316	2921	0	89	0	0	1229	33171	4964	2949	8357	1594	172	144	31	0	1474	1387	5078	11686	100	0	2910	0	2910	Average price	
Maximum	15858	2	-650	2227	13290	1	89	0	0	11800	58642	15505	10935	15447	5910	31147	16277	106	0	1561	1387	23103	37163	100	296	10000	0	10000	(EUR/MWh)	
Minimum	20	0	-650	0	0	0	89	0	0	-288	17155	1	0	5738	0	0	0	2	0	1199	1387	0	0	100	0	0	0	0	230	264
TWh/year	31,80	0,00	-5,71	2,77	25,66	0,00	0,78	0,00	0,00	10,80	291,37	43,60	25,91	73,40	14,00	1,51	1,27	274	0,00	12,95	12,19	44,60	102,65		0,00	25,56	0,00	25,56	0	6738

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon- version	Electro- Fuel	Wind	PV and CSP	Wind off Wave	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (Mt): Total	Net
Coal	-	-	0,00	-	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-	4,43	4,43	0,00	4,43	1,50	1,50
Oil	-	13,72	0,00	-	-	1,18	-	-	-	-	-	-	-	-	-	-	-	126,34	8,78	34,55	184,58	0,00	184,58	50,96	50,96
N.Gas	0,73	83,12	0,00	-	-	179,81	-	-	-	-	-169,85	-	-	-	-	-	-	35,02	84,53	71,63	285,00	0,00	285,00	59,18	60,98
Biomass	2,35	11,42	0,00	-	-	36,96	-	-	46,87	-	205,16	-	-	-	-	-	-	-	75,30	17,85	395,90	0,00	395,90	5,40	5,40
Renewable	-	-	-	-	-	-	129,50	-	-	-	-	-	70,37	152,73	-	50,50	14,27	-	-	-	417,36	0,00	417,36	0,00	0,00
H2 etc.	-	0,00	0,00	-	-	0,00	-	-	-	-55,88	-	6,12	-	-	-	-	-	17,26	23,00	9,50	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-25,53	-4,25	-	-	-	-	-	29,77	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	3,08	108,26	0,00	-	-	217,94	129,50	-	46,87	-55,88	9,78	1,87	70,37	152,73	-	50,50	14,27	208,40	191,61	137,96	1287,27	0,00	1287,27	117,04	118,83

18-novembre-2021 [14:26]

Figure A.7: EnergyPLAN simulation: PPBS 4

Input 2040_Scenario_5.txt — The EnergyPLAN model 15.0

Electricity demand (TWh/year):			
Fixed demand	269,20	Flexible demand	0,00
Electric heating + HP	39,20	Fixed imp/exp.	-28,22
Electric cooling	22,17	Transportation	48,88
		Total	351,22

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	5,58	25,56	0,00	31,14
Solar Thermal	0,00	0,00	0,00	0,00
Industrial CHP (CSHP)	0,00	-20,90	0,00	-20,90
Demand after solar and CSHP	5,58	46,46	0,00	52,04

Wind	38672	MW	70,70	TWh/year	0,00	Grid
Photo Voltaic	150560	MW	149,29	TWh/year	0,00	stabili-
Wave Power	0	MW	0	TWh/year	0,00	sation
River Hydro	22910	MW	54,37	TWh/year	0,00	share
Hydro Power	0	MW	0	TWh/year		
Geothermal/Nuclear	1725	MW	12,95	TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	Efficiencies COP
Group 2:					
CHP	23103	13290	0,41	0,24	
Heat Pump	0	1			3,57
Boiler		0		0,90	
Group 3:					
CHP	0	0	0,00	0,00	
Heat Pump	0	0			3,00
Boiler		0		0,90	
Condensing	0		0,00		

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

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,00	12,19
Gr.3:	0,00	0,00

Regulation Strategy:	Technical regulation no. 2	
CEEP regulation	0,0000001	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	10000	MW
Distr. Name :	Hour_nordpool.txt	
Addition factor	0,00	EUR/MWh
Multiplication factor	2,00	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	227	EUR/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	19336	MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Efficiencies Ther.
Hydro Pump:	31147	103	0,92	
Hydro Turbine:	31147		0,92	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	5823	16000	0,66	
Ely. MicroCHP:	9709	0	1,00	
CAES fuel ratio:		0,000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	115,18	24,78	0,00
Household	0,00	8,62	98,27	73,96
Industry	4,43	14,90	67,05	5,60
Various	0,00	19,65	4,58	12,25

Output

District Heating

	Demand: Distr. heating MW	Production: Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba-lance MW
January	8496	0	-677	947	6236	0	89	0	0	1941
February	7598	0	-677	797	5583	0	89	0	0	1857
March	5531	0	-677	455	3156	1	89	0	0	2588
April	2620	0	-677	111	1910	0	89	0	0	1445
May	966	0	-677	7	1169	1	89	0	0	831
June	446	0	-677	0	911	1	89	0	0	666
July	392	0	-677	0	981	0	89	0	0	556
August	422	0	-677	0	1032	0	89	0	0	529
September	747	0	-677	0	1232	0	89	0	0	588
October	2884	0	-677	153	2363	0	89	0	0	1210
November	5272	0	-677	434	4473	0	89	0	0	1058
December	7687	0	-677	821	5724	0	89	0	0	1789
Average	3581	0	-677	310	2891	0	89	0	0	1255
Maximum	15687	2	-677	2196	13290	1	89	0	0	11714
Minimum	20	0	-677	0	0	0	89	0	0	-261
TWh/year	31,46	0,00	-5,95	2,72	25,40	0,00	0,78	0,00	0,00	11,02

Electricity / Exchange

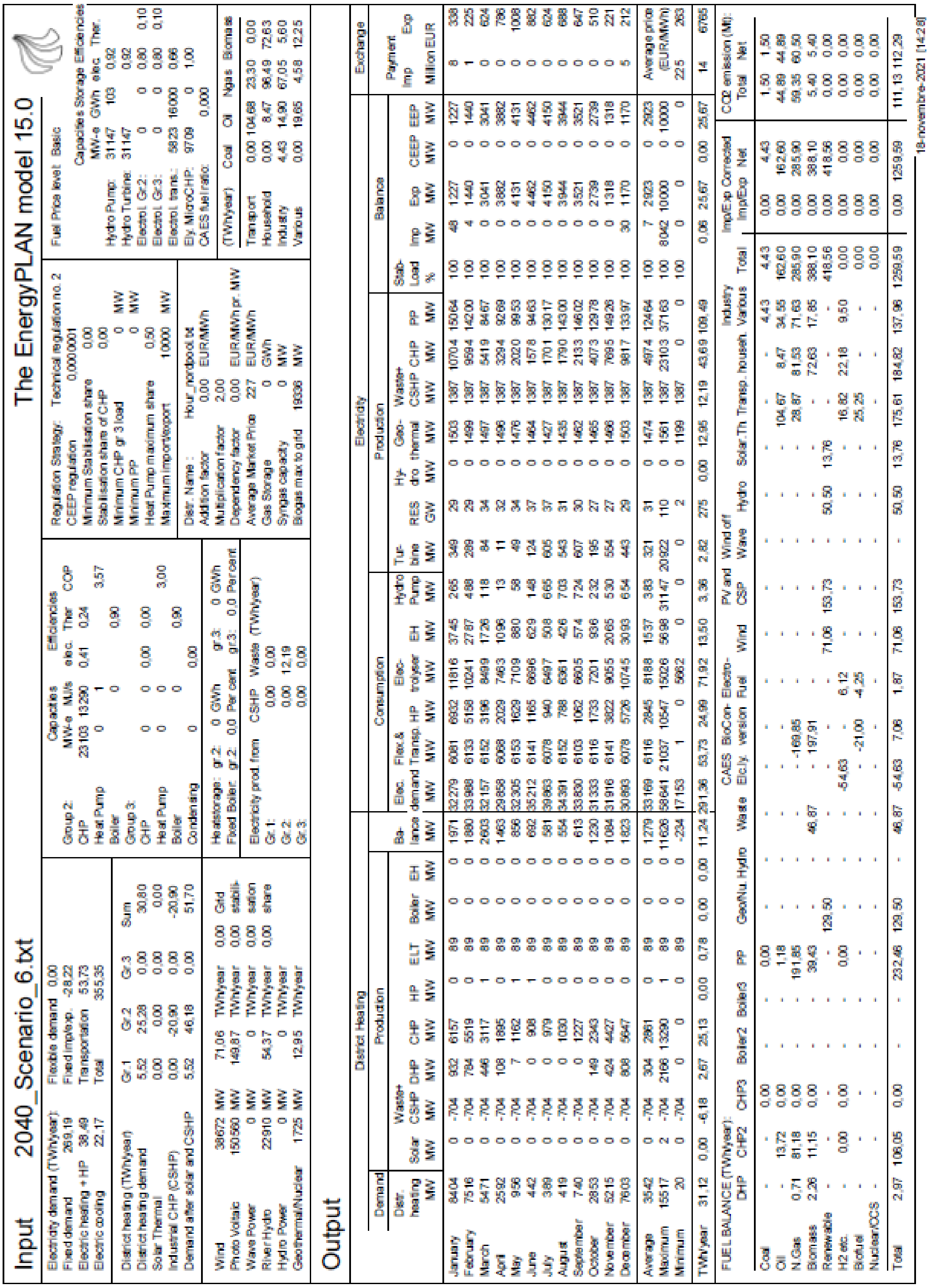
	Consumption: Elec. demand MW	Flex.& Transp. MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Production: Tur-bine MW	RES GW	Hy-dro MW	Geo-thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Balance: Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Exchange Payment Imp Million EUR	Exp Million EUR
January	32280	5529	7059	11968	3814	241	329	29	0	1503	1387	10841	14854	100	28	1210	0	1210	4	335
February	33989	5581	5253	10364	2838	416	221	29	0	1499	1387	9705	13901	100	0	1423	0	1423	0	223
March	32158	5600	3254	8589	1758	52	36	34	0	1497	1387	5486	8017	100	0	3033	0	3033	0	622
April	29859	5516	2066	7534	1116	4	3	32	0	1496	1387	3320	8773	100	0	3880	0	3880	0	786
May	32306	5600	1659	7173	897	27	22	34	0	1476	1387	2032	9477	100	0	4131	0	4131	0	1007
June	35213	5589	1186	6753	641	82	69	37	0	1464	1387	1584	9019	100	0	4467	0	4467	0	883
July	39864	5525	958	6550	517	440	404	37	0	1427	1387	1705	12709	100	0	4152	0	4152	0	624
August	34392	5600	802	6412	433	425	321	31	0	1435	1387	1794	14007	100	0	3942	0	3942	0	688
September	33831	5551	1081	6660	584	476	399	29	0	1462	1387	2142	14299	100	0	3518	0	3518	0	646
October	31334	5564	1765	7267	954	133	111	27	0	1465	1387	4107	12554	100	0	2733	0	2733	0	509
November	31917	5589	3892	9155	2103	374	396	26	0	1466	1387	7776	14642	100	0	1306	0	1306	0	219
December	30894	5526	5831	10877	3151	594	419	29	0	1503	1387	9951	13115	100	5	1155	0	1155	1	209
Average	33170	5564	2897	8272	1565	271	228	31	0	1474	1387	5026	12109	100	3	2917	0	2917	Average price	
Maximum	58641	18386	10741	15237	5804	31147	18848	110	0	1561	1387	23103	37163	100	5596	10000	0	10000	(EUR/MWh)	
Minimum	17154	1	0	5700	0	0	0	2	0	1199	1387	0	0	100	0	0	0	0	217	264
TWh/year	291,37	48,88	25,45	72,66	13,75	2,38	2,00	274	0,00	12,95	12,19	44,15	106,36		0,02	25,62	0,00	25,62	5	6751

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Electro-Fuel	Wind	PV and CSP	Wind off Wave	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (Mt): Total	Net
Coal	-	-	0,00	-	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-	4,43	4,43	0,00	4,43	1,50	1,50
Oil	-	13,72	0,00	-	-	1,18	-	-	-	-	-	-	-	-	-	-	-	115,18	8,62	34,55	173,26	0,00	173,26	47,83	47,83
N.Gas	0,72	82,15	0,00	-	-	186,35	-	-	-	-	-169,85	-	-	-	-	-	-	31,85	83,03	71,63	285,87	0,00	285,87	59,35	60,82
Biomass	2,30	11,28	0,00	-	-	38,30	-	-	46,87	-	201,42	-	-	-	-	-	-	-	73,96	17,85	391,99	0,00	391,99	5,40	5,40
Renewable	-	-	-	-	-	-	129,50	-	-	-	-	-	70,70	153,15	-	50,50	14,02	-	-	-	417,87	0,00	417,87	0,00	0,00
H2 etc.	-	0,00	0,00	-	-	0,00	-	-	-	-55,25	-	6,12	-	-	-	-	-	17,04	22,59	9,50	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-23,19	-4,25	-	-	-	-	-	27,44	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	3,02	107,15	0,00	-	-	225,83	129,50	-	46,87	-55,25	8,38	1,87	70,70	153,15	-	50,50	14,02	191,51	188,20	137,96	1273,42	0,00	1273,42	114,08	115,55

18-novembre-2021 [14:27]

Figure A.8: EnergyPLAN simulation: PPBS 5



Input 2040_Scenario_6.txt The EnergyPLAN model 15.0

Electricity demand (TWh/year): Flexible demand 0,00
Fixed demand 269,19 Fixed imp/exp. -28,22
Electric heating + HP 38,49 Transportation 53,73
Electric cooling 22,17 Total 355,35

	Gr.1	Gr.2	Gr.3	Sum
District heating (TWh/year)				
District heating demand	5,52	25,28	0,00	30,80
Solar Thermal	0,00	0,00	0,00	0,00
Industrial CHP (CSHP)	0,00	-20,90	0,00	-20,90
Demand after solar and CSHP	5,52	46,18	0,00	51,70

Wind	38672 MW	71,06 TWh/year	0,00	Grid
Photo Voltaic	150560 MW	149,87 TWh/year	0,00	stabili-
Wave Power	0 MW	0 TWh/year	0,00	sation
River Hydro	22910 MW	54,37 TWh/year	0,00	share
Hydro Power	0 MW	0 TWh/year		
Geothermal/Nuclear	1725 MW	12,95 TWh/year		

	Capacities MW-e	MJ/s	Efficiencies elec.	Ther	COP
Group 2:					
CHP	23103	13290	0,41	0,24	
Heat Pump	0	1			3,57
Boiler		0		0,90	
Group 3:					
CHP	0	0	0,00	0,00	
Heat Pump	0	0			3,00
Boiler		0		0,90	
Condensing	0		0,00		

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

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,00	12,19
Gr.3:	0,00	0,00

Regulation Strategy: Technical regulation no. 2
CEEP regulation 0,0000001
Minimum Stabilisation share 0,00
Stabilisation share of CHP 0,00
Minimum CHP gr 3 load 0 MW
Minimum PP 0 MW
Heat Pump maximum share 0,50
Maximum import/export 10000 MW

Distr. Name : Hour_nordpool.txt
Addition factor 0,00 EUR/MWh
Multiplication factor 2,00
Dependency factor 0,00 EUR/MWh pr. MW
Average Market Price 227 EUR/MWh
Gas Storage 0 GWh
Syngas capacity 0 MW
Biogas max to grid 19336 MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Ther.
Hydro Pump:	31147	103	0,92	
Hydro Turbine:	31147		0,92	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	5823	16000	0,66	
Ely. MicroCHP:	9709	0	1,00	
CAES fuel ratio:		0,000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	104,68	23,30	0,00
Household	0,00	8,47	96,49	72,63
Industry	4,43	14,90	67,05	5,60
Various	0,00	19,65	4,58	12,25

Output

	District Heating Demand: Distr. heating MW	Production: Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba-lance MW	Electricity Consumption: Elec. demand MW	Flex.& Transp. MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Production: Tur-bine MW	RES GW	Hy-dro MW	Geo-thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Stab-Load %	Balance: Imp MW	Exp MW	CEEP MW	EEP MW	Exchange Payment Imp Million EUR	Exp Million EUR
January	8404	0	-704	932	6157	0	89	0	0	1971	32279	6081	6932	11816	3745	265	349	29	0	1503	1387	10704	15064	100	48	1227	0	1227	8	338
February	7516	0	-704	784	5519	0	89	0	0	1880	33988	6133	5158	10241	2787	488	289	29	0	1499	1387	9594	14200	100	4	1440	0	1440	1	225
March	5471	0	-704	446	3117	1	89	0	0	2603	32157	6152	3196	8499	1726	118	84	34	0	1497	1387	5419	8467	100	0	3041	0	3041	0	624
April	2592	0	-704	108	1895	0	89	0	0	1463	29858	6068	2029	7463	1096	13	11	32	0	1496	1387	3294	9269	100	0	3882	0	3882	0	786
May	956	0	-704	7	1162	1	89	0	0	856	32305	6153	1629	7109	880	58	49	34	0	1476	1387	2020	9953	100	0	4131	0	4131	0	1008
June	442	0	-704	0	908	1	89	0	0	692	35212	6141	1165	6696	629	148	124	37	0	1464	1387	1578	9463	100	0	4462	0	4462	0	882
July	389	0	-704	0	979	0	89	0	0	581	39863	6078	940	6497	508	665	605	37	0	1427	1387	1701	13017	100	0	4150	0	4150	0	624
August	419	0	-704	0	1030	0	89	0	0	554	34391	6152	788	6361	426	703	543	31	0	1435	1387	1790	14300	100	0	3944	0	3944	0	688
September	740	0	-704	0	1227	0	89	0	0	613	33830	6103	1062	6605	574	724	607	30	0	1462	1387	2133	14602	100	0	3521	0	3521	0	647
October	2853	0	-704	149	2343	0	89	0	0	1230	31333	6116	1733	7201	936	232	195	27	0	1465	1387	4073	12978	100	0	2739	0	2739	0	510
November	5215	0	-704	424	4427	0	89	0	0	1084	31916	6141	3822	9055	2065	530	554	27	0	1466	1387	7695	14926	100	0	1318	0	1318	0	221
December	7603	0	-704	808	5647	0	89	0	0	1823	30893	6078	5726	10745	3093	654	443	29	0	1503	1387	9817	13397	100	30	1170	0	1170	5	212
Average	3542	0	-704	304	2861	0	89	0	0	1279	33169	6116	2845	8188	1537	383	321	31	0	1474	1387	4974	12464	100	7	2923	0	2923	Average price	
Maximum	15517	2	-704	2166	13290	1	89	0	0	11626	58641	21037	10547	15026	5698	31147	20922	110	0	1561	1387	23103	37163	100	8042	10000	0	10000	(EUR/MWh)	
Minimum	20	0	-704	0	0	0	89	0	0	-234	17153	1	0	5682	0	0	0	2	0	1199	1387	0	0	100	0	0	0	0	225	263
TWh/year	31,12	0,00	-6,18	2,67	25,13	0,00	0,78	0,00	0,00	11,24	291,36	53,73	24,99	71,92	13,50	3,36	2,82	275	0,00	12,95	12,19	43,69	109,49		0,06	25,67	0,00	25,67	14	6765

FUEL BALANCE (TWh/year):	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Electro-Fuel	Wind	PV and CSP	Wind off Wave	Hydro	Solar.Th	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (Mt): Total	Net
Coal	-	-	0,00	-	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-	4,43	4,43	0,00	4,43	1,50	1,50
Oil	-	13,72	0,00	-	-	1,18	-	-	-	-	-	-	-	-	-	-	-	104,67	8,47	34,55	162,60	0,00	162,60	44,89	44,89
N.Gas	0,71	81,18	0,00	-	-	191,85	-	-	-	-	-169,85	-	-	-	-	-	-	28,87	81,53	71,63	285,90	0,00	285,90	59,35	60,50
Biomass	2,26	11,15	0,00	-	-	39,43	-	-	46,87	-	197,91	-	-	-	-	-	-	-	72,63	17,85	388,10	0,00	388,10	5,40	5,40
Renewable	-	-	-	-	-	-	129,50	-	-	-	-	-	71,06	153,73	-	50,50	13,76	-	-	-	418,56	0,00	418,56	0,00	0,00
H2 etc.	-	0,00	0,00	-	-	0,00	-	-	-	-54,63	-	6,12	-	-	-	-	-	16,82	22,18	9,50	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-21,00	-4,25	-	-	-	-	-	25,25	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	2,97	106,05	0,00	-	-	232,46	129,50	-	46,87	-54,63	7,06	1,87	71,06	153,73	-	50,50	13,76	175,61	184,82	137,96	1259,59	0,00	1259,59	111,13	112,29

18-novembre-2021 [14:28]

Figure A.9: EnergyPLAN simulation: PPBS 6

Bibliography

[1] Francesco Gracceva, Bruno Baldissara, Alessandro Zini, Andrea Colosimo, E. Bompard. E. Desogus, and D. Grosso anmd S. Lo Russo. *Analisi trimestrale del SISTEMA ENERGETICO ITALIANO - Anno 2020*. ENEA, 2021 (cit. on pp. 1, 12).

[2] Assolombardia. *Lo smart working in numeri*. Rapporto n° 04/2021 (cit. on pp. 1, 13, 76, 78).

[3] Masson-Delmotte V. et al. *Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. IPCC, 2021 (cit. on pp. 1, 15).

[4] *Piano nazionale di ripresa e resilienza (PNRR) - Italia domani*. Italy: Ministro dell'Economia e delle Finanze, 2021 (cit. on p. 1).

[5] Microsoft Corporation. *Microsoft Excel*. Version 2019 (16.0). Sept. 24, 2018. URL: `https://office.microsoft.com/excel` (cit. on p. 2).

[6] Henrik Lund and Jakob Zinck Thellufsen. *EnergyPLAN Advanced Energy Systems Analysis Computer Model*. Documentation Version 15. Denmark: Sustainable Energy Planning Research Group, Sept. 2019 (cit. on pp. 2, 22, 23).

[7] *Eurostat - National Energy Balances https://ec.europa.eu/eurostat/web/energy/data/energy-balances*. Online (cit. on pp. 4–8, 10, 24–33, 38, 39, 72, 73).

[8] *IEA Total CO2 Emissions - https://www.iea.org/data-and-statistics?country=ITALY&fuel=Key%20indicators&indicator=Total%20CO2%20emissions*. Online (cit. on pp. 4, 11, 33).

[9] *TERNA - Transparency report: Dashboard https://www.terna.it/en/electric-system/transparency-report*. Online (cit. on pp. 4, 24, 25, 29, 30).

[10] *IEA Total Primary Energy Supply - https://www.iea.org/countries/italy*. Online (cit. on pp. 5, 33).

[11] *TERNA - THE EVOLUTION OF THE ELECTRICITY MARKET - https://www.terna.it/en/electric-system/statistical-data-forecast/evolution-electricity-market.* Online (cit. on p. 9).

[12] *Global Energy Review 2021.* IEA, Apr. 2021 (cit. on pp. 11, 12).

[13] *Global Energy Review 2020.* IEA, Apr. 2020 (cit. on p. 11).

[14] *Covid-19 impact on electricity.* IEA, 2021 (cit. on p. 12).

[15] *Global Energy Review: CO2 Emissions in 2020.* IEA, 2021 (cit. on p. 12).

[16] *Google - COVID-19 Community Mobility Reports - https://data-explorer.it/mobilita/google/.* Online (cit. on pp. 13, 14).

[17] Thijs Bouman, Linda Steg, and Thomas Dietz. *Insights from early COVID-19 responses about promoting sustainable action.* Apr. 2021 (cit. on pp. 14, 72, 79, 80).

[18] Copernicus Atmosphere Monitoring Service (CAMS). *https://atmosphere.copernicus.eu/* (cit. on pp. 14, 15).

[19] ECMWF - European Centre for Medium-Range Weather Forecasts. *https://www.ecmwf.int/* (cit. on p. 15).

[20] *Climate Watch Historical GHG Emissions.* Washington, DC: World Resources Institute, Available online at: https://www.climatewatchdata.org/ghg-emissions, 2021 (cit. on p. 16).

[21] *European Union 2020, Energy Policy Review.* IEA, June 2021 (cit. on p. 16).

[22] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT THE EUROPEAN COUNCIL THE COUNCIL THE EUROPEAN ECONOMIC, SOCIAL COMMITTEE, and THE COMMITTEE OF THE REGIONS. *The European Green Deal.* Brussel, BE: European Commission, Dec. 2019 (cit. on p. 18).

[23] *Integrated National Energy and Climate Plan.* Italy: Ministry of Economic Development Ministry of the Environment Protection of Natural Resources, the Sea Ministry of Infrastructure, and Transport, Dec. 2019 (cit. on pp. 19, 41, 78).

[24] S. Bellocchi, M. Manno, M. Noussan, M. G. Prina, and M. Vellini. *Electrification of transport and residential heating sectors in support of renewable penetration: Scenarios for the Italian energy system.* Italy, 2020 (cit. on pp. 24–26, 28, 29, 32).

[25] Sara Bellocchi, Marco Gambini, Michele Manno, Tommaso Stilo, and Michela Vellini. *Positive interactions between electric vehicles and renewable energy sources in CO2-reduced energy scenarios: The Italian case*. Italy: Dept. of Industrial Engineering, University of Rome Tor Vergata, July 2018 (cit. on pp. 24–30, 53).

[26] Paardekooper S. et al. *Heat Roadmap Europe 4: Quantifying the Impact of Low-Carbon Heating and Cooling Roadmaps*. Aalborg Universitet, 2018 (cit. on pp. 24–27, 36, 42, 62, 63, 67, 82).

[27] Martina Bembi. *Analisi del sistema energetico italiano: modellazione degli effetti a breve termine del Covid-19*. Master thesis. Turin, Italy: Politecnico di Torino and ENEA, Oct. 2020 (cit. on pp. 24, 32).

[28] *Snam web site - https://www.snam.it/it/media/*. Online (cit. on pp. 25–27).

[29] *Il riscaldamento urbano - annuario 2019*. n.65. Italy: AIRU, Dec. 2019 (cit. on pp. 26, 27, 31, 39).

[30] TERNA. *DATI STATISTICI SULL'ENERGIA ELETTRICA IN ITALIA 2018*. Italy: TERNA s.p.a. e gruppo TERNA, 2019 (cit. on pp. 28–30, 62).

[31] *ISPRA - Fattori di emissione per la produzione ed il consumo di energia elettrica in Italia - http://www.sinanet.isprambiente.it/it/sia-ispra/serie-storiche-emissio ni/fattori-di-emissione-per-la-produzione-ed-il-consumo-di-energia-elettrica-in- italia/view*. Online (cit. on pp. 32, 83).

[32] Tobias Fleiter et al. *Heat Roadmap Europe 4: Baseline scenario of the heating and cooling demand in buildings and industry in the 14 MSs until 2050*. Aalborg Universitet, Aug. 2017 (cit. on p. 36).

[33] Alice Dénarié, Fabrizio Fattori, Mario Motta, Giulia Spirito Vincenzo Francesco Cirillo, Samuel Macchi, Marianna Pozzi, Mauro Montrucchio, and Vittorio Verda. *Valutazione del potenziale di diffusione del teleriscaldamento efficiente sul territorio nazionale*. Milan, Italy: Politecnico di Milano, Politecnico di Torino commissioned by AIRU, and UTILITALIA, Dec. 2019 (cit. on pp. 40, 62).

[34] The European House - Ambrosetti. *H2 ITALY 2050 - Una filiera nazionale dell'idrogeno per la crescita e la decarbonizzazione dell'Italia*. Snam, Sept. 2020 (cit. on pp. 42, 50, 56, 66).

[35] Micah Sweeney, Jeff Dols, Brian Fortenbery, and Frank Sharp. *Induction Cooking Technology Design and Assessment*. Electric Power Research Institute, 2014 (cit. on p. 45).

[36] *STRATEGIA ITALIANA DI LUNGO TERMINE SULLA RIDUZIONE DELLE EMISSIONI DEI GAS A EFFETTO SERRA*. Italy: Ministero dell'Ambiente e della Tutela del Territorio e del Mare, Ministero dello Sviluppo Economico, Ministero delle Infrastrutture e dei Trasporti, Ministero delle Politiche agricole, Alimentari e Forestali, Jan. 2021 (cit. on p. 46).

[37] *Previsioni di domanda energetica e petrolifera italiana 2019-2040*. Roma, Italy: unione petrolifera, 2019 (cit. on pp. 49, 72, 78, 83).

[38] José Rodríguez-Fernández, Juan José Hernández, Alejandro Calle-Asensio, Ángel Ramos, and Javier Barba. *Selection of Blends of Diesel Fuel and Advanced Biofuels Based on Their Physical and Thermochemical Properties*. Universidad de Castilla-La Mancha, May 2019 (cit. on p. 50).

[39] Aiman ALBATAYNEH, Mohammad N. ASSAF, Dariusz ALTERMAN, and Mustafa JARADAT. *Comparison of the Overall Energy Efficiency for Internal Combustion Engine Vehicles and Electric Vehicles*. 2020 (cit. on p. 50).

[40] *Roadmap to decarbonising European aviation*. Brussel: Transport and Environment, Oct. 2018 (cit. on p. 52).

[41] *Roadmap to decarbonising European shipping*. Brussel: Transport and Environment, Oct. 2018 (cit. on p. 52).

[42] IEA. *World Energy Outlook 2020*. Paris, France: OECD Publishing, 2020 (cit. on pp. 55, 72, 83).

[43] IEA. *World Energy Model documentation*. May 2021 (cit. on p. 55).

[44] IEA. *Energy Technology Prospective 2020*. Paris, France, 2020 (cit. on pp. 57, 68).

[45] Alberto Gelmini. *Webinair: Scenari energetici. L'Italia, con l'Europa, alla sfida della decarbonizzazione; Presentation: La decarbonizzazione del sistema energetico italiano, Impatto sul sistema elettrico degli scenari al 2050*. RSE, Dec. 2020 (cit. on p. 61).

[46] *Waste-to-energy sustainability roadmap - Towards 2035*. Brussel: CEWEP, 2019 (cit. on p. 63).

[47] *Calculation on residual waste in 2035*. Brussel: CEWEP, July 2019 (cit. on p. 64).

[48] OSSERVATORIO Sistemi di Accumulo. *ELABORAZIONE ANIE RINNOVABILI DATI GAUDì FONTE TERNA*. ANIE Rinnovabili, Mar. 2021 (cit. on p. 66).

[49] Dr Agr Stefano Bozzetto, Eng Christian Curlisi, Dr Claudio Fabbri, Eng Marco Pezzaglia, Dr Agr. Lorella Rossi, and Dr Fabrizio Sibilla. *THE DEVELOPMENT OF BIOMETHANE: A SUSTAINABLE CHOICE FOR THE ECONOMY AND THE ENVIRONMENT*. CIB Consorzio Italiano Biogas, Feb. 2017 (cit. on p. 67).

[50] IEA. *Net Zero by 2050 - A Roadmap for the Global Energy Sector*. Oct. 2021 (cit. on p. 72).

[51] Marina Colaiezzi. *Webinair: Il settore dei trasporti: scenari emissivi ed energetici*. ISPRA, Apr. 2021 (cit. on p. 73).

[52] *European Parliament resolution of 13 September 2016 on creating labour market conditions favourable for work-life balance (2016/2017(INI))*. European Parliament, Sept. 2016 (cit. on p. 74).

[53] Chrisalena Athanasiadou and Georgios Theriou. *Telework: systematic literature review and future research agenda*. Kavala, Greece: Management Science and Technology Department, International Hellenic University, 2021 (cit. on p. 74).

[54] The European Commission's science and knowledge service. *Telework in the EU before and after the COVID-19: where we were, where we head to*. European Union, 2020 (cit. on pp. 75, 76).

[55] Rada Business. *The new art of business*. Royal Academy of Dramatic Art, 2021 (cit. on p. 75).

[56] Daniela Loi. *The impact of teleworking and digital work on workers and society - Annex VI - Case study on Italy*. Policy Department for Economic, Scientific and Quality of Life Policies - European Parliament, Apr. 2021 (cit. on pp. 75, 77).

[57] Manuela SAMEK LODOVICI et al. *The impact of teleworking and digital work on workers and society - Special focus on surveillance and monitoring, as well as on mental health of workers*. Policy Department for Economic, Scientific and Quality of Life Policies - European Parliament, Apr. 2021 (cit. on pp. 75, 76).

[58] Eurofound and International Labour Office (ILO). *Working anytime, anywhere: The effects onthe world of work*. Publications Office of the European Union, 2017 (cit. on pp. 75, 76).

[59] OECD. *Productivity gains from teleworking in the post COVID-19 era: How can public policies make it happen?* Publications Office of the European Union, Sept. 2020 (cit. on pp. 76, 78).

[60] William O'Brien and Fereshteh Yazdani Aliabadi. *Does telecommuting save energy? A critical review of quantitative studies and their research methods.* Department of Civil and Environmental Engineering, Carleton University, July 2020 (cit. on p. 78).

[61] ISFORT. *17° Rapporto sulla mobilità degli italiani - Tra gestione del presente e strategie per il futuro.* Nov. 2020 (cit. on p. 78).

[62] Jessica Long, Lizzie Gordon, and Ruth Townend. *NOW WHAT? CLIMATE CHANGE & CORONAVIRUS.* IPSOS, June 2020 (cit. on pp. 80, 81).

[63] Behnam Zakeri, Katsia Paulavets, Leonardo Barreto-Gomez, and Luis Gomez Echeverri. *Transformations within reach: Pathways to a sustainable and resilient world - Rethinking energy solutions.* International Institute for Applied Systems Analysis - International Science Council, Nov. 2020 (cit. on p. 81).