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Coupling power and gas systems models

A PLEXOS model for Italy and the EU

VANDENBERGH, M.

GIACCARIA, S.

GERBELOVA, H.

PURVINS, A.

COSTESCU, A.

BOLADO-LAVIN, R.

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Joint Research Centre

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Contact information
Name: MICHEL VANDENBERGH
Address: Westerduinweg 3, 1755 LE Petten
Email: michel.vandenbergh@ec.europa.eu
Tel.: +31 224 56 5256

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Contents

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Authors

VANDENBERGH, M.

GIACCARIA, S.

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BOLADO-LAVIN, R.

Abstract

The interconnections between gas and electricity networks and markets are relevant to the Regulation 2017/1938 on security of gas supply. Indeed, gas-fired power plants require gas to be able to deliver electricity to the network, and a number of facilities in the gas transmission network need electricity to work adequately. The only way to address the interactions between those two systems is by using an integrated model. We adopt a techno economic approach based on the PLEXOS® software, as a suitable compromise to represent large scale transmission systems adding economic detail to both the gas and electricity parts. This technical report presents the European market model (including a more detailed description of the Italian power market) for the year 2016, focusing on the structure of the model, the main assumptions and input data. The performance of the model for simulating the Italian power and gas markets is briefly evaluated.

1 Introduction

The simulation of the behaviour of gas and electricity system can provide crucial information in the design of energy policies and regulatory measures, specifically in the field of security of supply. The EU regulation 2017/1938 states that a member state may decide to ensure the gas supply to power plants if they have a key role in ensuring the stability of the electricity supply, or to ensure the functioning of heating systems that rely on electricity for their operations even if they are fuelled by natural gas. Gas supplies generally provide flexibility for electricity systems. The analysis of the unsatisfied demand of electricity due to the disruption of gas supply is one of the main purposes to develop an integrated gas and electricity model. There is an unavoidable trade-off between the level of integration the two systems can have in a single modelling application, and the accuracy in reproducing the physics of the two systems.

One approach to analyse the coupling of electricity and gas systems is using a soft-link between two individual models where a result of one model is integrated as an input parameter to the other model. In the study by Cole [1], the authors used the gas price derived from the gas system model and applied it into the electricity model. Then the obtained gas demand from the electricity model contributed back to the simulation of the gas system, closing the loop. The main advantage of this approach is that the two individual models can be run in parallel and thus defined in a very detailed way without compromising the simulation time compared to a fully integrated model. The interested reader will find a detailed overview on other modelling tools for power systems in [8]. Yet, the soft-linking of various parameters that influence each other can become a complex issue. Therefore, adopting a single integrated model for the gas and electricity systems is frequently used to study the interaction between the two sectors and their impacts on different parameters.

Most of the developed integrated models are aiming at analysing the security of gas supply. Erdener developed an integrated electricity-gas model to study how one system affects another under a gas disruption scenario [2]. The model represents a detailed technical aspect of the gas and electricity transmission network considering physical interactions between the two systems. Other developed models integrate the economic perspective. For example, Ordoudis developed a co-optimization gas and electricity systems model to analyse the operational flexibility of the line pack while minimizing the costs [3]. Chaudry demonstrated application of such model in a great detail at the level of a single country like the UK [4]. Möst developed an EU wide integrated electricty-gas model for studying the techno-economic impacts of the gas market on the electricity sector within the context of the CO_2 reduction targets [5]. Rad developed an integrated electricity-gas market model focusing on the generation and transmission long term capacity planning [6]. Deane studied the European gas and electricity network under different gas disruption scenario for the year 2030 [7].

This report describes an integrated market model for gas and electricity, covering the EU with a coarse spatial granularity of one node per country, except in Italy where the main nodes corresponding to the electricity market bidding zones are represented. The time granularity is 1 hour, which allows to model the day-ahead market. The model represents the gas and power systems in 2016 and may be used to identify various issues related to the security of gas supply, such as for instance the identification of critical gas-fired power plants.

The model is built using the software PLEXOS® Integrated Energy Model version 8.1 of the company Energy Exemplar. In PLEXOS® the properties and behaviour of the integrated gas and power system are converted into a mathematical cost minimization problem, which is solved by finding the best dispatch from a range of available options.

The specificity of this integrated gas and electricity model is that it is built by combining databases of two separate already operational market models. Neither gas nor power is the dominant technology in the model.

2 The model structure

The integrated gas and electricity model is built by combining databases of the two separate already operational JRC market models, described in sections 3 and 4. In addition to connecting the gas model to the power model, a higher granularity has been also achieved for Italy by including a power market node for each of its six main bidding zones. New interconnectors between the Italian bidding zones have been defined. The Italian generation fleet is also more detailed in the new database, by modelling individually all power plants with a significant size.

The software used is PLEXOS®, which allows an integrated modelling of gas and electricity transmission networks.

Model key assumptions are presented in following subsections with a special focus on Italy.

2.1 Gas electricity coupling

In our approach we limit the gas-electricity interaction to the connection of each gas fired power plant as a load in the gas system. The impact of power restrictions on the operation of the gas system is neglected because adequate power back-up solutions (i.e. emergency generators) are assumed to be available.

The model includes following features:

- Power infrastructure: generators, loads, storages, nodes, interconnectors
- Gas infrastructure: gas fields, gas loads (excluding power needs), gas storages, nodes, pipelines
- Interconnection gas-power: the gas fired generators are connected to a specific gas fuel resource, which is a load attached to the closest gas node.
- Static parameters and dynamic behaviours for the different assets
- Simulation in two phases: (a) preschedule phase for defining on a yearly basis, forced outages and optimal maintenance schedule. (b) 365 x Day-ahead optimal unit commitment and economic dispatch (UCED) for gas and power assets.

2.2 Geographical coverage

2.2.1 Natural gas system

The natural gas system is modelled with 43 nodes, corresponding to EU28 + 15 neighbouring countries:

- Albania (AL)
- Azerbaijan (AZ)
- Bosnia and Herzegovina (BA)
- Switzerland (CH)
- Algeria (DZ)
- Iceland (IS)
- Libya (LY)
- Morocco (MA)
- Montenegro (ME)
- North Macedonia, Republic of (MK)
- Norway (NO)
- Serbia (RS)
- Russia (RU)

- Turkey (TR)
- Ukraine (UA)

2.2.2 Power system

The power system is modelled with 40 nodes:

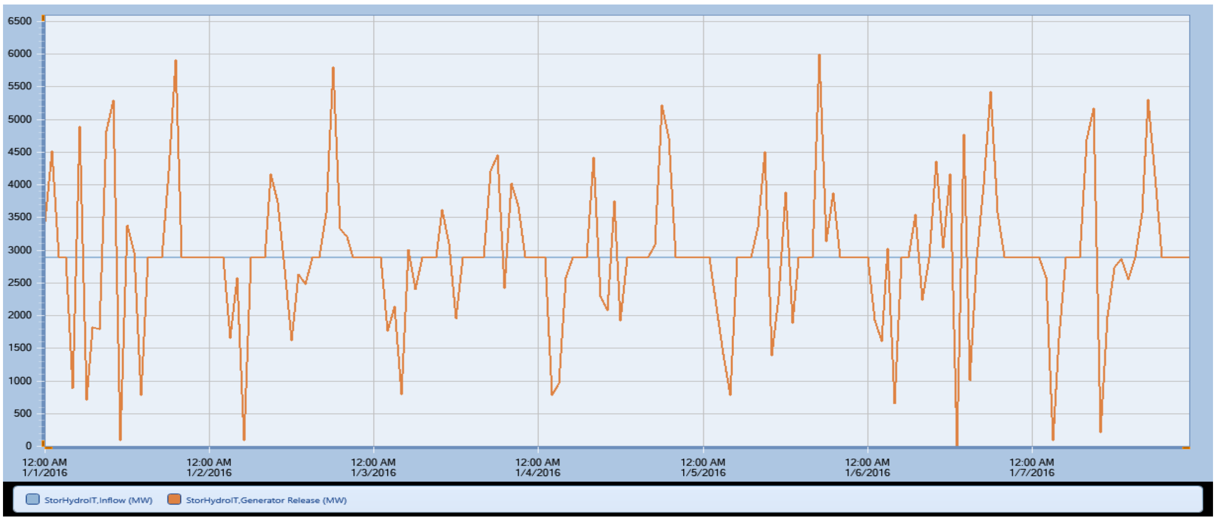
- 27 nodes for EU28 without Italy
- 6 nodes for Italy, corresponding to the main Italian bidding zones (North, Central North, Central South, South, Sardinia, Sicily)
- 5 Balkan countries: Albania (AL), Bosnia and Herzegovina (BA), Montenegro (ME), Macedonia, Republic of (MK) and Serbia (RS)
- Switzerland (CH)
- Norway (NO)

2.3 Seasonal storage management

The model includes several seasonal storage facilities for both gas (underground gas storage) and electricity (hydro with large reservoir). Although the simulation software PLEXOS® has the capability to calculate annual optimal trajectories for seasonal storages during the pre-schedule simulation phase, a different approach has been chosen to better reflect historical behaviour of the energy system. In the model, seasonal storages are forced to follow predefined yearly profiles, with a different approach for gas and electricity.

2.3.1 Hydro reservoir behaviour

Figure 1. Italian hydro reservoir: Power inflow and production (model result 01-07.01.2016)

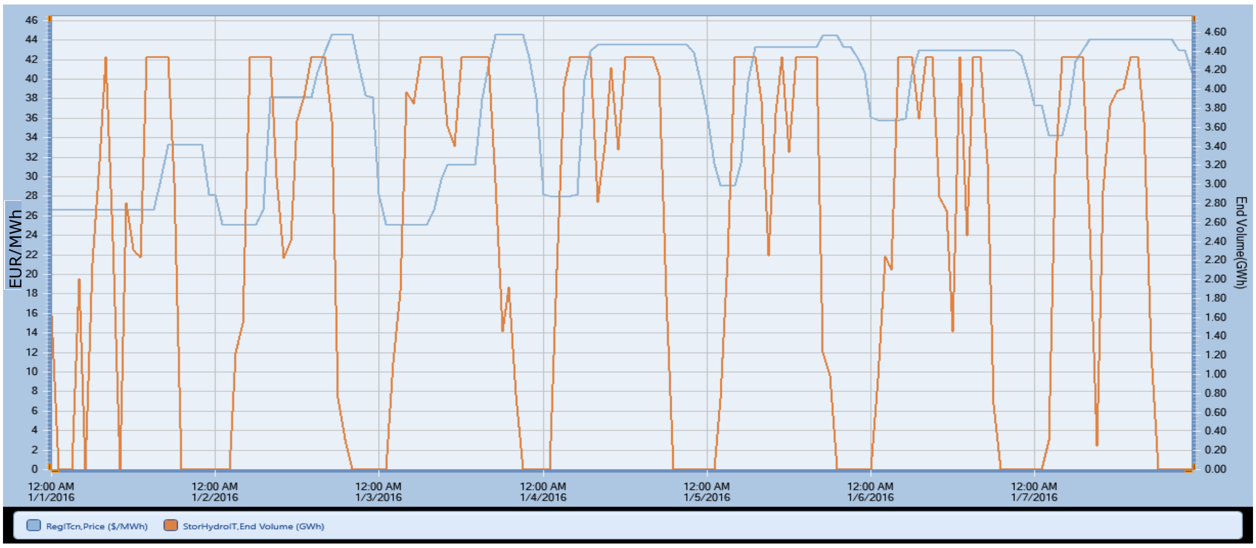


Source: JRC

For modelling large hydro, the real size of the water reservoirs is not used. Instead, the reservoir is sized to represent only its maximum daily balancing capacity. The hydro power output is controlled by defining a synthetic hourly profile for the water inflow which represents the statistical power production of the unit. As hydro power is among the cheapest resources, the inflow energy is always dispatched and the output results match closely the statistics. The storage capacity assigned for daily balancing to the conventional hydro power plants is estimated as X*24h, where X is 1% of the net rated capacity of the power plant [1]. As an example, Norway has a net rated capacity of 31.8 GW and is hence modelled with a balancing reservoir of 24 x 31.8 x 0.01 = 7.6 GWh, when the real maximum energy stored in the Norwegian seasonal hydro reservoir is estimated by ENTSO-E in 2016 to be 5128 GWh [11].

Concerning Italy, the aggregated hydro reservoir capacity usable for balancing represents a total of 4.34 GWh. Figure 1 shows over 1 week the constant inflow power of 2.9 GW and the optimal output power of the hydro unit which fluctuates between 0 and 6 GW. Figure 2 indicates clearly a daily cycle. The storage level is always zero at the end and start of the day. The storage is filled completely in the morning when electricity is cheaper and emptied in the evening when electricity is more expensive.

Figure 2. Italian hydro reservoir: reservoir level and price in ITcn zone (model result 01-07.01.2016)



Source: JRC

2.3.2 Gas storage behaviour

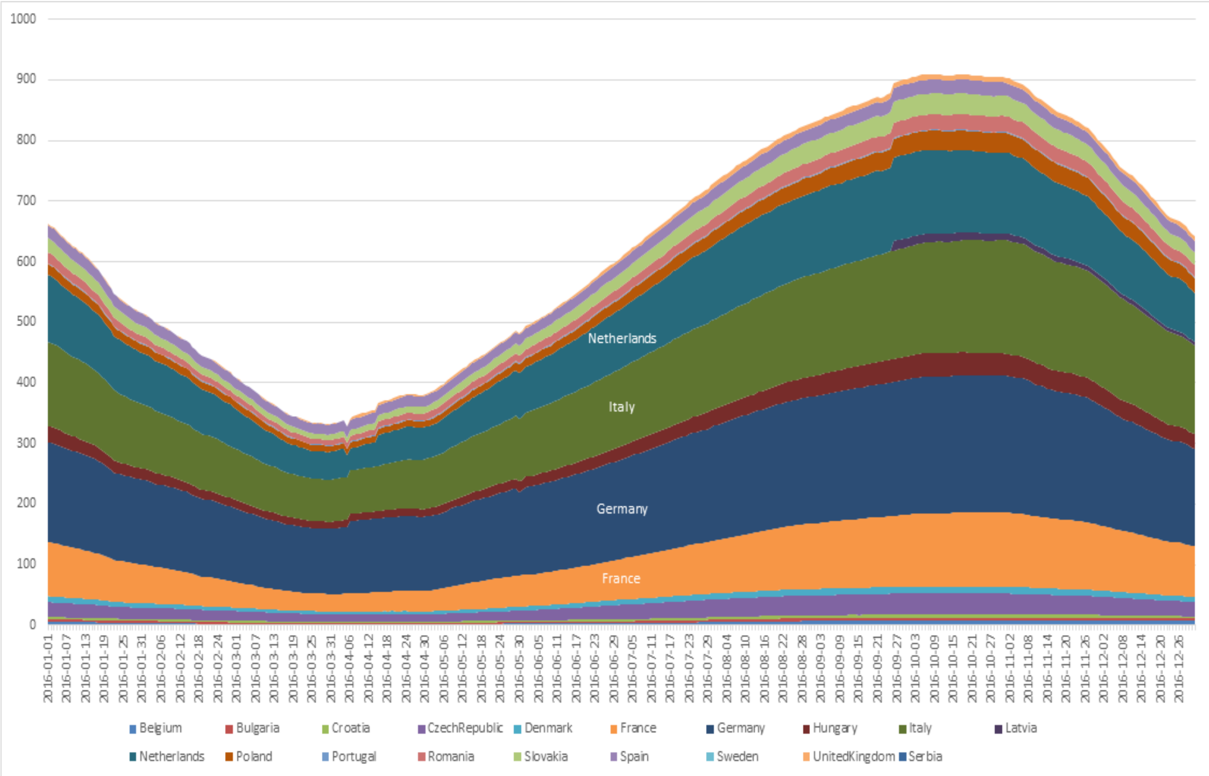
For modelling gas storages, the real size of storages is used. However, the gas storage inventory level is constrained to follow the historical profile for 2016, with a tolerance of +/- 5%.

To define the historical time profile of the gas in storage, GIE-AGSI data[1] are used to draw a space of solutions consistent with the 2016 facts. The Figure 3 presents a series of daily values of the level of gas in the EU storage, providing a breakdown by country and the overview of the whole aggregated volume. It is worth noting that the 55% of the total area in the graph refers to just three countries: Germany, Italy and the Netherlands.

Injection and withdrawal rates and the initial inventory level at the beginning of the time horizon of the simulation, are presented in a more extensive way in section 4 of this report.

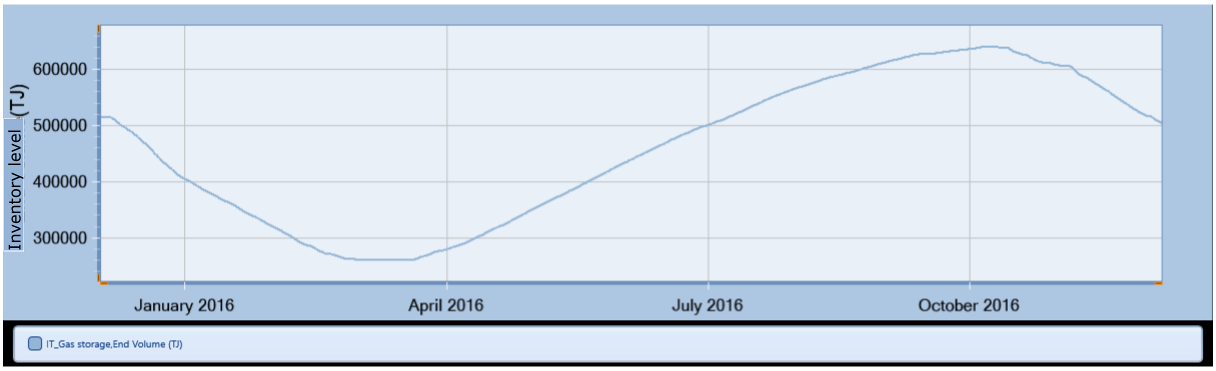
[1] Available at https://agsi.gie.eu/#/

Figure 3. Level of gas in storages of EU countries (TWh) in 2016



Source: GIE-AGSI+

Figure 4. Italian gas storage inventory level (model result)



Source: JRC

3 European electricity system

Assuming a perfect forecast, the model optimizes the day-ahead generation dispatch and power flows, and provides an asset performance valuation in terms of electricity prices and social welfare. Chronological modelling is carried out using deterministic programming techniques that aim to minimise an objective function of the expected cost of electricity dispatch, subject to a number of constraints including availability and operational characteristics of generating plants and energy storage, fuel costs, emissions prices, operator and power transmission constraints, and availability of RES.

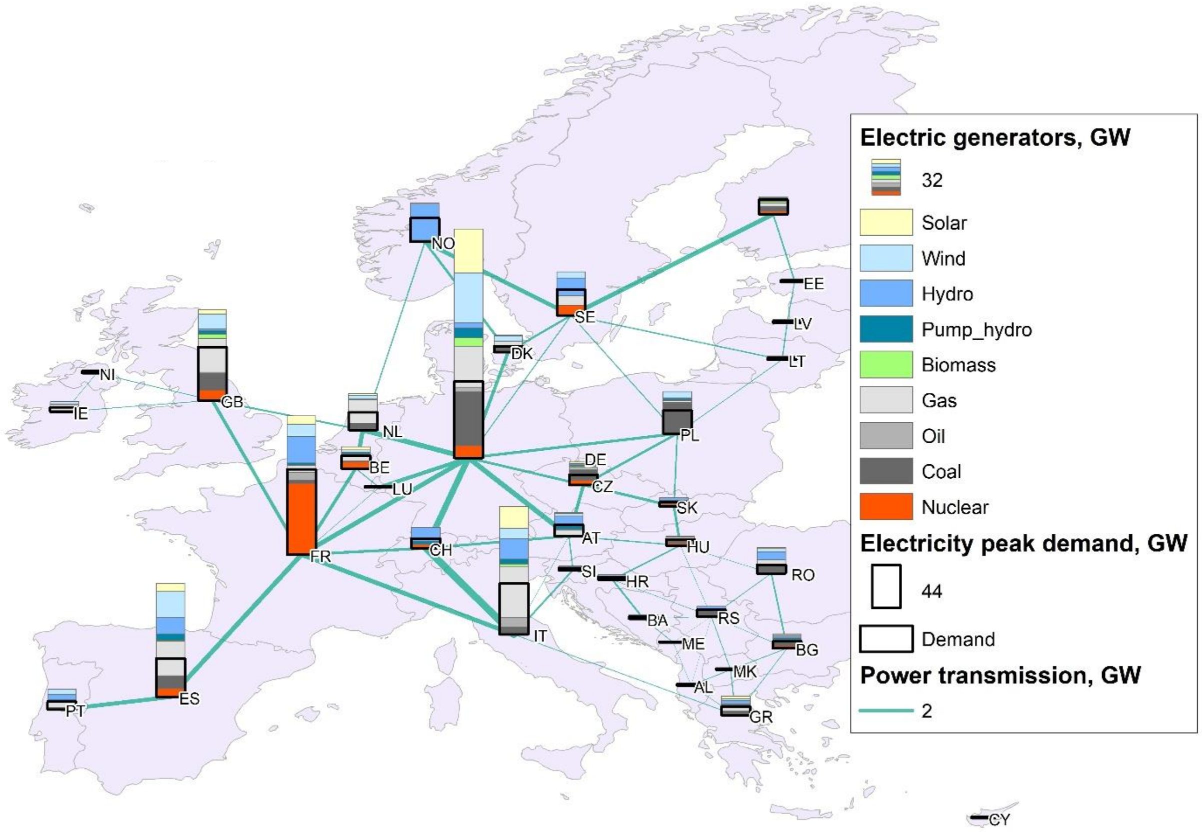
The 2016 base scenario model is built on historical data of that year. An overview of the input data is given in the following sections.

3.1 Electricity network

The electricity system part of the model is depicted in Figure 5, based on ENTSO-E data. The electricity system is comprised of 35 European countries modelled as 40 power nodes: 1 node per country except Italy with 6 nodes (not shown in the figure). Each node in Figure 5 has its unique hourly demand pattern, hourly generation profiles from solar irradiance and wind, monthly water inflow profile for hydro power plants, and mix of aggregated generation capacities divided by technology. Cross-border connections between the countries are used for electricity trading.

Cross-border electricity trading capacity is acquired from historical records of physical flows in 2016 available from the ENTSO-E Transparency Platform [11]. The capacity in the model is set to a constant value which is the 95th percentile from the hourly annual historical records. This downsizing avoids exceptionally high values.

Figure 5. European electricity system 2016

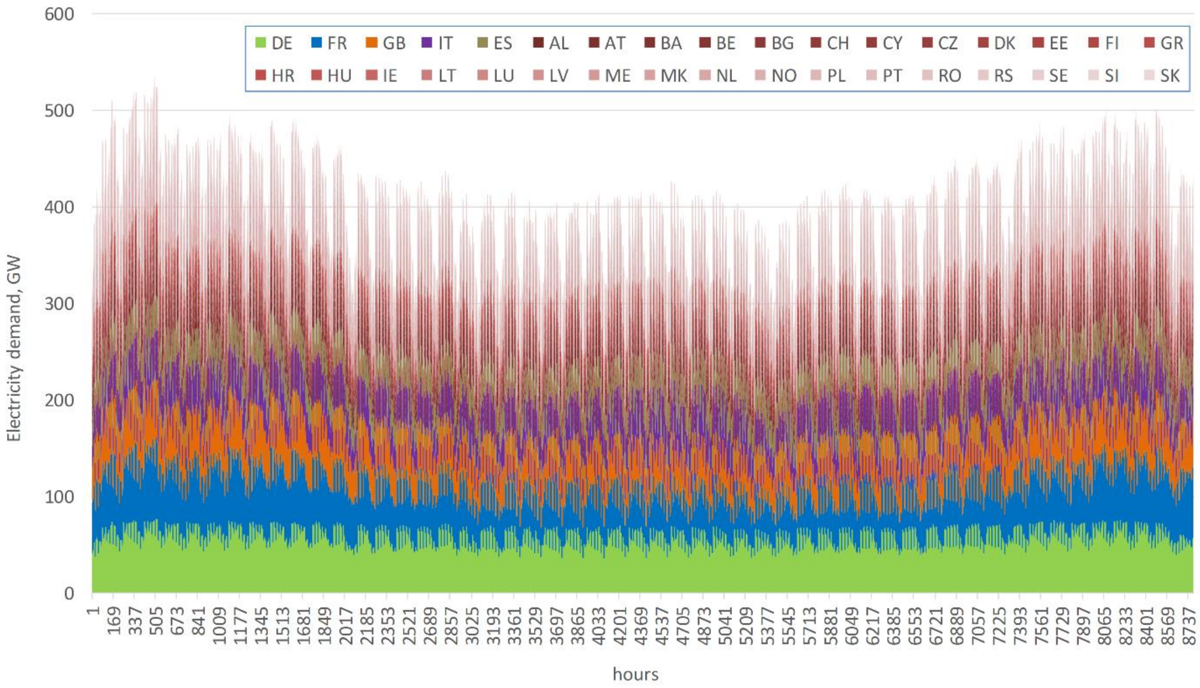


Source: JRC, based on ENTSO-E data

3.2 Electricity demand

The annual electricity demand profiles with hourly time step (see Figure 6) are obtained from the ENTSO-E Transparency Platform [11].

Figure 6. Electricity demand: input data 2016

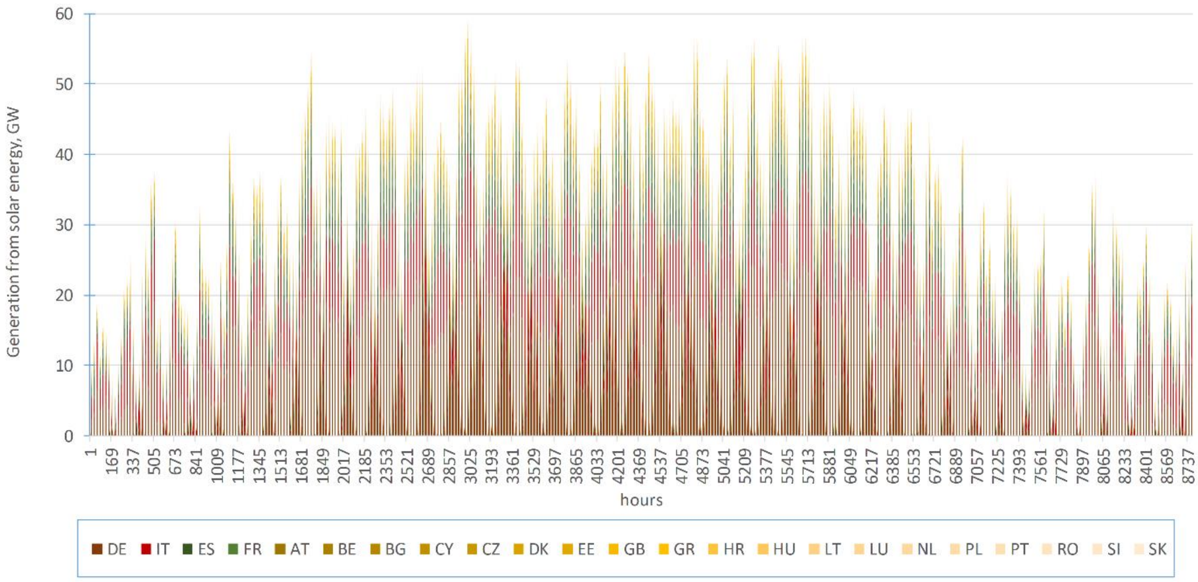


Source: ENTSO-E

3.3 RES generation

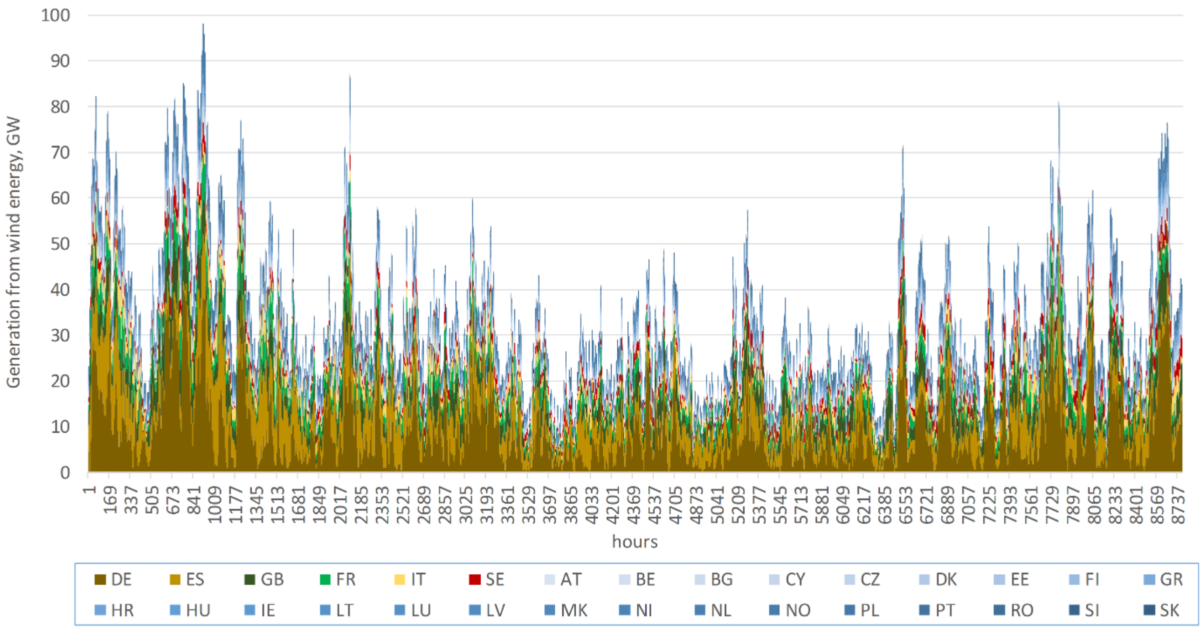
Annual hourly generation profiles from wind and solar resources are obtained from the open database NINJA [12][13][14] and depicted in Figure 7 and Figure 8. Figure 9 represents the total electricity generation from wind and solar energy. At European level, the power generation from solar and wind has daily fluctuations between 10 and 110 GW. These fluctuations have to be balanced within the electricity system. Among RES, hydro power plants contribute significantly in power balance due to their high generation flexibility. Generation from hydro energy is however limited by water inflow. Figure 11 shows these limits expressed in maximum monthly generation. This data is obtained from historical EUROSTAT records [16] and shows the maximum electricity which can be produced monthly by hydro power plants. This is a constraint in the model, which adds seasonal behaviour in the electricity generation. Still hydro power plants can contribute in daily power balancing as a small fictitious water reservoir is added to each plant.

Figure 7. Electricity generation from solar energy: input data 2016



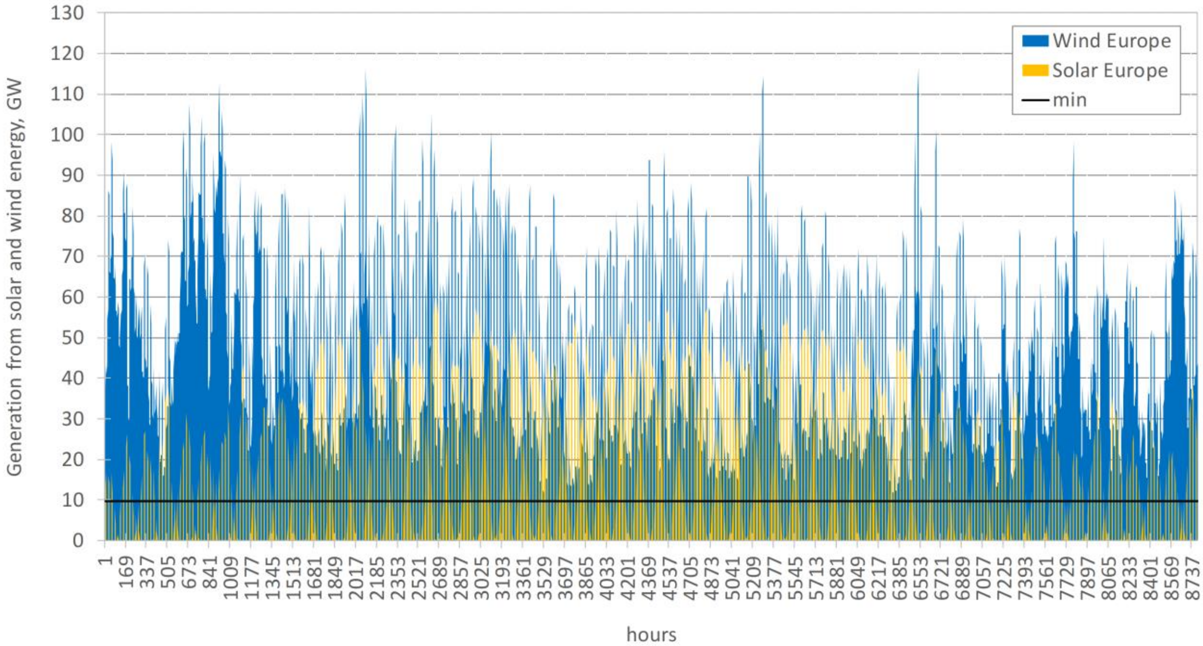
Source: ENTSO-E

Figure 8. Electricity generation from wind energy: input data 2016



Source: ENTSO-E

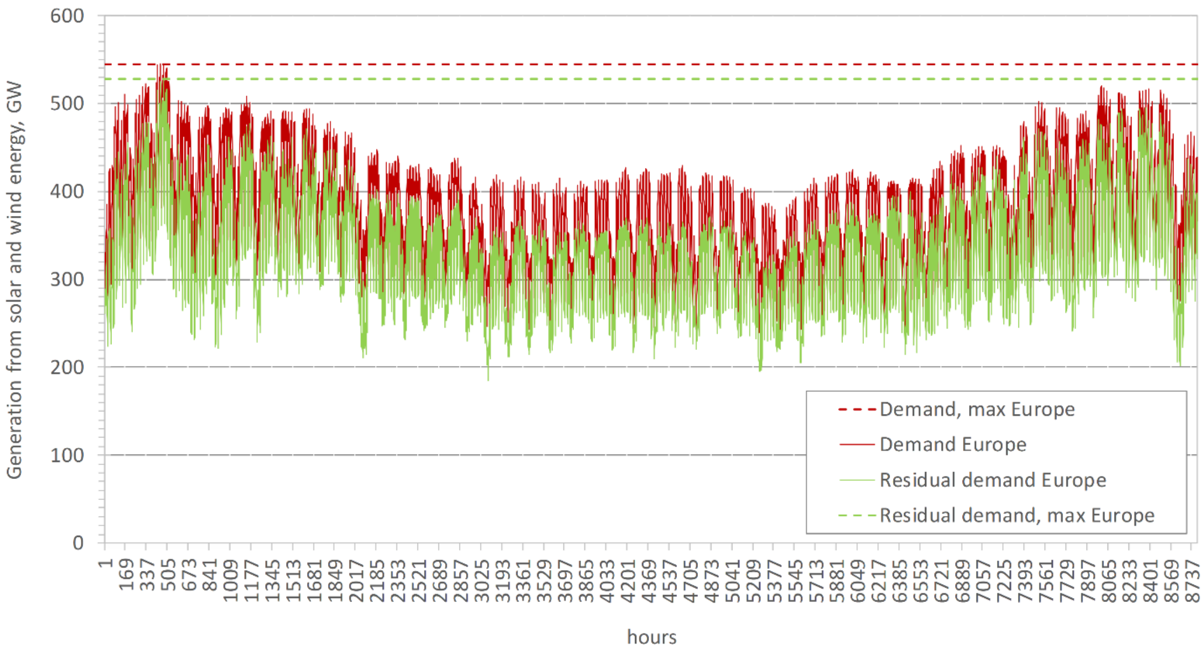
Figure 9. Total electricity generation from wind and solar energy: input data 2016



Source: ENTSO-E

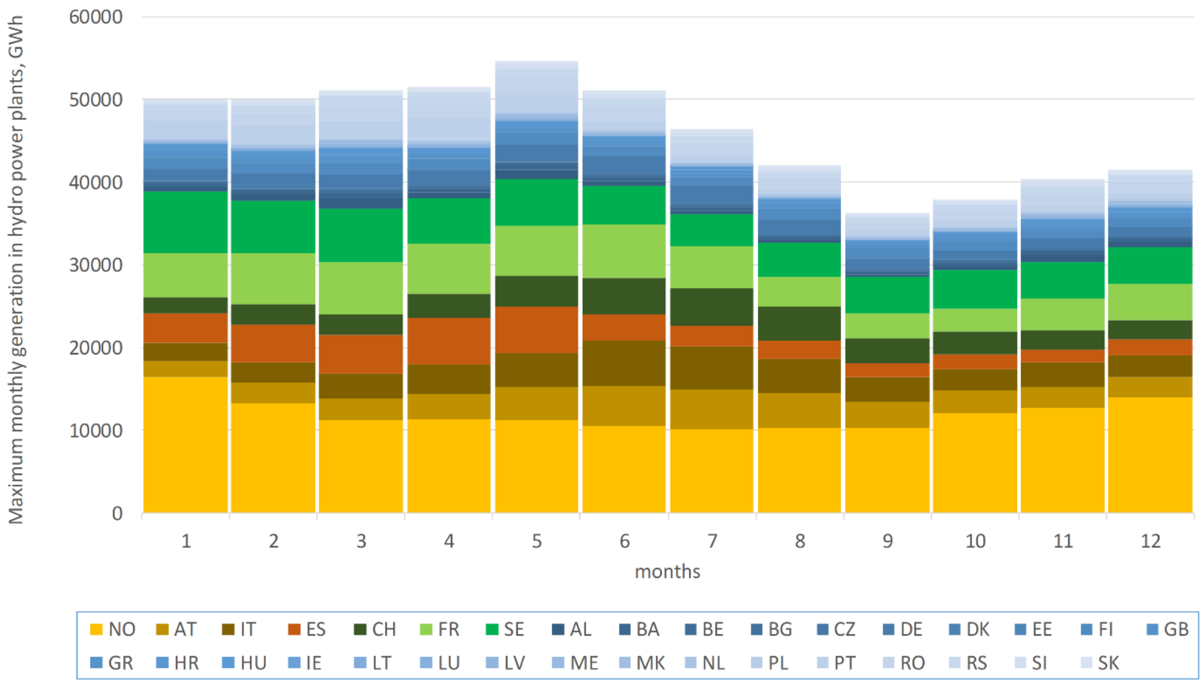
Figure 10 shows the residual electricity demand in 2016. Residual demand is the result of demand minus variable generation from wind and solar resources. So part of demand can be covered by variable RES and the remaining demand is called the residual demand, which should be covered by other generators. Figure 10 also shows RES contribution in reduction of annual peak demand.

Figure 10. Residual demand in 2016



Source: ENTSO-E

Figure 11. Maximum monthly generation by hydro power plants: input data 2016



Source: ENTSO-E

3.4 Power generation fleet in Italy

In all European countries except Italy the generation fleet is modelled as a few big power plants aggregating multiple identical generators fired with the same fuel type (Hydro, Hydro-pump, solar, wind, nuclear, natural gas, coal, oil, biomass, geothermal). In the six Italian market zones, the following more detailed approach was followed to model the generators:

- No aggregation for gas fired power plants, as one important future application of the model is to identify potentially critical gas fired power plants.
- No aggregation of generators with a rated power > 50 MW
- Hydro (reservoir+river) generators share a single reservoir common to the 6 Italian nodes. The reservoir is sized to represent only the daily balancing capacity.
- Hydro pump storage units are modelled each with their own reservoir
- Wind and solar generation are aggregated per bidding zone and their production profiles depend on the available average resources in each of the 6 zones
- The reference source for the available conventional generator fleet for each bidding zones is ENTSO-E, complemented with market data taken from the JRC Power Plant Database [9].

3.5 Maintenance and forced outages

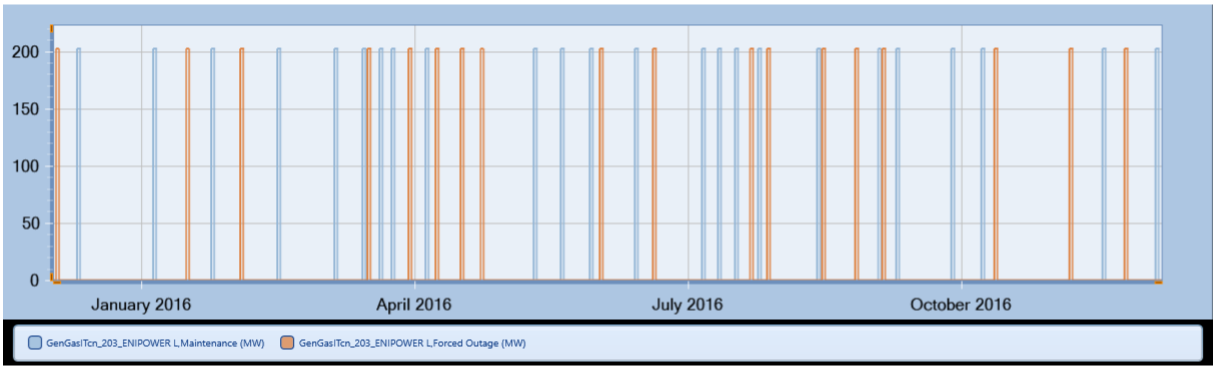
For power generators, the model includes forced and planned outages. The planning for the outages are defined by the model during the preschedule phase. As example, the input parameters for a single gas fired plant are:

- mean time to repair = 24 hours
- annual forced outage rate = 5%

- annual maintenance rate = 6%

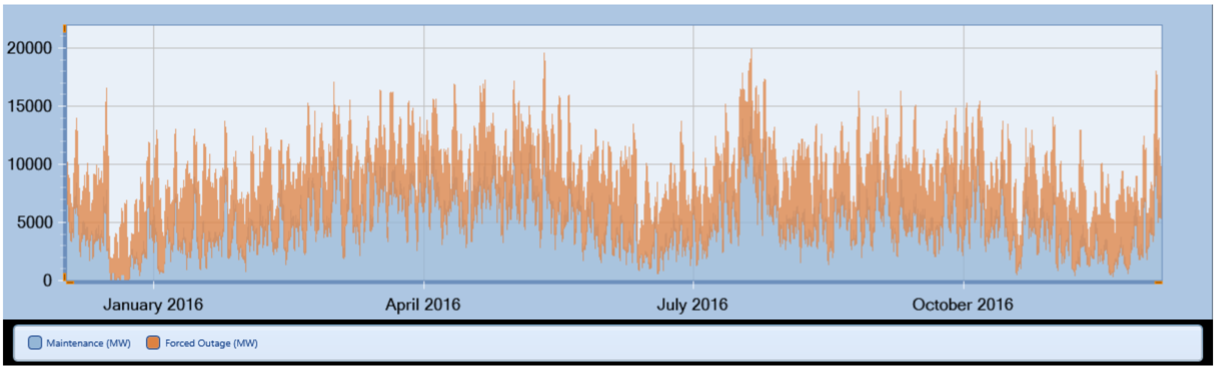
Figure 12 shows a typical schedule with 42 outages calculated from these inputs. Figure 13 indicates at the country level how much capacity is unavailable in Italy.

Figure 12. Typical outages schedule for a single gas fired plant (model result)



Source: JRC

Figure 13. Total generation capacity under maintenance and forced outage in Italy (model result)



Source: JRC

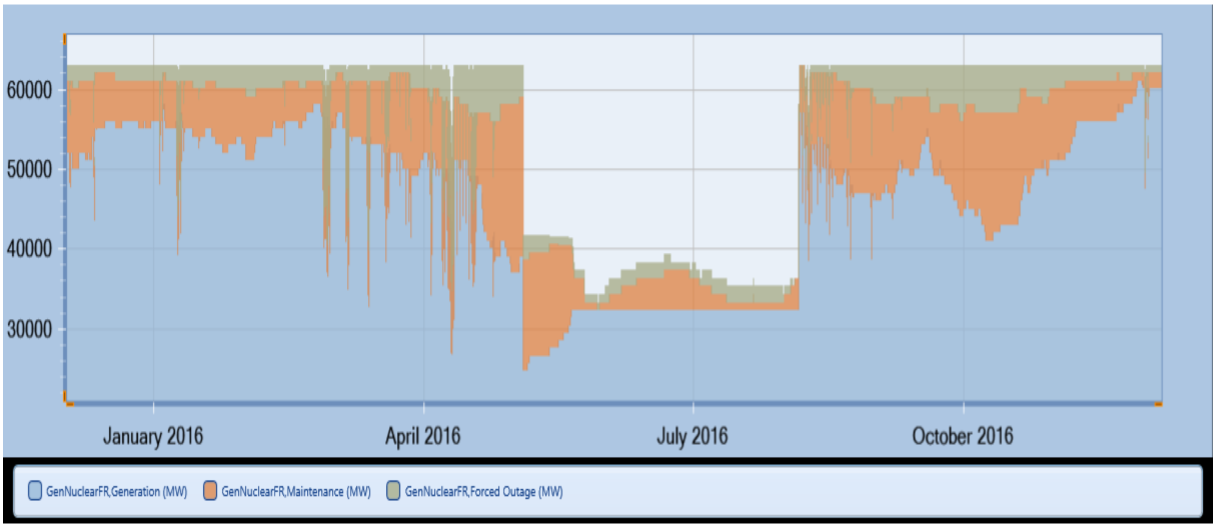
3.6 Capacity limiting scenarios

Two capacity limiting scenarios representing the impact of non technical parameters, have been applied in the base case. The first scenario limits the available nuclear capacity in summer time. The second scenario reduces the coal capacity all year long. Without these scenarios, the coal and nuclear generation would have been too high compared with historical records.

3.6.1 Nuclear in France

In summer, in order to consider the scarcity of cooling water (= environmental constraint), the nuclear capacity available in France is reduced from 63 GW to 32.3 GW. Due to forced and maintenance outages, the operational capacity is also reduced outside of the summer period, as can be seen in Figure 14. In the summer period, outages are not affecting the already reduced operational capacity. As expected, most of the time, the full operational nuclear capacity is dispatched due to its competitive electricity price.

Figure 14. Cumulated generating and outage capacities (in MW) for the French nuclear sector (model result)

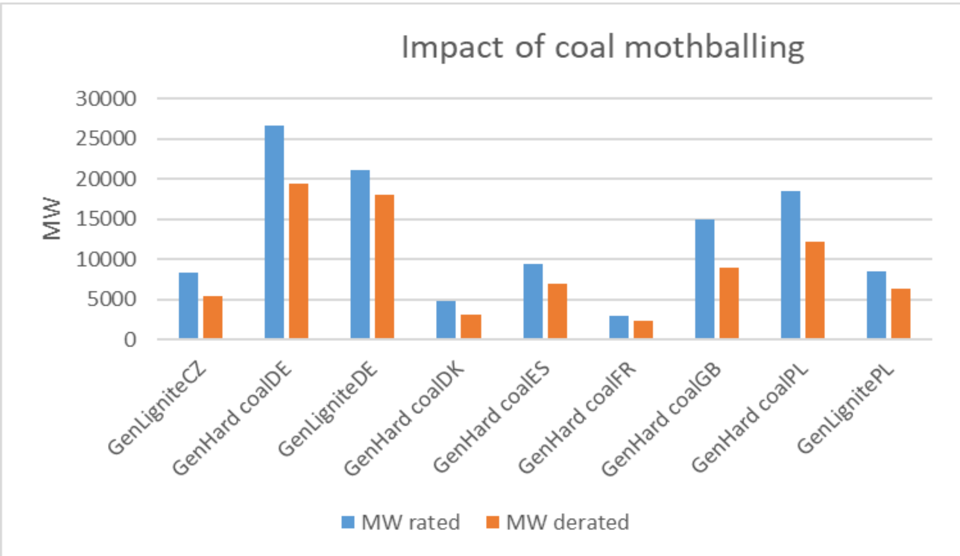


Source: JRC

3.6.2 Coal mothballed

Mothballed power plants are existing assets referenced in ENTSO-E database which were taken out of the market in 2016. In this scenario the available capacity of coal power plants is reduced in 7 countries (CZ, DE, DK, ES, FR, GB, PL) as indicated in Figure 15.

Figure 15. Capacity reduction for coal power plants



Source: JRC

4 European gas system

The gas system is described over five main sections:

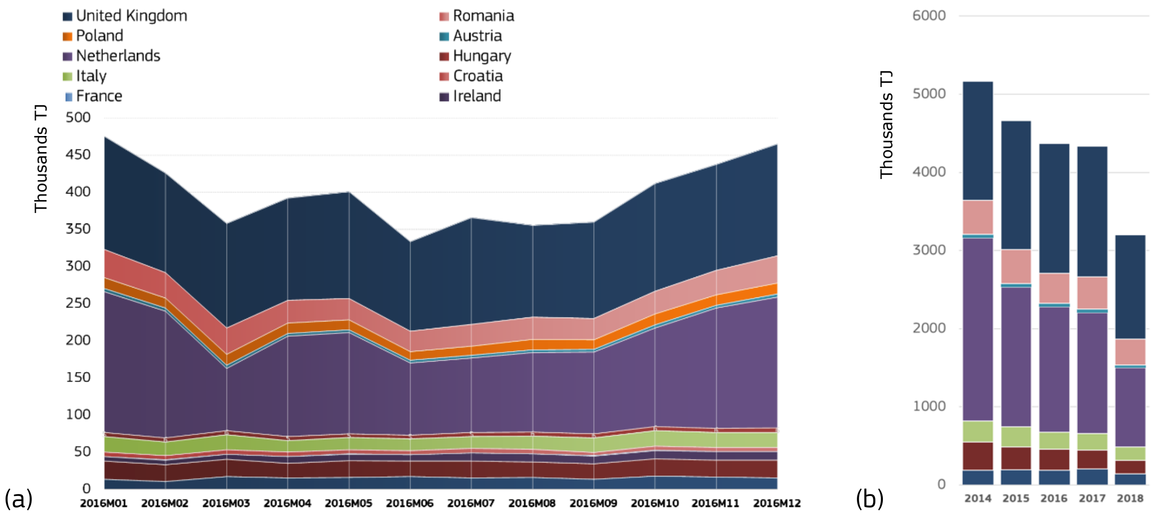
- The gas production from gas fields active in the EU and extra-EU regions
- The conventional gas demand, which is the total consumption excluding power generation
- The transmission systems, in the form of interconnection capacities among countries
- The gas storages
- The liquefaction and regasification terminal for Liquefied Natural Gas (LNG)

In what follows, we present the main input data for the 2016 scenario. The main technical and economic parameters presented in this section are also utilised for other JRC modelling applications concerning the gas system, as the METIS model.

4.1 Gas production

The gas production is defined in the model at a country-wide granularity. The indigenous production of the EU, represented in 2016 the 27 percent of the total consumption[2] of natural gas of the EU, (ACER elaboration on Eurostat, IEA and GIINGL data [20]). In the model, the production level is constrained for EU suppliers to fit within +/-5% of the historical value according to the Eurostat statistics. Monthly values of historical production are reported in Figure 16 (a), while Figure 16 (b) shows the declining trend observable from 2014 to 2018, remarkably for the case of the Netherlands.

Figure 16. (a) Monthly EU natural gas production (TJ), breakdown by country (b) Annual production 2014-2018 (TJ)



Source: ACER

[2] As total consumption we here consider the gross inland consumption, defined by EUROSTAT as **Gross inland energy consumption**, sometimes abbreviated as **gross inland consumption**, which is the total energy demand of a country or region. It represents the quantity of energy necessary to satisfy inland consumption of the geographical entity under consideration.

Gross inland energy consumption covers (i) consumption by the energy sector itself; (ii) distribution and transformation losses; (iii) final energy consumption by end users; (iv) 'statistical differences' (not already captured in the figures on primary energy consumption and final energy consumption). More details can be found on the website of EUROSTAT [16].

The cost parameters concerning EU indigenous production are assumed to be constant over the year, and the values are derived from RYSTAD data as indicated in Table 1.

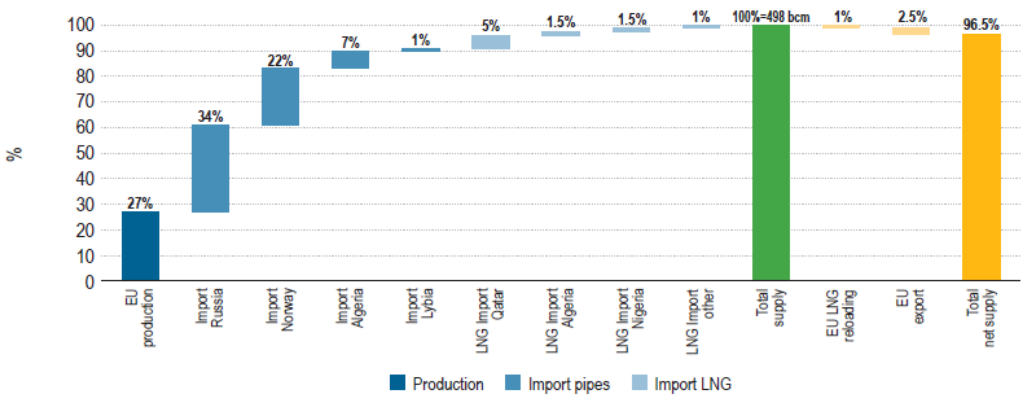
Table 1. Extraction costs for EU indigenous production of natural gas

Region	Node	EUR/GJ
United Kingdom	GB	5.60
The Netherlands	NL	4.11
Germany	DE	7.44
Italy	IT	4.93
Romania	RO	6.69
Other nodes		5.75

Source: RYSTAD

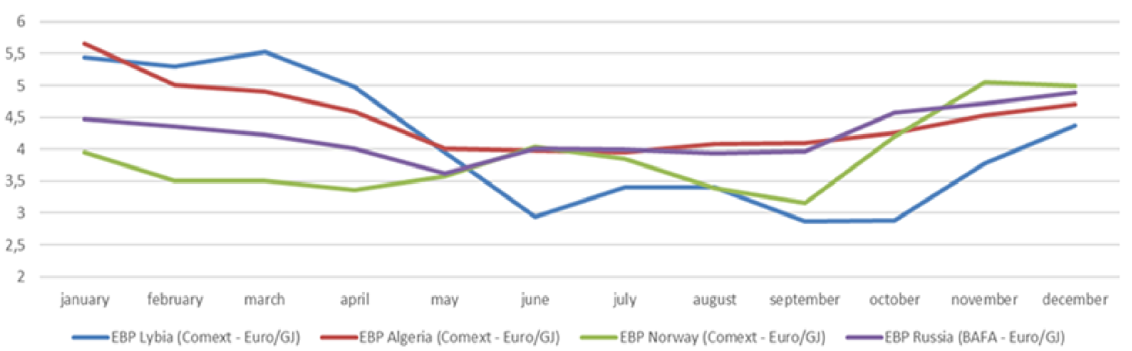
The pipeline imports from extra-EU suppliers include the Norwegian, the Russian, Algerian and Libyan production of gas (Figure 17.). The modelling approach for the exogenous production is different as only a cost profile (Figure 18) is defined with no volume limitations. Additional gas supply are imported via LNG terminals. With the exception of Norway, all the other extra-EU regions supplying natural gas are only modelled as a gas source node with no demand, no storage and no LNG terminal.

Figure 17. EU gas supply portfolio by origin



Source: ACER based on International Energy Agency (IEA), Eurostat and GIGNL[19].

Figure 18. Cost of pipeline gas from major suppliers in 2016 (EUR/GJ)



Source: JRC based on Comext and BAFA

4.2 The conventional demand of natural gas

The model generates a least cost solution for the electricity generation mix, combining in an integrated market the power and the gas supply chain. Hence, the demand of gas for power production ("Gas to Power", or G2P) is a result generated by the model, depending on the fuel consumption of the gas fired power plants. An important input provided to the model is hence the demand of gas for other uses (i.e.: residential and industrial heating, transport and other processes), which is called conventional demand. The total demand of gas for each region is the sum of the G2P and the conventional demand. Some statistical sources (as the dataset JODI [19]) provide the detail of the G2P and non-G2P gas consumption with annual data, which is not suitable to provide the model with accurate time profiles. The total consumption of natural gas with daily granularity has been obtained through a JRC survey involving the national Transmission System Operators, ENTSO-G and national regulators. When operational data on the total national demand were not available a mass-balance estimation has been applied to all supply sources to the Member State.

The gas demand for other sectors than power generation is modelled with an hourly profile for 24 countries (EU28 except Cyprus, Malta, Luxembourg and Croatia). For Croatia a constant gas demand of 2.78 GW is used as no profile was available. The gas demand for the other 3 countries represents less than 0.2% of the total EU28 and is neglected.

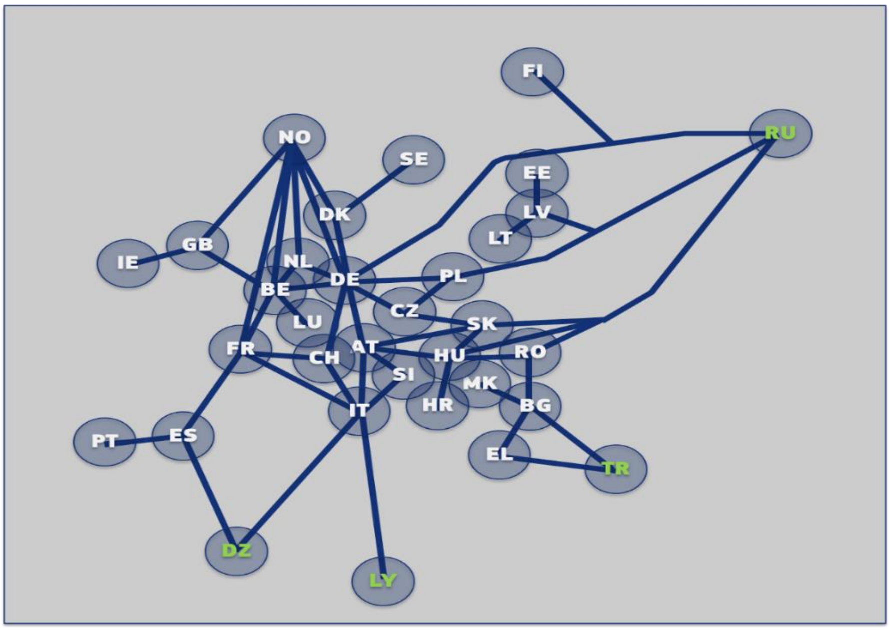
The gas demand for the power sector depends on the use of gas fired power plants, which are available in all EU28 countries (except Cyprus and Malta) and in the three following non EU28 countries:

- Macedonia, Republic of (MK)
- Norway (NO)
- Serbia (RS)

4.3 Gas transmission system

Figure 19 represents interconnections between the different regions in the model which allow to trade natural gas. Based on data provided by ENTSO-G, all the interconnection points connecting two adjacent regions are aggregated in one virtual pipeline. The main interconnector parameters are the directionality of the exchange and the maximum flow. Nodes with green labels have no explicit gas demand, they just supply gas to the system (RU, DZ, LY) or act as transit country (TR).

Figure 19. Interconnection network for pipeline gas trade



Source: JRC elaboration

4.4 Gas liquefaction and regasification terminals

In addition to pipeline gas imports, LNG represents another exogenous gas source with unconstrained volume. LNG is modelled as a unique source; its price is the average of the monthly spot landed prices in BE, ES, FR, UK, as indicated in Table 2.

Table 2. Spot landed prices of LNG

Year	Month	BE	ES	FR	UK	Average
		EUR/GJ	EUR/GJ	EUR/GJ	EUR/GJ	EUR/GJ
2016	1	3.86	4.68	4.68	4.14	4.34
2016	2	3.43	4.03	4.03	3.56	3.76
2016	3	3.33	3.64	3.64	3.43	3.51
2016	4	3.18	3.43	3.43	3.33	3.34
2016	5	3.59	3.72	3.72	3.51	3.64
2016	6	3.92	4.10	4.10	4.03	4.04
2016	7	3.98	4.24	4.24	3.98	4.11
2016	8	3.86	4.29	4.29	3.76	4.05
2016	9	3.70	4.48	4.48	3.84	4.12
2016	10	4.67	5.05	5.05	4.86	4.91
2016	11	5.12	5.52	5.52	5.36	5.38
2016	12	4.47	5.79	5.79	4.75	5.20

Source: JRC elaboration on Thomson Reuters Waterborne LNG data

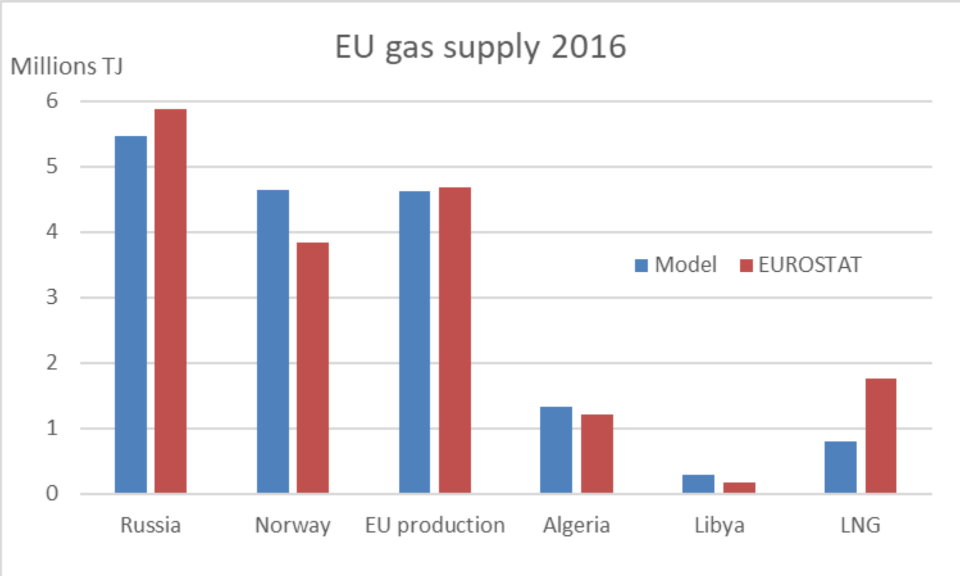
5 Evaluation of the model performance

The performance of the integrated model has been evaluated by comparing the base case results with statistics for the year 2016, both at European (EU28) level and at country level (mainly Italy).

5.1 Gas supply mix in Europe

The model is calculating the yearly total EU gas supply as 17.1 Million TJ, which represents only a small under-estimation (-2.2 % or -0.39 Million TJ) of the historical values [16]. Historical and model results values are compared in Figure 20. The difference can be explained by an underestimation of the gas demand for other sectors than power production. The lower total gas load corresponds roughly to the reduction of the Russian imports which are under-estimated by 7.3 % (-0.43 Million TJ). The model is also over-estimating the contribution from Norway by 21.4 % (+0.82 Million TJ), which is compensated by an underestimation of the LNG by 54.4 % (-0.95 Million TJ).

Figure 20. EU gas supply (model versus historical)

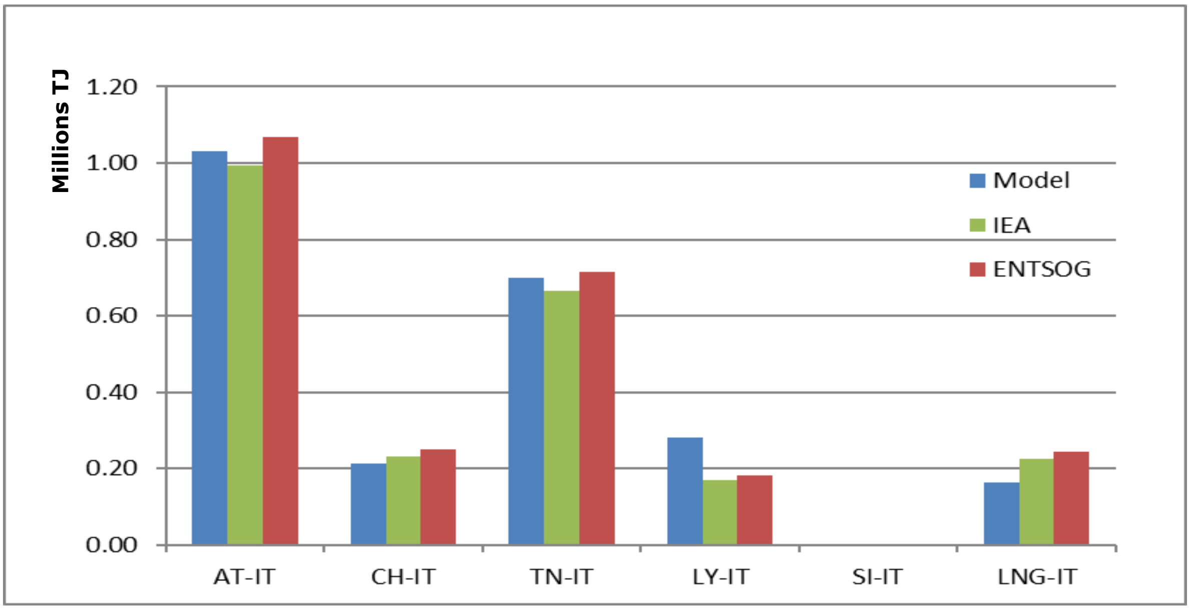


Source: JRC and EUROSTAT

5.2 Gas imports in Italy

According to the IEA statistics [15] in 2016, Italy's total gas imports were 2.28 million TJ. Italy's main import (43.5%) was Russian gas through the Austrian interconnection. The second gas provider (29%) was Algeria through the Tunisian interconnection. The rest of the imports were provided by the Swiss interconnector (10.2%), the LNG terminals (9.8 %) and by Libya (7.4 %). Figure 21. indicates that the model in Italy reproduces relatively well the statistics. Results lay generally between the historical values provided by the two reported statistical data sources (IEA [15] and ENTSO-G [18]), except for the smallest import sources (LNG, Libya and Switzerland). Compared with the IEA import statistics, the model is over-estimating the total imports by 4.5%. The model over-estimates the imports through Austria, Tunisia and Libya. The imports from Switzerland and the LNG are under-estimated. However if compared with ENTSO-G statistics, the model is under-estimating the total imports by 3% and only Libyan imports are over-estimated.

Figure 21. Italian gas imports in 2016 (model and historical)

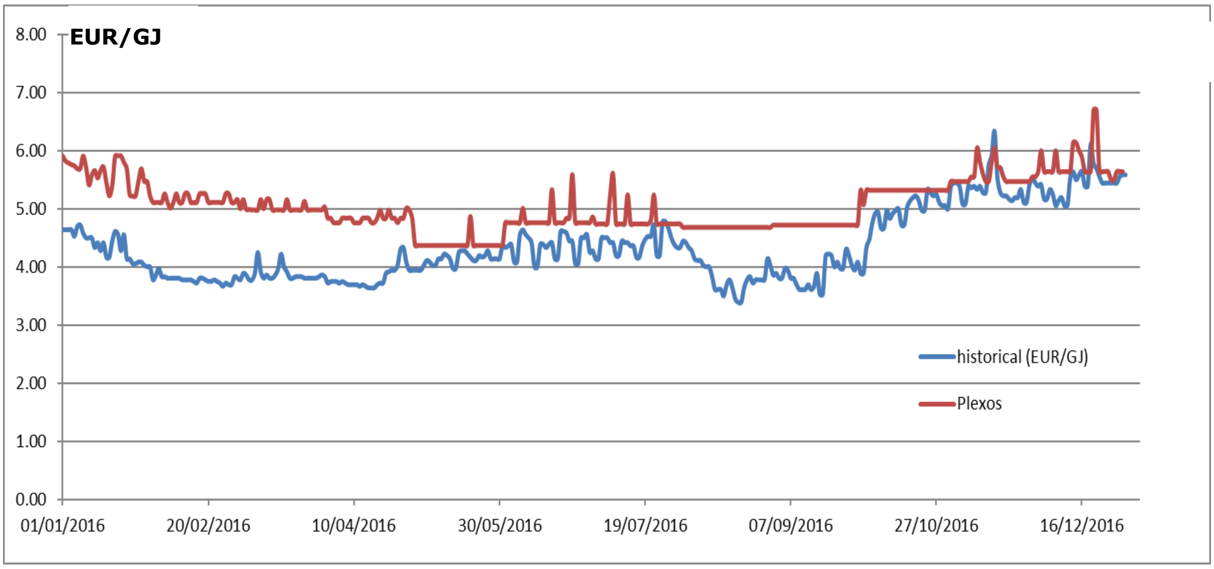


Source: JRC, ENTSO-G and IEA

5.3 Evolution of gas prices in Italy

The model results concerning the evolution of gas prices are compared in Figure 22. for the Italian market. The gas prices calculated by the model are higher than historical prices [17]. In average, modelled gas prices are 0.7 EUR/GJ higher than historical values. The relative error is in average +17.6 %, with a minimum of -7.7% and a maximum of 42.4 %.

Figure 22. Italian gas prices (model and historical)

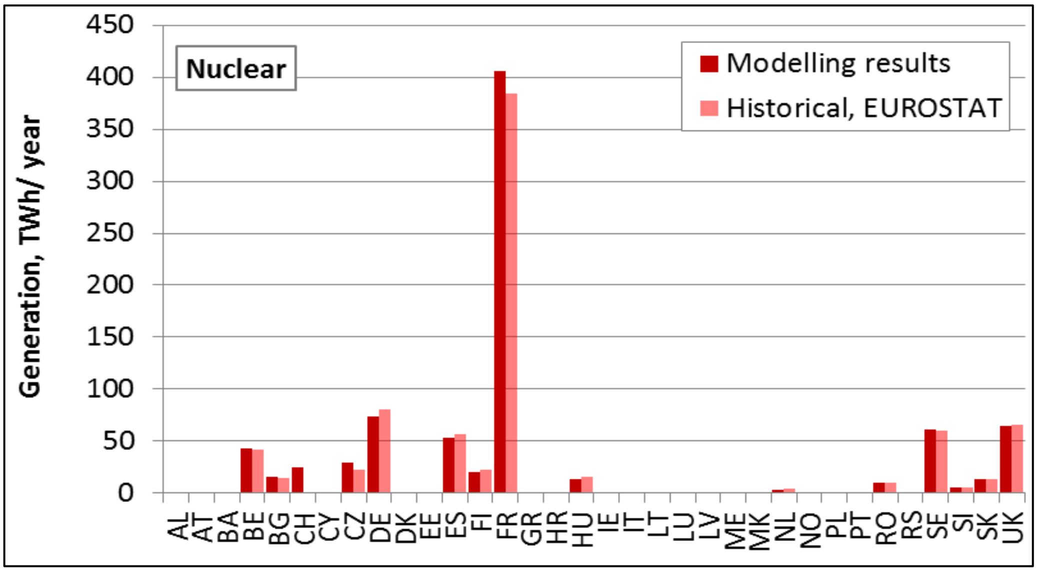


Source: JRC

5.4 EU Fuel mix for power production

In this section, the fuel mix annual results are compared with the historical data provided by EUROSTAT [16], at a country level and at European level. Concerning nuclear electricity (Figure 23), the simulated annual country generation is close to the 2016 statistics. The generation by the dominant producer France is overestimated by 6% in the model.

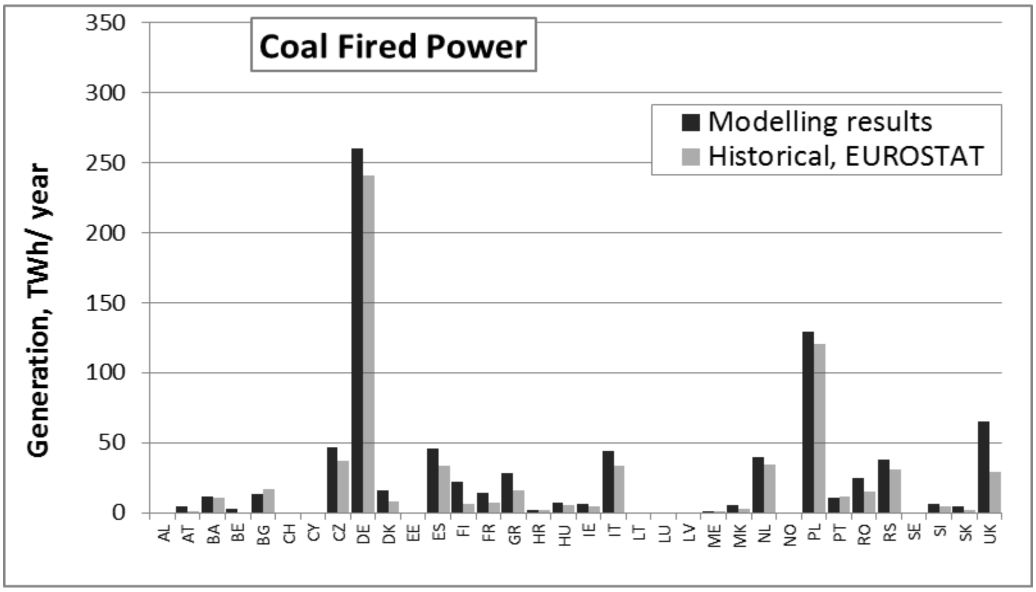
Figure 23. Yearly production by nuclear power plants in 2016 (model and EUROSTAT)



Source: JRC and EUROSTAT

The results for coal electricity indicate in most countries an overestimation compared with the real production in 2016. For the two main producers (Germany and Poland), the model has a limited error of respectively +8% and +7%. For other countries however, the relative overestimation can be much higher, e. g. reaching 126% for the UK.

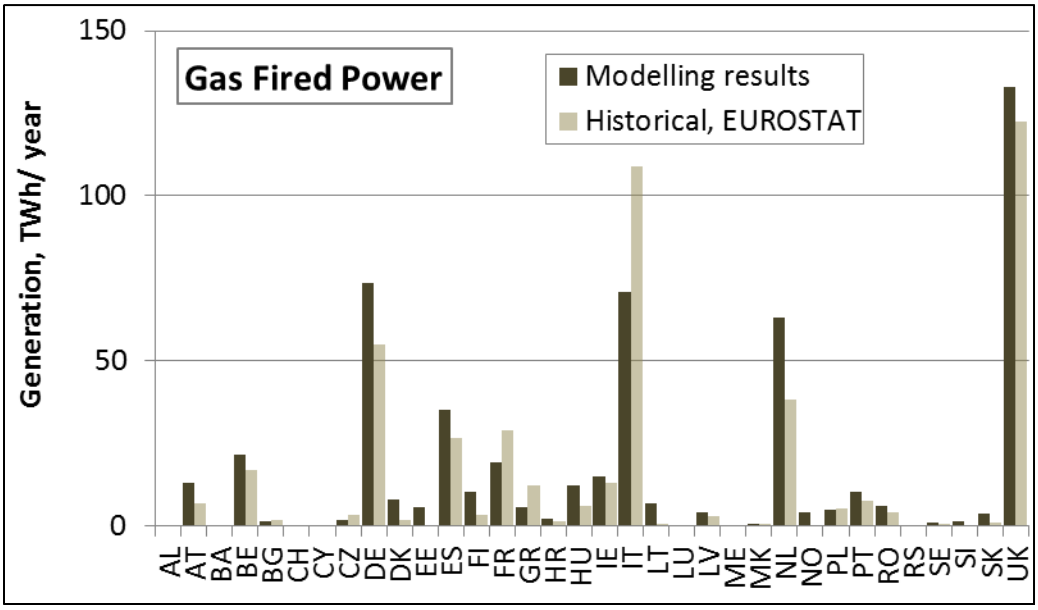
Figure 24. Yearly production by coal fired power plants in 2016 (model and EUROSTAT)



Source: JRC and EUROSTAT

For gas fired power plants (Figure 25), the generation is in most countries overestimated, except in a few cases i.e. Italy and France. The total generation by gas fired plants is 13.6 % higher in the model compared to EUROSTAT [16]. One reason can be the unique relatively optimistic heat rate used for the whole generation fleet.

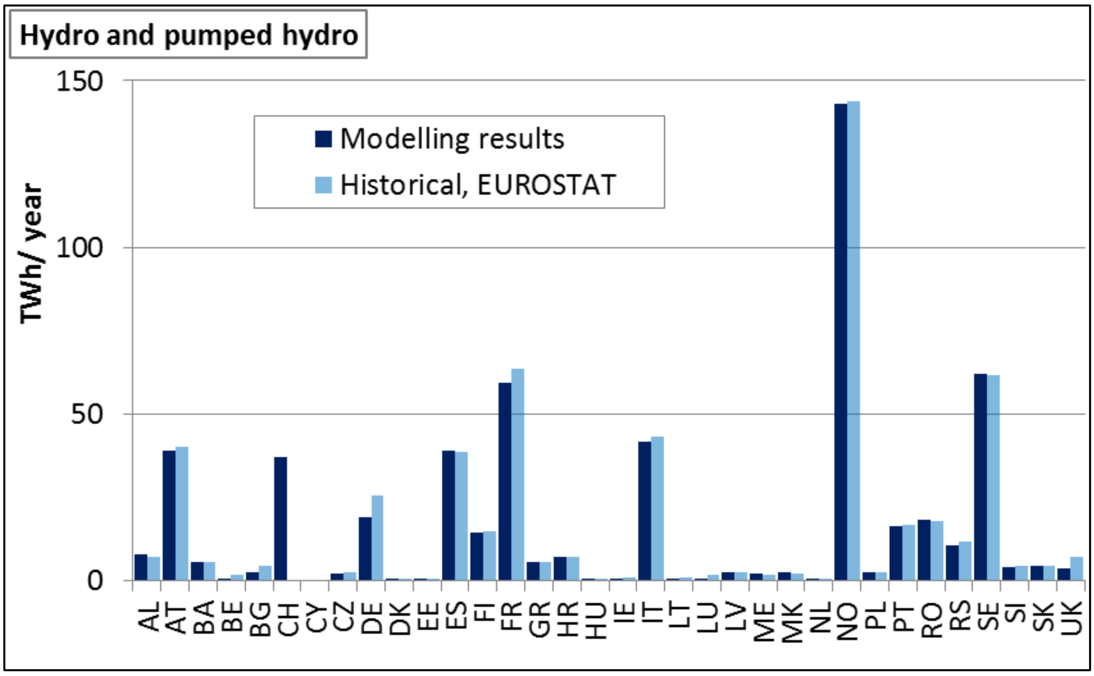
Figure 25. Yearly production by gas fired power plants in 2016 (model and EUROSTAT)



Source: JRC and EUROSTAT

The generation by hydro plants (including pumping units) is well in line with the historical values (Figure 26). For Switzerland the EUROSTAT data is missing.

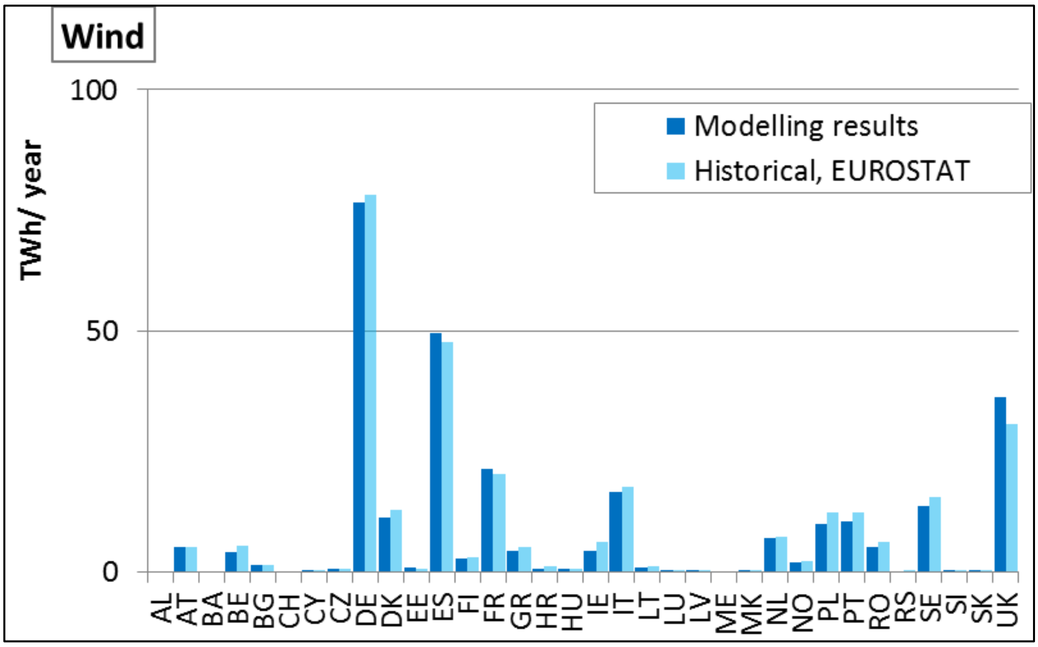
Figure 26. Yearly production by hydro and pumped hydro power plants in 2016 (model and EUROSTAT)



Source: JRC and EUROSTAT

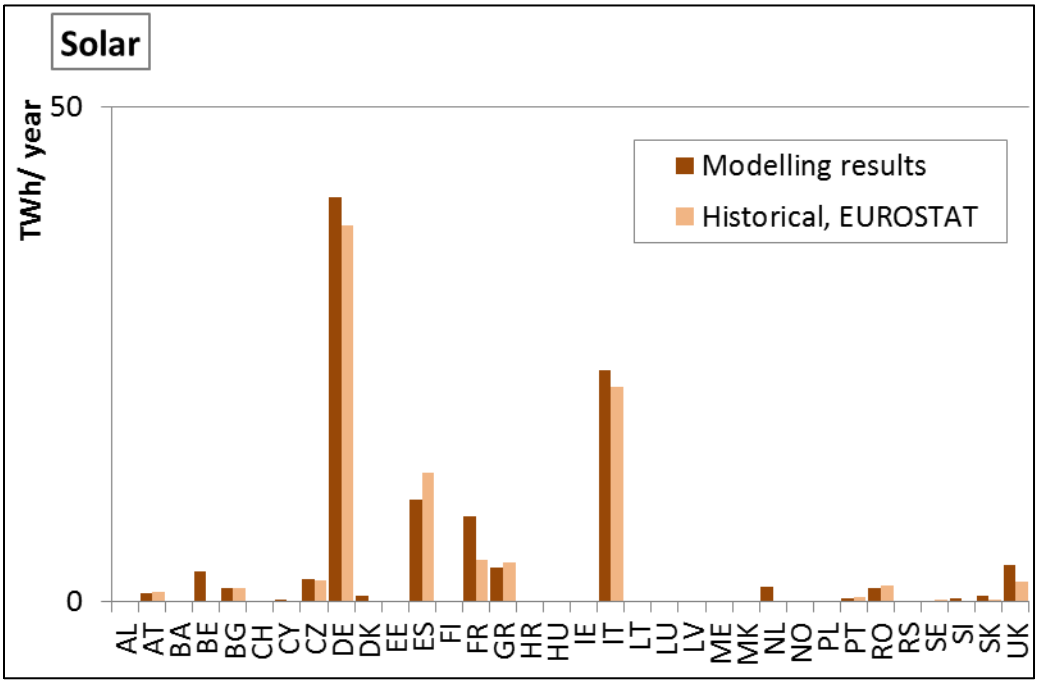
Modelled production from variable RES (Wind and Solar) is generally well in line with the EUROSTAT statistics as can be seen in Figure 27 and Figure 28.

Figure 27. Yearly production by wind power plants in 2016 (model and EUROSTAT)



Source: JRC and EUROSTAT

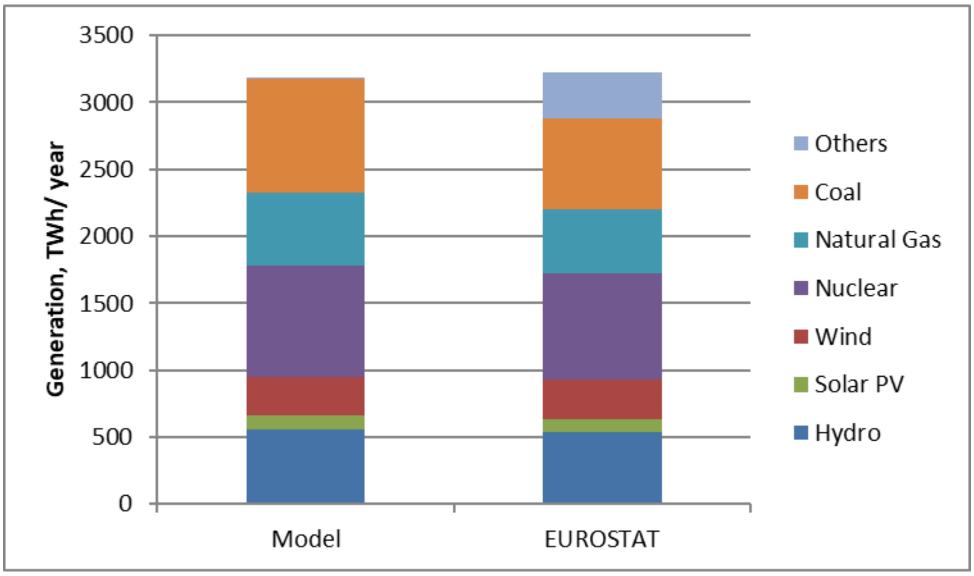
Figure 28. Yearly production by solar power plants in 2016 (model and EUROSTAT)



Source: JRC and EUROSTAT

The power generation mix results at EU level are summarized in Figure 29. The model is slightly under-estimating the total power generation. The main differences are due to the fact that EUROSTAT has a much more detailed granularity in terms of fuel sources than the model. EUROSTAT reports also about generators which are dispatched outside of the day-ahead market. The EUROSTAT category "Others" groups generator types which have no corresponding category in the model. It can be seen that the generation of the "Others" group has been compensated in the model by an increase of production by coal and gas fired power plants. For the other technologies (wind, solar, hydro, nuclear), the model errors are negligible.

Figure 29. European power mix in 2016 (model and EUROSTAT)

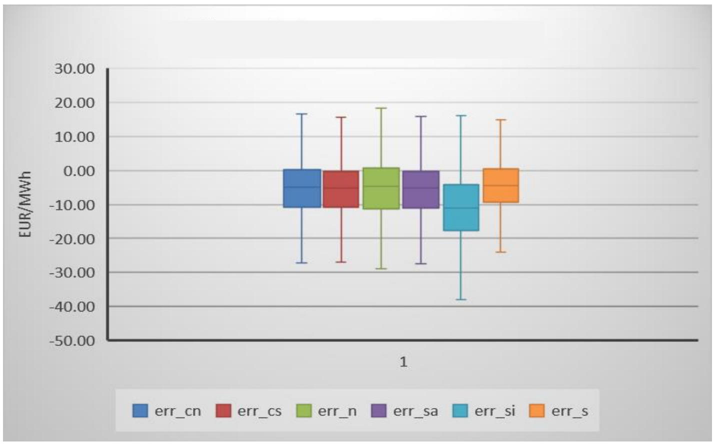


Source: JRC and EUROSTAT

5.5 Evolution of electricity prices in Italy

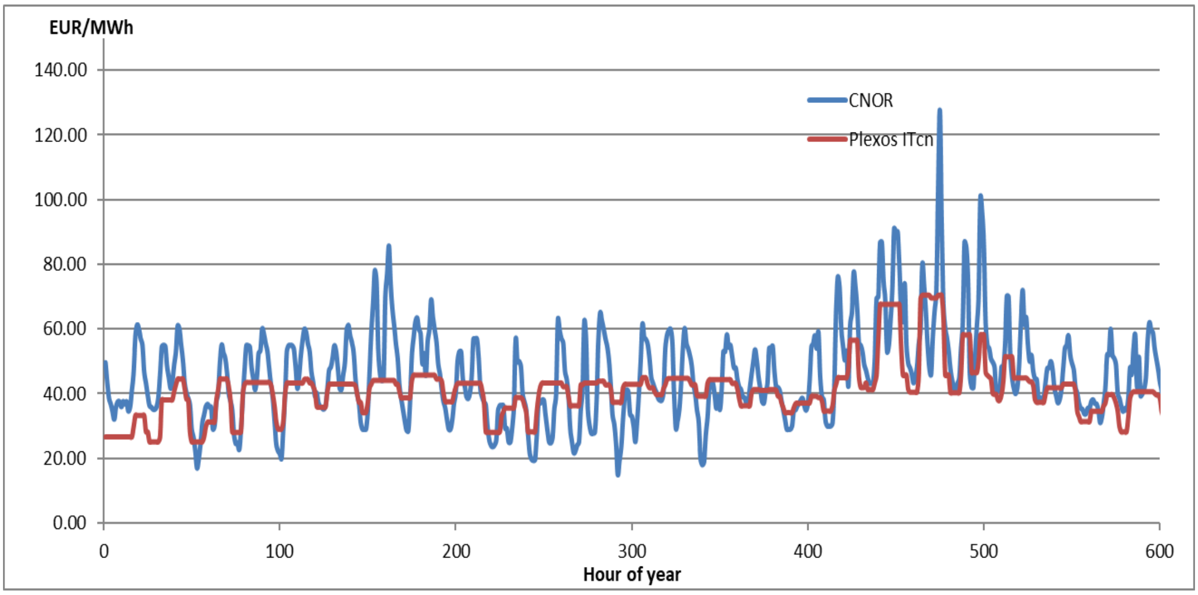
The electricity prices in all Italian bidding zones except Sicily are in the model in average 5 EUR/MWh lower than the historical statistics (Figure 30). In Sicily the difference is even higher with an average underestimation of 10 EUR/MWh. Figure 31 presents an example of hourly evolution of prices for the first 600 hours of the year in the Central-North market zone. The daily price variations are captured by the model but with less volatility than in the reality. These differences can be due to technical parameters (heat rate functions, start-up procedures,...) and economical parameters (strategies of market players) which are not accurately simulated by the model.

Figure 30. Electricity prices differences in 2016 (model – historical [17])



Source: JRC

Figure 31. Hourly evolution of electricity prices in the Italian Central-North zone (model versus historical [17])



Source: JRC

5.6 Small crisis analysis

The base case model results include some short periods of limited unserved energy (Table 3), representing less than 0.01 % of the total load. These simulated events which do not correspond to real black-outs in 2016, are negligible on a yearly basis. They are however interesting to illustrate how the electricity market coupling works in the model in case of a small crisis.

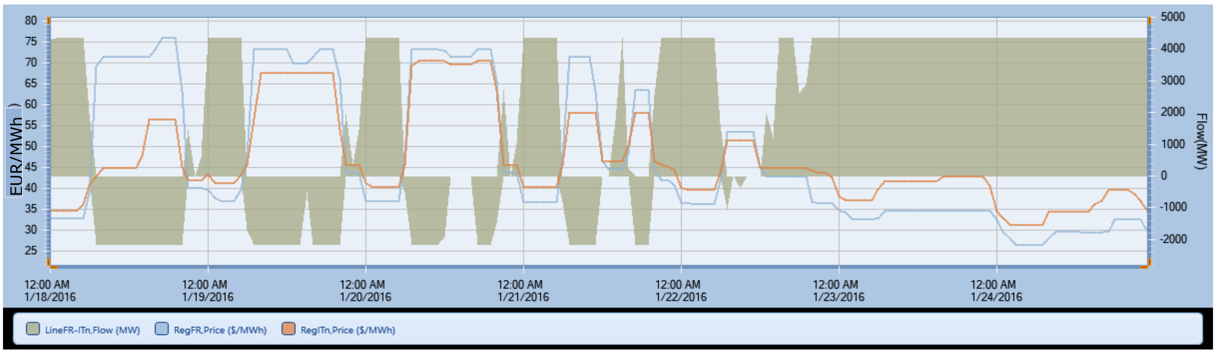
Table 3. Unserved energy results

Country	Unserved GWh
Poland	29.08
United Kingdom	22.66
Sweden	10.71
Finland	0.77
France	0.45

Source: JRC

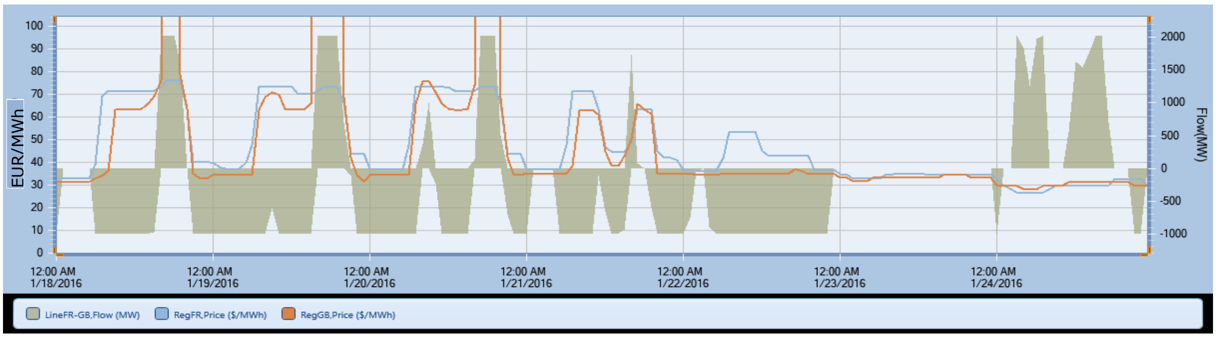
In order to investigate the impact on Italy of high electricity prices, the simulation results for week 3 in 2016 are analyzed as example. Simulated prices go high due to unserved energy in the UK in the period 18-20.01.2016, with consequent higher price on the French market, triggering exports from North Italy to France. Figure 32 represents the power flowing through the interconnector FR-ITn from France to Italy. In normal situation Italy is always importing cheap nuclear power from France. However during the UK crisis, the flow reverses due to higher prices available in France. Figure 33 shows the corresponding flows from France to the UK, which reverse when prices go high in the UK. Figure 34 shows that the Italian pump-hydro storage units are activated during the same period, taking advantage of the high daily price fluctuations. Figure 35 indicates that gas fired power plants in zone ITn are used only when prices are high.

Figure 32. Electricity prices and interconnector flows between France and North Italy for week 3 in 2016 (model)



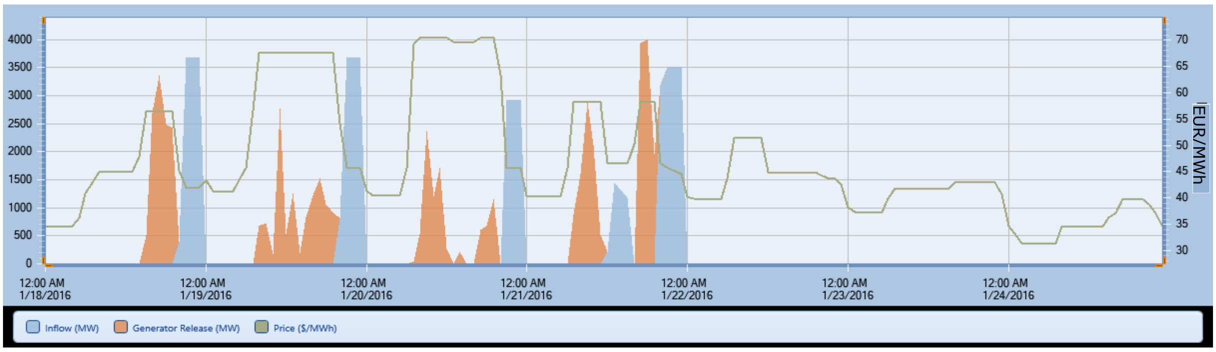
Source: JRC

Figure 33. Electricity prices and interconnector flows between France and Great-Britain for week 3 in 2016 (model)



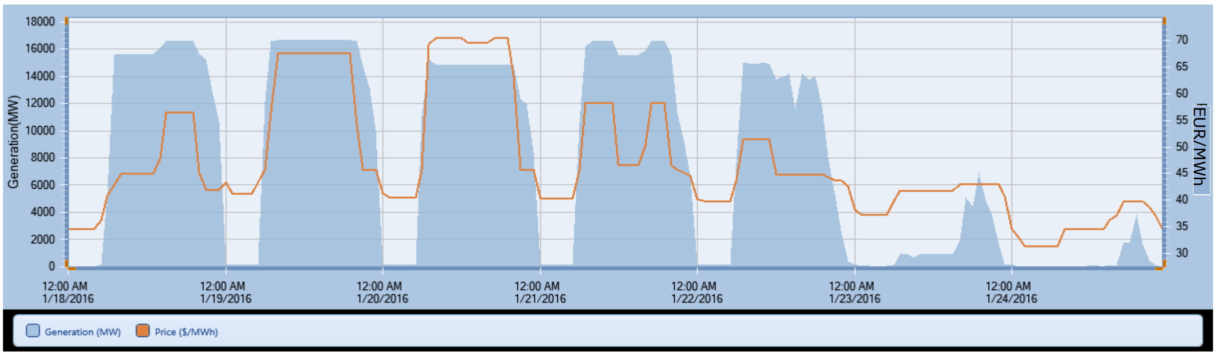
Source: JRC

Figure 34. Pump hydro generation and pumping (inflow) for week 3 in 2016 (model)



Source: JRC

Figure 35. Generation by Gas fired power for week 3 in 2016 (model)



Source: JRC

6 Conclusions

An integrated gas and electricity model has been built for a base case representing the EU gas and power system in 2016. The results of the model have been cross-checked with historical statistics in Italy and average annual errors are within acceptable limits for the indicators analysed.

A permanent bias has been identified for electricity prices, indicating a possible under-estimation of some technical or non technical generation costs. The daily price variations are captured by the model but with less volatility than in the reality. The differences can be due to technical parameters (heat rate function, start-up procedures) and economical parameters (strategies of market players) which are not correctly simulated by the model. This lower volatility in the electricity prices probably explains also why some assets like pump hydro storage are not used enough compared with historical records.

On the contrary to electricity, gas prices are slightly over-estimated in the simulations (+17 % in average in Italy).

Further work is needed to improve the model. Proposed areas for future developments are:

- Investigate the benefits of implementing more sophisticated heat rate functions for the generators. Especially gas fired units shall be investigated.
- Update the profile for gas demand by sectors other than power generation for Croatia and Luxembourg.
- Check in all EU countries if the gas demand by sectors other than power generation has not been under-estimated.
- Investigate competitiveness of LNG against Norwegian natural gas.
- Analyse why modelled gas prices are higher in Italy compared to reality
- Identify parameters making the use of pump hydro storage more cost efficient.
- Include new and future infrastructure developments (TYNDPs, PCIs) to enable easy modelling of future scenarios.
- Investigate the benefits of modelling more precisely gas fired combined heat and power (CHP) generators, by taking into account the variation of their marginal cost due to the seasonal profile of the heat demand.

References

[1] Wesley J., Cole, Kenneth B., Medlock, Aditya and Jani: “A view to the future of natural gas and electricity: An integrated modeling approach”, Energy Economics. Volume 60, November 2016, Pages 486-496

[2] Burcin Cakir Erdener, Kwabena A. Pambour, Ricardo Bolado Lavin, Berna Dengiz: “An integrated simulation model for analysing electricity and gas systems”, International Journal of Electrical Power & Energy Systems, Volume 61, October 2014, Pages 410-420

[3] Christos Ordoudis, Pierre Pinson, Juan M. Morales: “An Integrated Market for Electricity and Natural Gas Systems with Stochastic Power Producers”, European Journal of Operational Research, Volume 272, Issue 2, 16 January 2019, Pages 642-654

[4] Modassar Chaudrya, Nick Jenkins, Goran Strbac: “Multi-time period combined gas and electricity network optimisation”, Electric Power Systems Research, Volume 78, Issue 7, July 2008, Pages 1265-1279

[5] Dominik Möst, Holger Perlwitz: “Prospects of gas supply until 2020 in Europe and its relevance for the power sector in the context of emission trading”, Energy, Volume 34, Issue 10, October 2009, Pages 1510-1522

[6] Vahid Zahedi Rad, S. Ali Torabi, Hamed Shakouri G.: “Joint electricity generation and transmission expansion planning under integrated gas and power system”, Energy, Volume 167, 15 January 2019, Pages 523-537

[7] J.P.Deane, M.Ó Ciaráin, B.P.Ó Gallachóir: “An integrated gas and electricity model of the EU energy system to examine supply interruptions”, Applied Energy, Volume 193, 1 May 2017, Pages 479-490

[8] Fernandez Blanco Carramolino, R., Careri, F., Kavvadias, K., Hidalgo Gonzalez, I.,Zucker A. and Peteves, E.: “Systematic mapping of power system models: Expert survey”, EUR 28875 EN, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-76462-2, doi:10.2760/422399, JRC109123

[9] K. Kanellopoulos, I. Hidalgo, H. Medarac, A. Zucker: “The Joint Research Centre Power Plant Database (JRC-PPDB) - A European Power Plant Database for energy modelling”, EUR 28549 EN, doi:10.2760/329310

[10] Purvins A., Sereno L., Ardelean M., Covrig C. et al.: “Submarine power cable between Europe and North America: A techno-economic analysis”, Journal of Cleaner Production, Volume 186, 10 June 2018, Pages 131-145

[11] ENTSO-E transparency website: https://transparency.entsoe.eu/

[12] Renewable Ninja database: http://renewables.ninja

[13] S. Pfenninger and I. Staffell: “Long-term patterns of European PV output using 30 years of validated hourly reanalysis and satellite data”, Energy, vol. 114, p. 1251–1265, 2016

[14] I. Staffell and S. Pfenninger: "Using bias-corrected reanalysis to simulate current and future wind power output", Energy, vol. 114, p. 1224–1239, 2016

[15] IEA natural gas statistics: https://www.iea.org/topics/naturalgas/statistics/

[16] EUROSTAT statistics: https://ec.europa.eu/eurostat/data/browse-statistics-by-theme

[17] Italian energy market statistics: https://www.mercatoelettrico.org/

[18] ENTSO-G transparency website: https://transparency.entsog.eu/

[19] JODI transparency website: https://www.jodidata.org/gas/

[20] ACER public data sets website: https://aegis.acer.europa.eu/chest/

List of abbreviations and definitions

ACER	Agency for the Cooperation of Energy Regulators
CHP	Combined heat and power
ENTSO-E	European Network of Transmission System Operators for Electricity
ENTSO-G	European Network of Transmission System Operators for Gas
EUROSTAT	European Statistical Office
G2P	gas to power
GIIGNL	International Group of Liquefied Natural Gas Importers
IEA	International Energy Agency
IP	Interconnection Points
ITxx	Italian bidding zones for electricity
LNG	Liquefied natural gas
PCI	Project of common interest
RES	renewable energy source
TYNDP	Ten years national development plan

List of figures

List of tables

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