Dataset and description of an

ENERGYPLAN MODEL OF THE ITALIAN ENERGY SYSTEM IN 2017

last update: January 16, 2020

Sara Bellocchi, Michele Manno
Department of Industrial Engineering
University of Rome Tor Vergata
sara.bellocchi@uniroma2.it, michele.manno@uniroma2.it

Contents

List of Figures

List of Tables

Introduction

This document illustrates the methodology followed and the set of data implemented by the authors to fully characterise the Italian energy system in 2017. Such reference scenario was modelled with EnergyPLAN and validated against crucial energy indicators with respect to the same year, i.e. CO_2 emissions, Total Primary Energy Supply (TPES), electricity generation from Renewable Energy Sources (RES) and conventional power plants. The present document and the full data-set are available on the open-access repository Zenodo [1].

EnergyPLAN allows the characterisation of a whole energy system with respect to a certain region or country; different scenarios can be created and compared with respect to energy and/or economical indicators by modifying input data related to the various energy sectors (e.g. installed capacity, fuel distribution, user demand, etc.). The software is an input/output model of an energy system and includes a wide range of technologies with a particular attention to the synergies and interactions that can be exploited among energy sectors by adopting a holistic approach that gives rise to a “smart energy system”.

General inputs on the demand side (Section 1) are represented by annual electricity loads (that can be further subdivided in the contributions for cooling, heating and transport), individual heating demand (fulfilled by boilers) as well as district and process heat demand, direct fuel consumption for transport and industry sectors. To allow the software to perform energy balances, the supply side (Section 2), as in power plants capacities, efficiencies, fuel shares as well as renewable generation hourly distributions, must be fully defined.

The software works on an hourly basis, therefore hourly power distributions are required to describe electricity, heating, cooling and transport demands. Distributions are defined as the ratio between power demand at a particular hour and its yearly peak value. Total electricity demand is fulfilled via renewable energies, which also follow an hourly power distribution given as input, and conventional power plants, defined in terms of installed

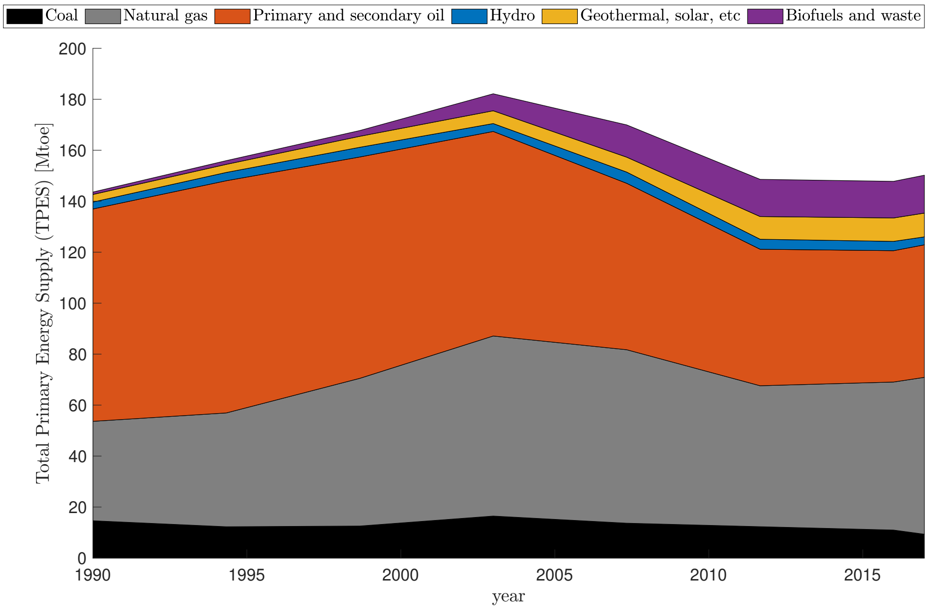

Figure 1. TPES divided by source (Source [2]).

capacity and efficiencies.

This report characterises in detail the Italian energy system in 2017, which, as shown in Fig. 1, still highly relies on fossil fuels and thus requires effective energy policy measures to be implemented when aiming to meet ever more ambitious climate targets.

In this regard, energy system modelling is an essential tool for a proactive planning of renewable and low-carbon energy policies to qualitatively understand and quantify potential benefits and drawbacks and ultimately advise policy makers.

The following sections of this report give a detailed description of the input parameters used to characterise each specific area of the Italian energy system, providing also specific sources and the methodology applied. The different sections are organised following the order in which EnergyPLAN tabs are disposed to facilitate the reader/user following the process of the characterisation of the energy system. Finally, a model validation section is also included to prove the validity of the reference scenario implemented (Section 3).

1. Demand

Demand is the first tab in EnergyPLAN and consists of different subsections related to the different possible energy requirements that may arise in any energy system: electricity, heating and cooling, industry and various sectors, transport and desalinisation. This latter does not concern the Italian case.

Figs. 1.1–1.3 show energy demand in the final uses divided by fuel according to International Energy Agency (IEA) balances [2]. The three major energy vectors (oil products, natural gas and electricity) are further broken down by sector, outlining the remarkable impact of building and transport sectors in terms of energy consumption, especially with regard to fossil fuels.

1.1 Electricity

Electricity demand was categorised according to the type of loads used in EnergyPLAN, which are shown in Table 1.1 along with the related source. Most data were derived from Terna database [3], the company in charge of managing the high voltage Italian transmission grid. Terna not only provides the annual net value, but also the net exchanged power as well as the total load on an hourly basis for the year 2017; they have been both normalised with respect to the maximum value to derive the normalised power distribution as required by EnergyPLAN. Such distributions are displayed in Figs. 1.4 and 1.5. The power duration curve is shown in Fig. 1.6.

1.2 Heating

Heating demand was modelled starting from IEA data for Italy with reference to 2017 related to residential, commercial and public services [2]. Table 1.2 gives the distribution of heating demand, divided among different supply technologies, along with the corresponding average efficiency or Seasonal Performing Factor (SPF).

Consumption for space heating and sanitary hot water production only were derived from a document provided by Gestore dei Servizi Energetici

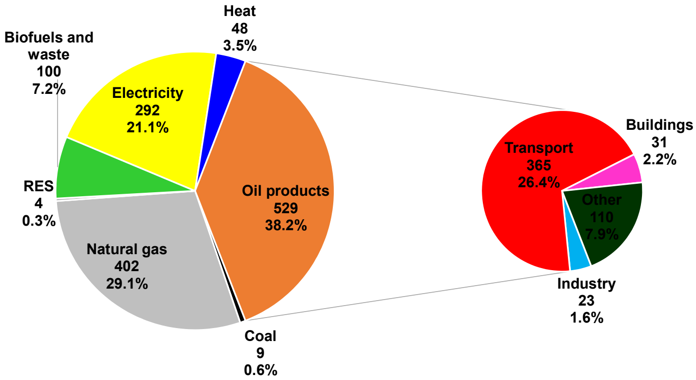

Figure 1.1. TFC divided by fuel (TWh): breakdown by sector for oil products.

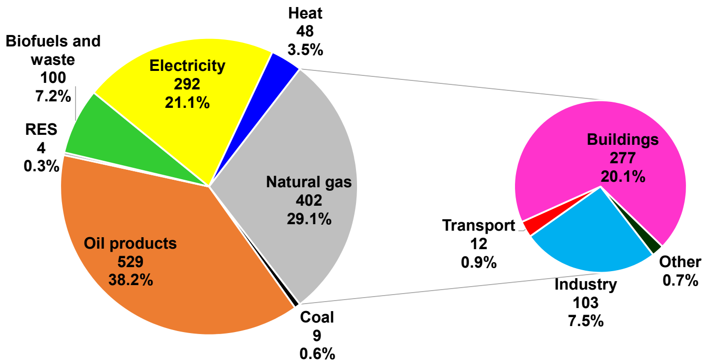

Figure 1.2. TFC divided by fuel (TWh): breakdown by sector for natural gas.

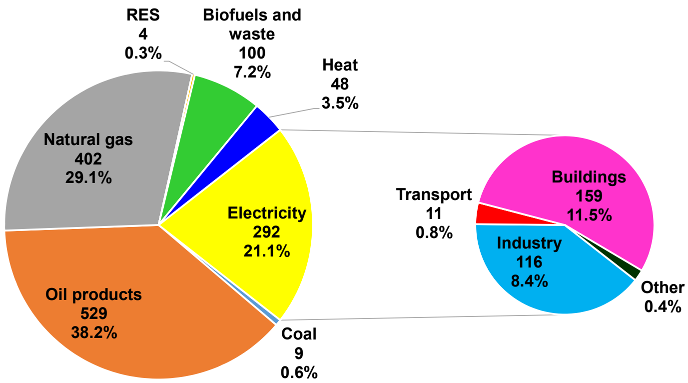

Figure 1.3. TFC divided by fuel (TWh): breakdown by sector for electricity.

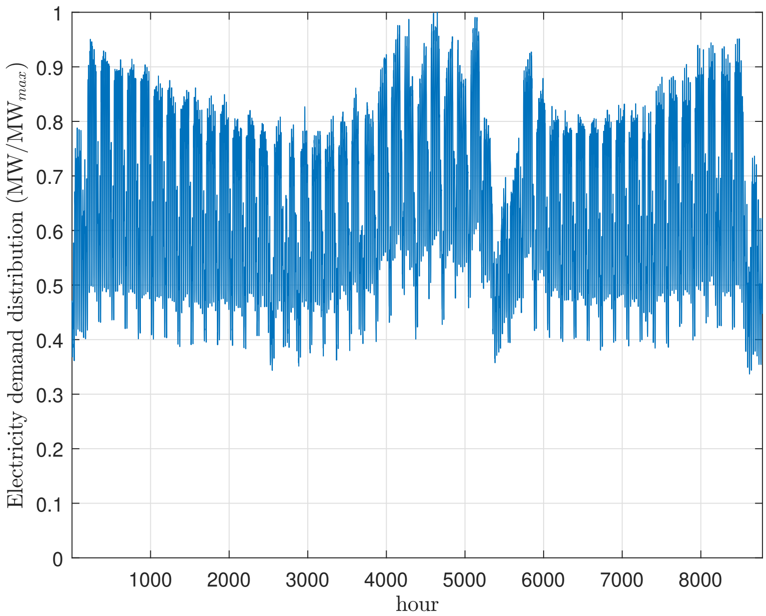

Figure 1.4. Electricity load distribution.

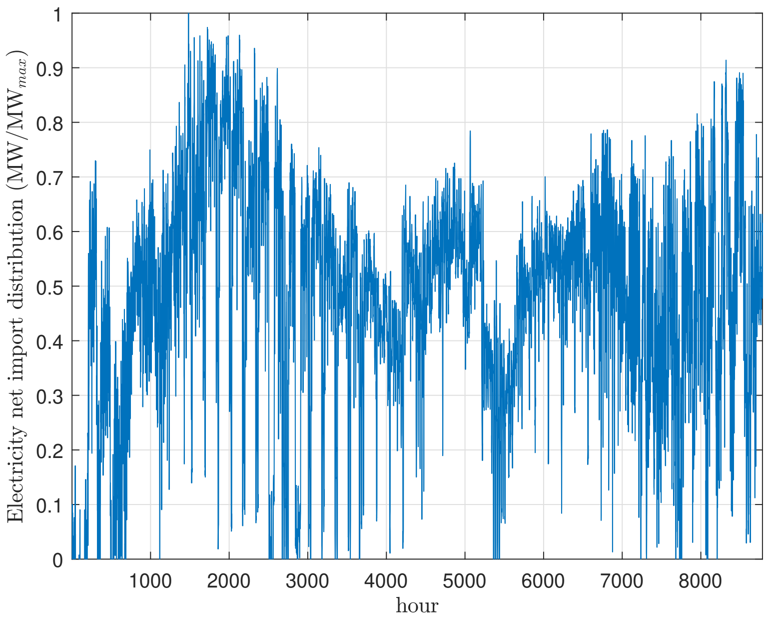

Figure 1.5. Electricity net import distribution.

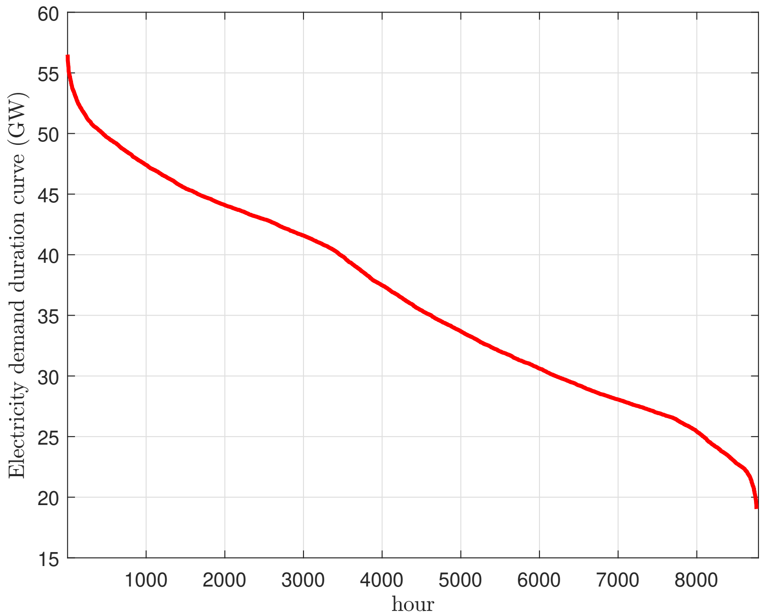

Figure 1.6. Electricity load duration curve.

Table 1.1. Electricity load by sector (TWh).

Load	Consumption	Source
Electric cooling	8.91	[4, 5]
Electricity for HPs (individual)	18.93	[6]
Electric heating (individual)	8.07	[7]
Electricity for transport	11.38	[8]
Other electricity loads	286.30	[3]
Total demand (gross)	*333.59*	
Net import	-37.76	[3]
Total domestic production (gross)	295.83	

Table 1.2. Heating loads (TWh) and efficiency of heating devices.

Technology	Consumption (Sources: [10, 2])	Efficiency/SPF (Sources: [9, 6])	Demand
Oil boilers	27.02	0.90	24.32
NG boilers	265.08	0.92	243.87
Biomass boilers	82.33	0.75	61.75
Electric boilers	8.07	1.00	8.07
HP	18.93	2.63	49.79
Total			387.80

(GSE) that provides a detailed breakdown of energy consumption in residential and services sectors for the year 2014. The same percentages of consumption allocated to space heating and sanitary hot water were used to estimate consumption in 2017 of oil products, Natural Gas (NG) and biomass. With respect to Heat Pumps (HPs), data were taken from another GSE report related to the usage of renewable sources in the various sectors for the Italian case [6]. Electricity consumption for other heating devices was assessed starting from the total electricity consumption for heating purposes [7] and subtracting the amount of electricity consumed by HPs.

Energy efficiency for oil, NG and biomass boilers was derived from average values provided in Ref. [9]. The value used for SPF, indicating the seasonally-averaged Coefficient Of Performance (COP) over the heating season, was assessed based on actual measured data available from GSE [6].

Hourly distribution for individual heating demand was derived considering that, in Italy, the majority of individual heating requirement is fulfilled through NG. Its hourly distribution is provided by SNAM, the national society for natural gas transportation and storage, for the year 2017 [11]. Gas consumption for heating purposes only was evaluated by subtracting, on an hourly basis, industry, power plants and transportation usage; the resulting distribution is shown in Fig. 1.7.

Within the same section, EnergyPLAN allows to input heating demand satisfied via District Heating (DH). These data were derived from the IEA statistics considering residential and services sector DH requirements and divided between DH boilers, providing for 3.76 TWh, and CHP plants producing 10.34 TWh, for a total of 14.10 TWh.

As concerns DH thermal load distribution, the distribution of Turin was taken as representative, since this is the Italian city featuring the largest share of heat demand supplied by DH, using data from year 2010 [12]. The overall useful heat produced by CHP plants, according to Terna [3], is equal to 61.07 TWh: as a result, the remaining derived demand (besides DH) is 50.73 TWh and includes energy industry own use, losses, industry and other

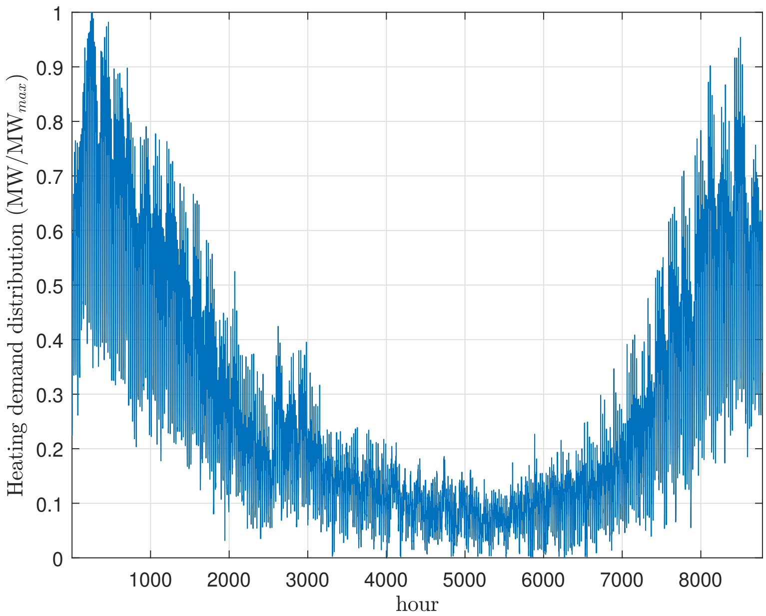

Figure 1.7. Individual heating demand distribution.

derived heat requirements.

1.3 Cooling

Electricity consumption for cooling was evaluated considering an annual cooling demand of 49 TWh [4] and a Seasonal Energy Efficiency Ratio (SEER) of 5.5 [5]. SEER is a commonly used measure of the average efficiency of cooling equipments that takes into account changes in operating conditions throughout the cooling season. These data allowed to calculate an annual electricity consumption for cooling purposes of 8.9 TWh (Table 1.1).

Cooling demand distribution was taken from the EU-funded project Heat Roadmap [13] and is shown in Fig. 1.8.

1.4 Industry and Fuel

Fuel consumption by industry and other sectors (agriculture, fishing, forestry, energy industry own use and other various non-specified areas) needs to be included as well to account for CO_2 emissions and energy consumption also in these areas of the energy system.

Values for the 2017 Italian energy system are displayed in Table 1.3.

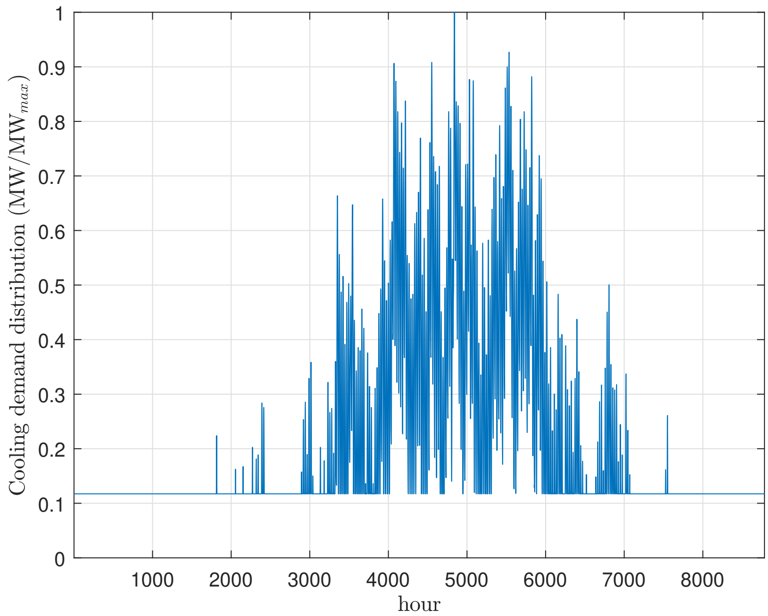

Figure 1.8. Cooling demand distribution.

Table 1.3. Industry and various sector fuel consumption (TWh; source: [2]).

Fuel	Industry	Various
Coal	8.22	0.65
Oil products	22.72	65.44
Natural gas	103.15	30.32
Biomass and waste	7.27	22.02
Total	141.36	118.43

Besides fuel consumption, EnergyPLAN allows to input fuel losses, estimated as a percentage of the total fuel consumed. Such losses were set equal to 0.5 % for NG in the Italian case [2]. Hourly distribution for NG consumption in the industry sector was derived from SNAM [11].

1.5 Transport

With respect to the transport sector, energy demand was modelled by including fuel and electricity consumption as listed in Table 1.4. In the Italian case, fuel consumption for 2017 provided by GSE [8] was considered to derive how to divide the overall consumption among different fuels. With specific reference to Jet Petrol (JP), the value reported by GSE sums up

Table 1.4. Transport sector fuel consumption (TWh; sources: [8, 14]).

Fuel	Consumption
JP	8.44
Diesel	244.04
of which biodiesel	11.97
Petrol	86.43
of which biopetrol	0.38
Natural gas	12.37
LPG	21.30
Electricity	11.38

consumption related to both national and international aviation, and the former was assessed considering the share of JP for national aviation only based on data provided by Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA) for 2016 [14].

2. Supply

Besides demand, EnergyPLAN also allows (and requires) the modelling of energy supply technologies of a given energy system. This section of the software includes technologies for both heat and power generation (to be produced either separately or simultaneously via cogeneration systems), taking into account renewable and conventional technologies and, for these latter, the distribution among the different fuels used.

Energy supply for the Italian case was modelled including the technology mix currently deployed to satisfy power and thermal (as in derived heat) demands and ultimately to achieve an hourly energy balance throughout the year. With respect to electricity supply, Fig. 2.1 shows gross electricity production by source in Italy, outlining how the major share of generation is still taken by fossil fuels, in particular by natural gas.

2.1 Heat and Electricity

CHP and DH plants were modelled to cater for derived heat demand, including DH as previously outlined in section 1.2. DH boilers were modelled to produce 3.76 TWh of national heat demand with a thermal efficiency equal to 0.71. In the base case scenario, CHP plants were modelled by means of their overall capacity, electric and thermal efficiency, in the "CHP Back-Pressure Mode Operation" subsection of the software, in what EnergyPLAN defines as Group 2 (thus named CHP2). Capacity values were derived from Terna annual report [3] while electric and thermal efficiencies were assessed based on consumption and generation data from IEA balances [2]. Data are shown in Table 2.1.

EnergyPLAN allows also to select, among CHP plants, large cogeneration plants that are able to operate, if required, in electricity-only mode and belong to what EnergyPLAN defines as Group 3; precisely, such power plants are named CHP3 when producing combined heat and power and PP1 when generating only electricity. This option was used by the authors in modelling future scenarios (not described in this document) to provide the

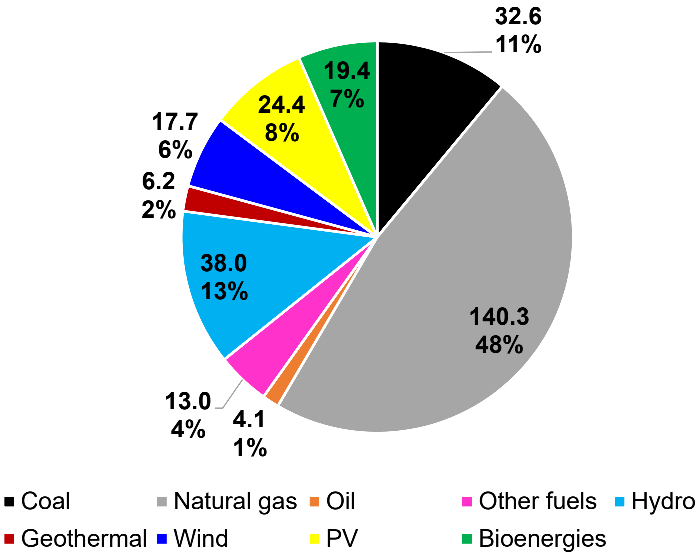

Figure 2.1. Gross electricity generation by source.

Table 2.1. CHP plants: installed capacity and efficiency.

Technology	Capacity (GW)	η_{el}	η_{th}
CHP2	26.16	39.14%	21.71%

Table 2.2. CHP plants operating in cogeneration and electricity-only modes: installed capacity and efficiency in future scenarios.

Technology	Capacity (GW)	η_{el}	η_{th}
PP1	20.10	43.30%	-
CHP2	6.06	36.16%	33.78%
CHP3	20.10	43.30%	18.73%

Table 2.3. Conventional power plants: installed capacity and efficiency.

Technology	Capacity (GW)	η_{el}
PP2	37.88	44.52%

energy system with additional flexibility, under the assumption that large CHP plants (such as large combined cycle plants or condensing turbines) might be able to support conventional power plants in fulfilling electricity demand. The remaining CHP technologies are located in CHP2.

For the sake of clarity, Table 2.2 lists data used in this particular configuration. Capacities and efficiencies to implement this option were derived from the Terna annual report [3], which breaks down electricity generation and primary energy consumption according to different types of CHP plants.

2.2 Central Power Production

This tab of EnergyPLAN software allows to model central power plants such as steam, nuclear, geothermal and dammed hydro power plants. However, with reference to the Italian reference scenario, this section was only used to characterise geothermal power plants and Conventional power plants (PP2). Overall capacity was derived from Terna annual report [3] while efficiency was obtained from IEA statistics [2].

As concerns future scenario modelling, overall PP2 capacity varies if coal phase-out is included in accordance to National Plan for Energy and Climate (PNEC) targets, by implementing the decommissioning of 7.89 GW coal power plants installed capacity [15], partially replaced by additional 3.4 GW capacity of NG power plants [16, p. 93].

Dammed hydro power plants, although dispatchable, were included in the "Variable Renewable Electricity" tab (see section 2.3) along with river hydro plants because dammed hydro power plants, in Italy, are already exploited almost at their maximum potential. As a result, in authors' studies for future national scenarios, no specific assumption are made with respect

Table 2.4. RES installed capacity and annual electricity generation (Source: [3]).

Source	Capacity (GW)	Generation (TWh)
Photovoltaic	19.7	24.4
Onshore wind	9.8	17.7
Hydro	22.8	38.0
Total	52.3	80.1

Table 2.5. Correction factors for RES generation.

Source	Value
Photovoltaic	-1.306
Onshore wind	-0.929
Hydro	-1.754

to dammed hydro power plants to require them to be modelled in a dedicated section.

2.3 Variable Renewable Electricity

This section models RES power plants with intermittent generation. EnergyPLAN requires overall capacity and annual electricity generation from each source to be supplied along with a normalised hourly power distribution throughout the year.

With particular reference to the Italian case, RES electricity generation was modelled by means of the overall capacity for wind, Photovoltaic (PV) and hydro plants and the related hourly power distributions as provided by Terna annual report and database [3, 17]. Data are displayed in Table 2.4 and hourly distributions in Fig. 2.2.

EnergyPLAN also allows the user to indicate a "correction factor" to modify hourly power distributions and electricity generation in turn. Using the available normalised power distributions combined with installed capacity data, EnergyPLAN would not produce results in accordance with actual generation (the model cannot reproduce curtailments, power plant unavailability or other situations that could affect generation results). To make up for this shortcoming, the user can supply correction factors, which need to be calibrated against actual generation values for each source, available from Terna [3]. Correction factors used to model the 2017 Italian energy system are given in Table 2.4.

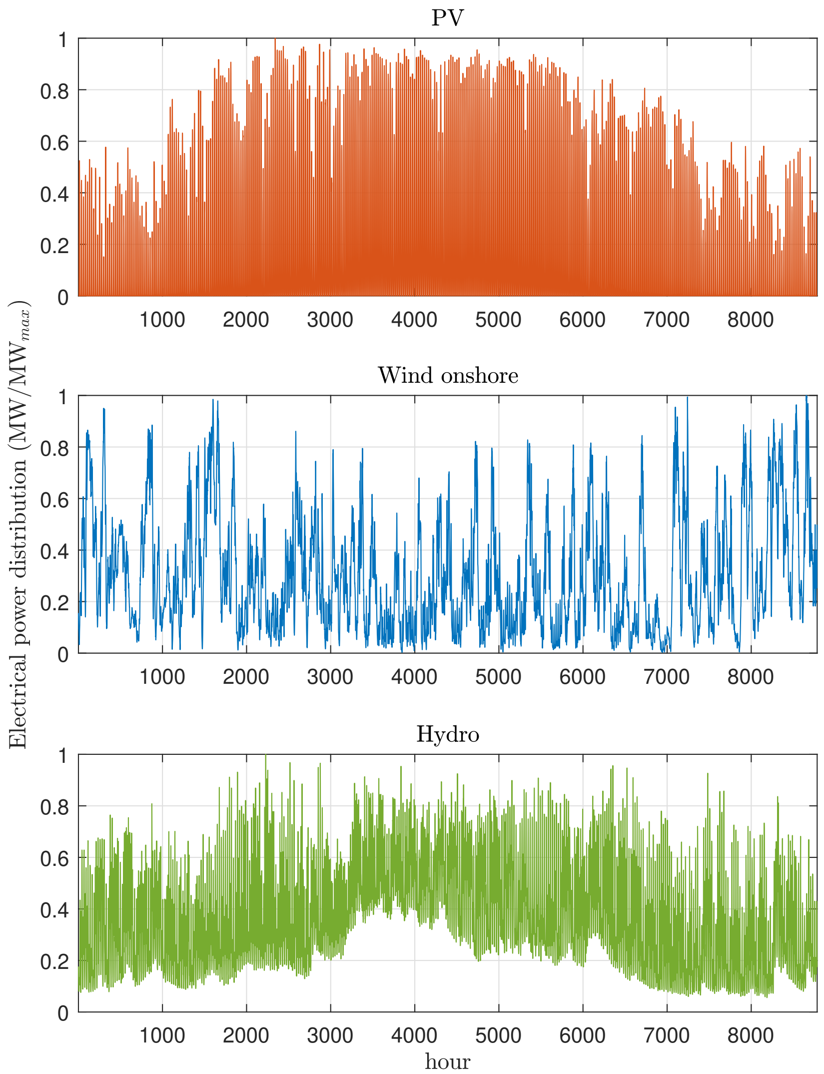

Figure 2.2. RES electricity generation distribution.

Table 2.6. Power plants fuel consumption (TWh) (Source: [2]).

Fuel	DH	CHP2	PP2
Coal	0	8.40	83.80
Oil products	0.02	42.59	5.83
Natural gas	2.87	190.30	100.23
Biomass	1.59	40.05	31.81

Table 2.7. Power plants fuel consumption (TWh) in the baseline model for future scenarios (Source: [2]).

Fuel	DH	CHP2	CHP3	PP2
Coal	0	0	0	0
Oil products	0.02	13.15	29.44	5.83
Natural gas	2.87	47.15	143.16	100.23
Biomass	1.59	17.86	22.19	31.81

2.4 Fuel Distribution

Power plants fuel consumption needs also to be considered to properly assess overall CO_2 emissions and primary energy consumption arising from electricity generation. With this regard, the software allows to set how the overall power plant energy consumption is distributed among fuels in the "Fuel Distribution" tab. This tab reports the fuel used by different heat, electricity and CHP plants. Values implemented for the Italian case were estimated based on IEA statistics [2] and are reported in Table 2.6.

As mentioned in section 2.1, CHP plants can be modelled to operate synergically with conventional power plants and authors adopted this configuration in future scenarios modelling. In this case, fuel distribution should be also differentiated according to CHP2 and CHP3 classification; data were taken from Ref. [3] and shown in Table 2.7. Coal phase-out is also implemented.

2.5 CO_2

In order to evaluate CO_2 emissions, users must supply emission factors to EnergyPLAN in the dedicated CO_2 tab. Emission factors used in the model here discussed were mostly taken from ISPRA and are listed in Table 2.8.

Table 2.8. CO_2 emission factors by fuel (Source: [18]).

Fuel	kg/GJ
Coal	93.89
Oil products	76.69
Natural gas	57.62
Liquefied Petroleum Gas (LPG) [13]	59.64

3. Model validation

The model was validated against the most significant energy indicators showing a negligible error (below 2 %: see Table 3.1) compared to actual values. Non-energy uses were subtracted from values given by the International Energy Agency [19]. RES electricity generation excludes bioenergies as EnergyPLAN includes them within thermoelectric generation. It is finally worth seeing how CO_2 emissions are divided by sector, (Fig. 3.1). This graph shows that the highest impact is related to electricity generation and transportation, with an almost equal share of just over 30 %.

Table 3.1. Model validation.

Indicator	Units	Model	Actual	Difference	Source
CO_2 emissions	Mt	325.0	321.5	1.1 %	[19]
TPES	Mtoe	143.1	145.5	−1.7 %	[19]
RES electricity*	TWh	86.3	86.4	0.0 %	[3]
PP electricity	TWh	99.6	98.7	0.9 %	[3]
CHP electricity	TWh	110.2	110.1	0.1 %	[3]

*Excl. bioenergies, including geothermal

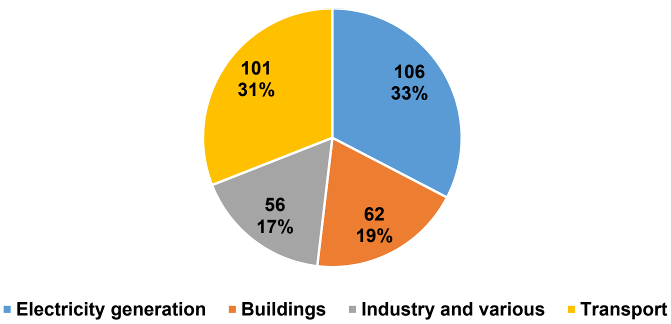

Figure 3.1. CO_2 emissions by sector.

Acronyms

CHP Combined Heat and Power

CHP2 Combined Heat and Power belonging to EnergyPLAN Group 2

CHP3 Combined Heat and Power belonging to EnergyPLAN Group 3

COP Coefficient Of Performance

DH District Heating

GSE Gestore dei Servizi Energetici

HP Heat Pump

IEA International Energy Agency

ISPRA Istituto Superiore per la Protezione e la Ricerca Ambientale

JP Jet Petrol

LPG Liquefied Petroleum Gas

NG Natural Gas

PNEC National Plan for Energy and Climate

PV Photovoltaic

PP Power Plants

PP1 Plants operating in electricity mode only

PP2 Conventional power plants

RES Renewable Energy Sources

SEER Seasonal Energy Efficiency Ratio

SPF Seasonal Performing Factor

TFC Total Final Consumption

TPES Total Primary Energy Supply

Bibliography

[1] S. Bellocchi and M. Manno. *Dataset and description of an EnergyPLAN model of the Italian energy system in 2017*. 2020. DOI: 10.5281/zenodo.3610063.

[2] International Energy Agency. *Italy: Balances for 2017*. https://www.iea.org/statistics/. Last retrieved: 2019-11-11.

[3] Terna Rete Italia. *Dati statistici sull'energia elettrica in Italia*. https://www.terna.it/it/sistema-elettrico/statistiche/pubblicazioni-statistiche. Last retrieved: 2019-11-08. 2017.

[4] S. Werner. "European space cooling demands". In: *Energy* 110 (2016), pp. 148–156. DOI: 10.1016/j.energy.2015.11.028. (Visited on 01/09/2020).

[5] International Energy Agency. *The Future of Cooling. Opportunities for energy-efficient air conditioning*. https://webstore.iea.org/the-future-of-cooling. 2018.

[6] Gestore dei Servizi Energetici. *Rapporto statistico 2017 - Fonti rinnovabili*. https://www.gse.it/documenti_site/Documenti%20GSE/Rapporti%20statistici/Rapporto%20Statistico%20FER%202017.pdf. 2018.

[7] *Zebra2020 Datamapper - Scenarios of the market transition to nZEBs*. http://eeg.tuwien.ac.at/zebra/. Last retrieved: 2019-03-08.

[8] Gestore dei Servizi Energetici. *Energia nel settore trasporti - 2005–2018*. http://bit.ly/GSE-energia-trasporti-2005-2018. 2018.

[9] M. Noussan and B. Nastasi. "Data Analysis of Heating Systems for Buildings—A Tool for Energy Planning, Policies and Systems Simulation". In: *Energies* 11.1 (2018), p. 233. DOI: 10.3390/en11010233.

[10] Gestore dei Servizi Energetici. *Valutazione del potenziale nazionale di applicazione della cogenerazione ad alto rendimento e del teleriscaldamento efficiente*. https://ec.europa.eu/energy/sites/ener/files/documents/it_potenziale_car_tlr_nazionale_e_regionale_dic_2016.pdf. 2015.

[11] SNAM. *Operating data - physical flows on the national network*. http://www.snam.it/en/transportation/operational-data-business/0-Phisical_Flows_on_the_national_network/. Last retrieved: 2019-11-11.

[12] M. Noussan, M. Jarre, and A. Poggio. "Real operation data analysis on district heating load patterns". In: *Energy* 129.0360-5442 (2017), pp. 70–78. DOI: 10.1016/j.energy.2017.04.079.

[13] *Heat Roadmap Europe 4. Energy models for 14 EU MSs*. https://heatroadmap.eu/energy-models/. (Last retrieved: 2019-02-14). 2018.

[14] ISPRA. *Annuario dei dati ambientali 2017 - Versione integrale*. http://www.webcitation.org/776BcqSOo. (in Italian. Last retrieved: February 2019).

[15] Assocarboni. *Le Centrali in Italia*. https://assocarboni.it/assocarboni/?page_id=5978. Last retrieved: 2019-11-13.

[16] Ministeri dello Sviluppo Economico, dell'Ambiente e della Tutela del Territorio e del Mare, delle Infrastrutture e dei Trasporti. *Proposta di Piano Nazionale integrato per l'Energia e il Clima (PNEC)*. https://www.mise.gov.it/images/stories/documenti/Proposta_di_Piano_Nazionale_Integrato_per_Energia_e_il_Clima_Italiano.pdf. in Italian. 2017.

[17] Terna Rete Italia. *Download Center - Generation*. https://www.terna.it/en/electric-system/transparency-report/download-center. (Last retrieved: 2019-11-11).

[18] Istituto Superiore per la Protezione e la Ricerca Ambientale. *Fattori di emissione per la produzione ed il consumo di energia elettrica in Italia*. http://bit.ly/ISPRA-fattori-emissione. in Italian. 2018.

[19] International Energy Agency. *Key World Energy Statistics 2019*. URL: https://webstore.iea.org/key-world-energy-statistics-2019.