METIS Technical Note T8

METIS Demand and Heat Modules

METIS Technical Notes
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1. Abbreviations

Abbreviation	Definition
AC	Air-conditioning
BEV	Battery electric vehicle
CAPEX	Capital expenditures
CHP	Combined heat and power
DH	District heating
DHW	Domestic hot water
DSR	Demand side response
EC	European Commission
ENTSO-E	*European Network of Transmission System Operators for Electricity*
ENTSO-G	*European Network of Transmission System Operators for Gas*
EV	Electric vehicle
FED	Final energy demand
G2CHP	Gas-to-combined heat and power
G2DH	Gas-to-district heat
G2FED	Gas-to-final energy demand
G2P	Gas-to-power
HP	Heat pump
MS	Member States
nTS	non-thermosensitive
OPEX	Operational expenditures
PHEV	Plug-in hybrid electric vehicle
RemNTs	Non-thermosensitive remainder
RemTS	Thermosensitive remainder
TS	Thermosensitive

2. INTRODUCTION

METIS is a project initiated by the European Commission's DG ENER for the development of an energy modelling software, with the aim to further support DG ENER's evidence-based policy making, especially in the areas of electricity, heat and gas.

In METIS, the power system is represented by a network in which each node stands for a geographical zone (typically one country) that can be linked to other zones via transmission assets. A number of assets are attached to the node, representing all production, storage and consumption assets of energy at this node (cf. Figure 1). The METIS model aims at minimising the overall cost of the system to maintain a supply/demand equilibrium at each node and at any point in time.

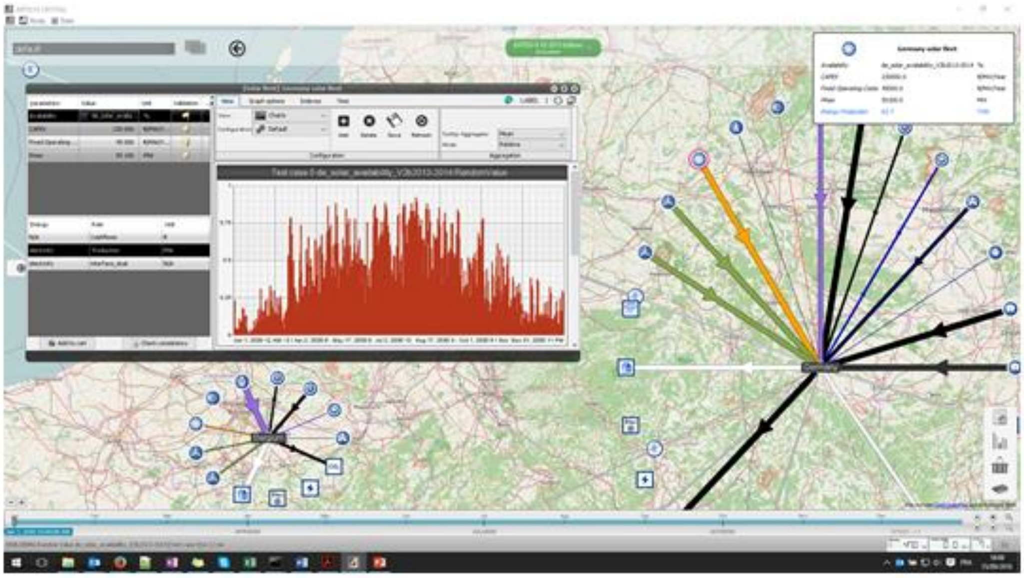


Figure 1: METIS models displayed in the Crystal Super Grid user interface

In the first versions of METIS, electricity and gas demand were considered as static, exogenous hourly/daily consumption time series, based on external sources, only varying in function of the selected weather year (see the METIS Technical Note 1, [1]).

The newly developed *METIS demand module* allows to further disaggregate the demand and to perform a detailed modelling of flexible consumers. This includes the disaggregation of the electricity and gas demand between end-uses and the detailed description how the hourly/daily demand profile (and in particular demand peaks) will evolve over time and across different scenarios. The end-use specific representation of demand enables the explicit modelling of flexible consumers (such as electric vehicles or heat pumps) and the adjustment of demand in response to market price signals.

The decomposition and projection of hourly/daily electricity and gas load curves builds upon historic load curves, using end-use specific load profiles and annual demand projections from the European Commission scenarios (cf. Section 3).

The load of all flexible (electric) end-uses is jointly optimised with all other generation, storage and transmission assets. This optimisation is subject to a number of assumptions and constraints that describe the behaviour of the individual consumers (cf. Section 4).

To allow full benefit from the extended METIS demand side functionalities, new indicators are included in the METIS demand module to easily explore the results (cf. Section 5).

In addition, the *METIS heat module* adds an additional energy dimension to the METIS tool. It allows to simulate the future configuration and operation of district heating networks. Section 6 explains the conceptual design of the METIS heat module and introduces the major functionalities.

Section 7 provides an overview of the scenarios incorporated in METIS demand and heat modules.

3. Load curve projection in the METIS demand module

The objective of the load curve projection is to estimate the evolution of the load pattern of a country's overall electricity or gas system load across different scenarios and years. This projection is based on historic load curves, using end-use specific load profiles and taking into account the annual demand projections from the European Commission's scenarios. The load curve projection reveals information about load peaks, ramp rates and load volatility. A disaggregated representation of the load allows to analyse in detail selected end-uses and their impact on the overall load curve or their potential contribution to demand side response (DSR).

The overall approach for the load curve projection is the same for all energy carriers and explained in the following. The peculiarities in the treatment of electricity and gas demand are outlined in further detail in Sections 3.2 and 3.3.

3.1. Introduction of the general approach

The load curve projection consists of three major steps, that are summarised in Figure 3.

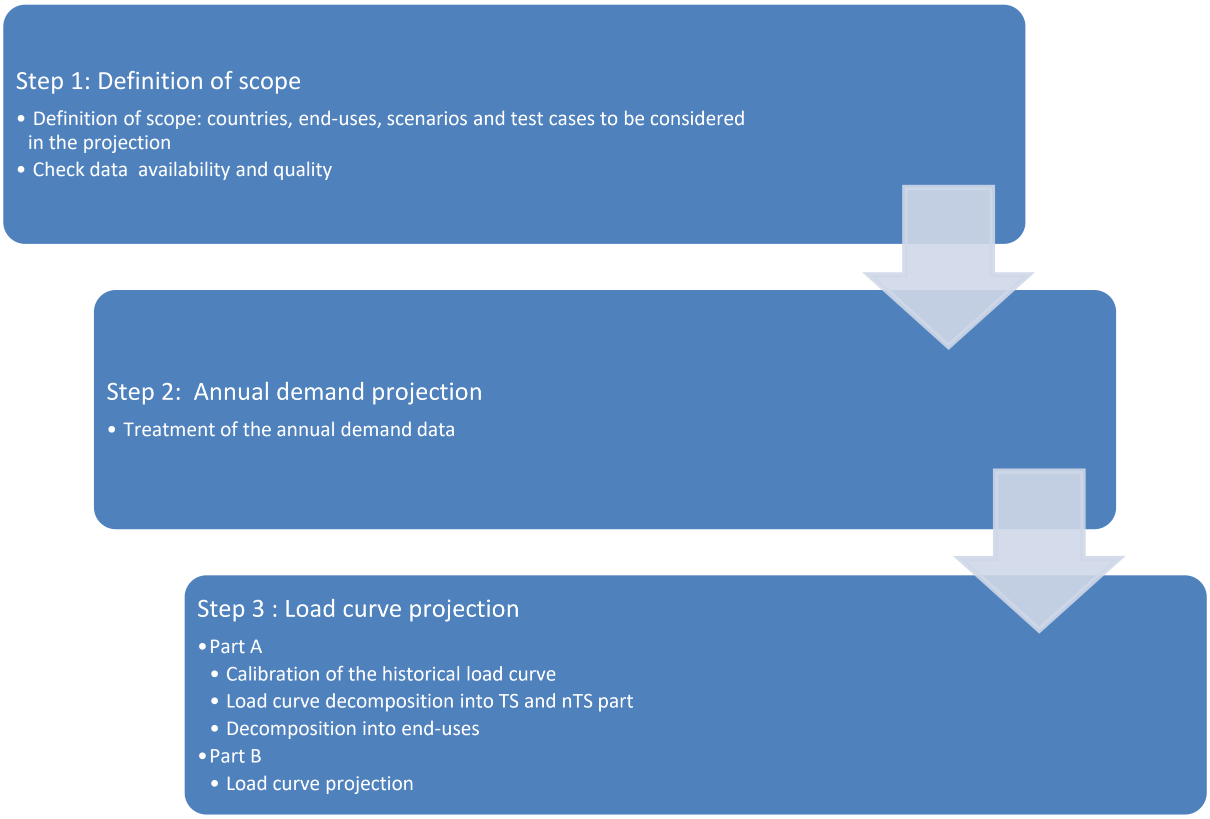


Figure 2: Schema of global approach

The first step is a preliminary step, it is to define the scope of the load curve projection, in terms of countries, end-uses, scenarios and test cases (i.e. weather years) that shall be covered. The scope depends on the quality and availability of the respective required input data. This is in particular relevant with respect to the end-use specific profiles.

In a second step, Artelys collected and consolidated all annual demand data available for historic years and the projection years. If required, data is extrapolated to counties with data gaps (e.g. non-EU countries).

The last step (Step 3 in Figure 2) involves the actual projection of the hourly/daily load curve. This part is divided into several sub-steps. The sub-steps 1-3 (Part A) imply the calibration and decomposition of a historic load curve. These steps were carried out once by Artelys and generate all required elements for a scenario-based load curve projection.

They thus do not need to be repeated by the METIS user.[1] Sub-step 4 (i.e. Part B) includes the actual projection of the load curve into the future. This sub-step may be adapted by the METIS user via the METIS demand module, taking into account his assumption on the evolution of overall and end-use specific energy demand[2].

1. The load curve projection starts from a historical load curve of a given country for the base year (e.g. 2015). The load curve is scaled according the historic annual demand provided by the IDEES database in case historic load curves were erroneous or incomplete.

Figure 3: Historic load curve on a sample day

2. The historical load curve is decomposed into a thermosensitive part and a non-thermosensitive part, by carrying out a statistical analysis that determines the part of the load that correlates with the hourly/daily temperature. The thermosensitive (TS) part is supposed to represent the demand of end-uses which depend on the ambient temperature (e.g. heating, air conditioning).[3] The non-thermosensitive (nTS) part represents the consumption of end-uses which are not depending to the temperature (e.g. electric appliances, industry). It is determined as the total load less the TS part and thus preserves all outliers and national peculiarities that cannot be captured by a fully synthetical load curve.

   Based on the determined relation between ambient temperature and thermosensitive demand, the hourly demand curve for all relevant test cases are generated. The TS part is generated as function of the temperature time series of the different weather years. The subsequent data treatment explained in the following is likewise applied to all test cases.

[1] This holds true if the user does not want to carry out a different decomposition (considering another set of end-uses) or use alternative decomposition input data (such as historic load, end-use load profiles or temperature data).

[2] In the delivered METIS version, the demand module is calibrated on demand data from the European Commission‘s Reference and EUCO30 scenarios.

[3] Given that this approach is purely driven by the correlation between temperature and demand, it may also include the demand from end-uses that do not depend from the temperature but feature a similar demand profile (such as lighting).

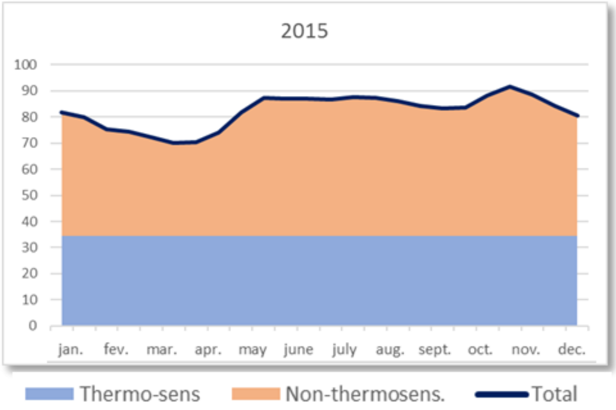


Figure 4: Split of the historical load curve into thermosensitive and non-thermosensitive demand

3. Both parts (TS and nTS) are further disaggregated into different end-uses and the remainder. The identification of the different end-uses in the load curve relies on exogenous end-use specific load profiles which are scaled according to the annual demand reported by the IDEES database for the base year. If the end-use is thermosensitive, the load profile and volume depend on the actual weather year and are generated for each test case. The remainder is calculated as difference between the overall TS or nTS part and the sum of the load from the individual end-uses (cf. Figure 5).

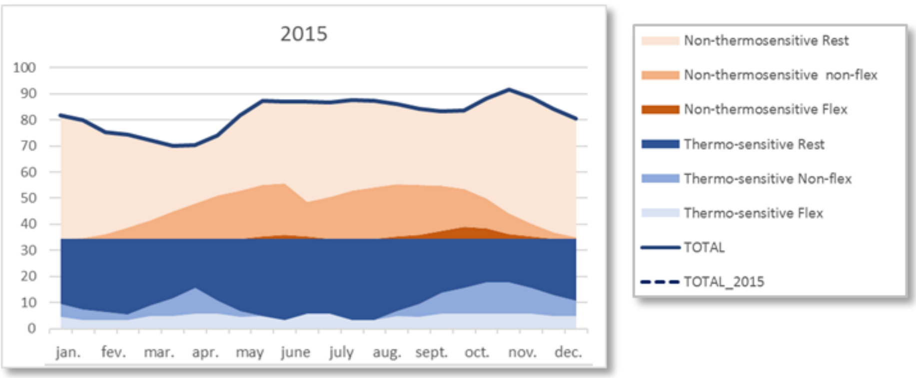


Figure 5: Split of the historical load curve into end-uses and remainders

Opportunities and limitations of the load curve decomposition

By considering more end-uses, the load curve projection results can be more precise and take into account more effects (reflecting the additional demand from new end-uses or diminishing demand from existing consumers). However, the number of end-uses individually considered in the load curve projection is constrained by two major aspects:

1) The representation of end-uses requires the information about the hourly/daily load profile and the historical as well as the future annual demand. This information is regularly subject to limited data availability. In METIS, load profile data collection is limited to the end-uses explicitly analysed in the individual METIS studies.

2) The demand module does not have for aim to fully decompose the historic load into its components, but to provide an explicit representation of the most relevant end-uses while keeping the remaining demand as an "anonymous" aggregated remainder (thus also referred to as "partial decomposition").

4. The decomposed load curve is then projected into the future, based on the evolution of annual demand, typically provided by the European Commission's scenario data (cf. Figure 6). This last step implies the scaling of the load curves of each end-use and the remainders according to the growth factors between the projection year (scenario data) and the base year (IDEES data). The sum of the projected load curves delivers a new aggregated load curve. As shown in Figure 6, the newly determined shape of the load curve is likely to differ from the initial shape.

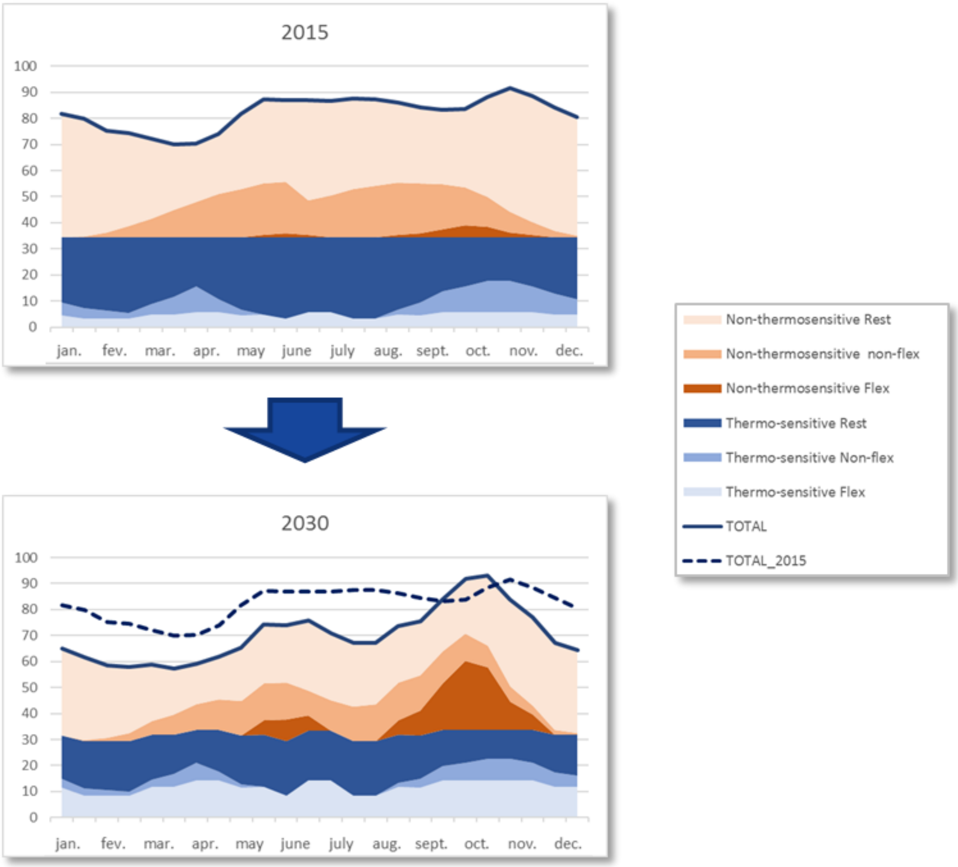


Figure 6: Projection of the decomposed load curve into the future

3.2. MODELLING THE ELECTRICITY DEMAND

3.2.1. *DEFINITION OF SCOPE*

In this part, the scope of the electricity load projection is defined in more detail. The scope depends on different parameters, namely the expected results from the METIS model and the available data. The objective is to create load curves by country for different end-uses, scenario and different temporal horizon.

Available data
Different datasets are used for the electricity load projection:

- Total electrical load curve by country in 2014 and 2015 from ENTSOE [5]
- Annual demand data by end-use are available for all EU MSs for the year 2015 from the JRC-IDEES database [2] and for the years 2030 and 2050 from the European Commission scenarios [3, 4]
- Hourly temperature between 1986 and 2015 (i.e. 30 test cases), based on the MERRA database [7]
- Calendar: National public holidays, summer and winter holidays
- Profile data for selected end-uses

Countries
Demand data at a country-level for 34 countries: the 28 EU Member States plus Norway, Switzerland, Bosnia and Herzegovina, FYROM, Montenegro and Serbia.

End-uses
The following electric end-uses are explicitly represented:

- Thermosensitive end-uses
  - Heat pumps (HP)
  - Air conditioning (AC)
- Non-thermosensitive end-uses
  - Domestic hot water (DHW, only for France and UK[4])
  - Plug-in hybrid electric vehicles (PHEV) charging at home
  - Plug-in hybrid electric vehicles charging at work
  - Battery electric vehicles (BEV) charging at home
  - Battery electric vehicles charging at work

Scenarios
The load curve projection builds upon the year 2015 and is realised for three European Commission scenarios: REF16-2030, EUCO30-2030 and EUCO30-2050.

Testcases
The thermal end-uses are simulated for 30 different test cases. Each test case represents the climatic conditions for one weather year between 1986 and 2015.

3.2.2. *ANNUAL DEMAND PROJECTION*

The compilation of annual electricity demand in the base year, based on the IDEES database, builds upon a set of assumptions[5]:

- Total electricity demand = Energy Available for Final Consumption + Distribution Losses + Consumption in Energy Sector - Own Use in Electricity, CHP and Heat Plants
- Air conditioning = Space cooling for residential[6]
- Heat pumps = Advanced electric heating
- TS part[7] = Space heating for residential + Space heating for tertiary + Space cooling for residential + Space cooling for tertiary
- Domestic hot water = Hot water for residential[8]
- Electric vehicles = Plug-in hybrid electric and battery electric vehicles

[4] Domestic hot water represents only boilers equipped with a hot water storage tank, as a load profile was only available for this technology. It is assumed that the majority of electric hot water boilers in France and the UK are equipped with a hot water tank and are thus categorised accordingly. For all other countries, electric hot water supply is not explicitly modelled.

[5] The different data categories comply with the names stated in the IDEES database.

[6] Space cooling for tertiary is considered in the thermosensitive remainder.

[7] The nTS part equals the *Total electricity demand* less the *TS part*.

[8] Applies only to the UK and France.

For the countries outside of the European Union, the total demand from ENTSO-E is used. The demand of end-uses is calculated with assumptions from neighbouring countries (i.e. share of total consumption). Table 1 gives an overview of these assumptions.

Table 1: Overview of assumptions for non-EU countries for calibration of base year demand

Countries (outside of the EU)	Reference country for the share of the end-use in total demand
Norway	Sweden
Switzerland	Austria
Bosnia-Herzegovina	Croatia
Montenegro, FYROM	Bulgaria
Serbia	Romania

Figure 7 illustrates the 2015 electricity demand data from IDEES with the cumulated hourly demand provided by ENTSO-E.

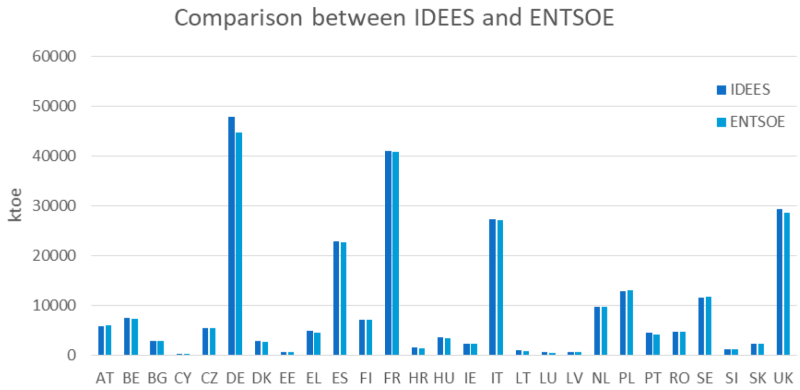


Figure 7: Comparison between IDEES and ENTSOE in 2015

For the load curve projection, annual demand data are compiled based on the European Commission scenario data.

Total electricity demand = Final electricity demand + Electricity demand for refineries & other uses of the energy branch + Transmission and distribution losses.

For all other end-uses and the TS part, the same categories as for the base year are used.

For the non-EU countries, the evolution of annual demand as well as the share of end-uses in total demand follows assumptions applied for the base year calculation (cf. Table 1).

Figure 8 presents the evolution of annual electricity demand for Germany and France for 2015, as well as the scenarios EUCO30-2030 and EUCO30-2050.

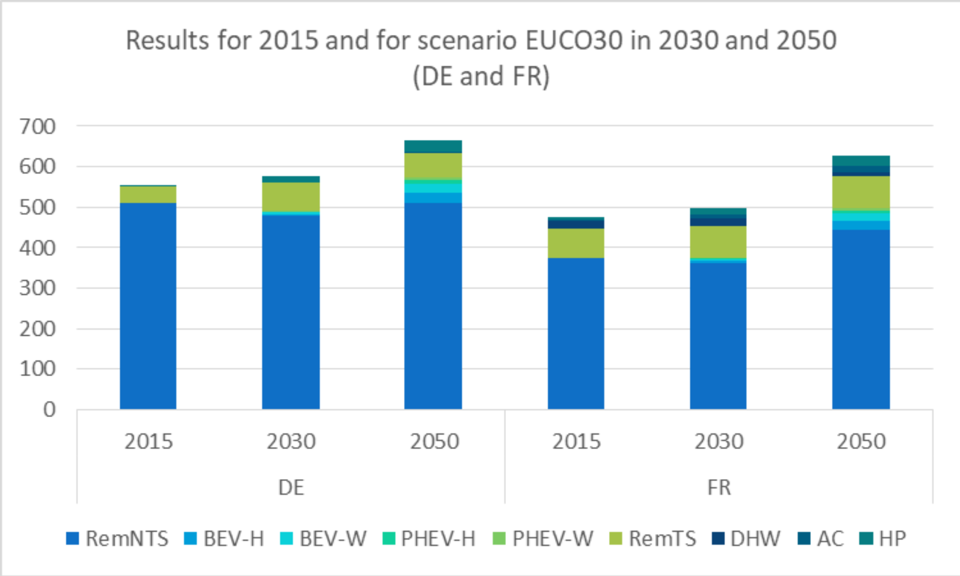


Figure 8: Overview of annual demand evolution in Germany (left) and France (right)

3.2.3. *LOAD CURVE PROJECTION*

Load curve decomposition into TS and nTS part

The hourly historical load curves from ENTSO-E are calibrated to the annual total electricity demand given by IDEES. The calibrated load curve is split into the TS and the nTS part. The relation between temperature and demand is determined based on two historic years (2014 and 2015, if the data is available). A statistical model is calibrated[9] to fit the thermosensitive part with reference temperatures for each country. The statistical model used is a GAM model (Generalized additive model). The model (one for each country) depends on the calendar days, the *exceptional days* (public holidays, summer holiday period and winter holiday period) and the hourly temperatures. However, the actual load curve projection builds only upon the load curve of the year 2015. Figure 9 illustrates the decomposition into the TS and the nTS part for France.

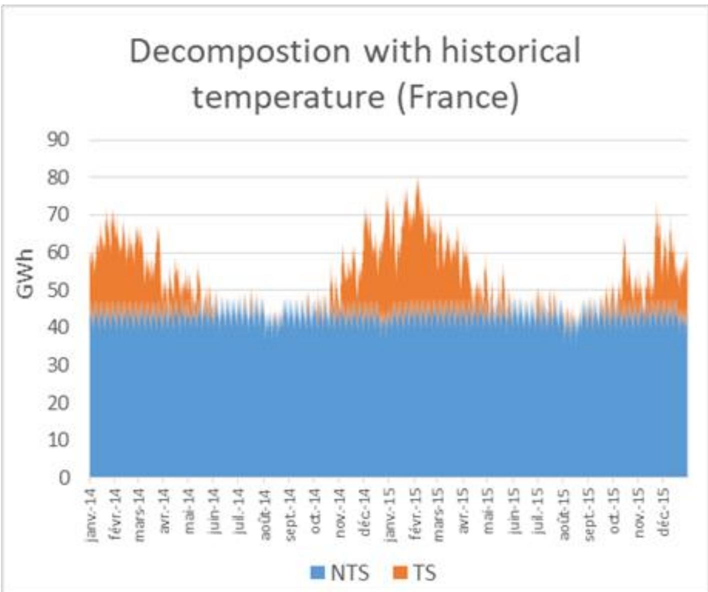


Figure 9: Decomposition of France's 2015 load curve (fully modelled), considering the historic temperature

[9] In the present case, the software *Artelys Crystal Forecast* was used to calibrate the statistical model. It builds upon the software RStudio for designing statistical models. For further information see: https://www.artelys.com/en/applications/artelys-crystal-forecast

Decomposition into end-uses and remainder

Subsequently, the load curve is further decomposed, detailing the load of the individual end-uses. Table 2 provides an overview of all considered end-uses and their related assumptions.

Table 2: Overview of the individual end-uses considered and the related assumptions

End-Use	Type	Profile source	Projection calculation
Heat pumps	Thermosensitive end-use	Profile defined in METIS study S6 [8]	Application of the specified formula
Air conditioning		AC profile based on [9]	Approximation via linear model
Domestic hot water		DHW profile based on [10]	Direct application of the profile
Thermosensitive remainder		Calculation by difference	Linear model
PHEV home charge	Non-thermosensitive end-use	Two profiles available (smart/ immediate charging), defined in METIS study S13 [11]	Direct application of the profile
PHEV work charge			
BEV home charge			
BEV work charge			
Non-thermosensitive remainder		Calculation by difference	Direct application (Base year 2015)

The TS remainder is calculated as the difference between the TS part of the load curve and the load profiles of the individual TS end-uses. The nTS remainder equals the overall system load, less the TS part (cf. Figure 10) and less the load profile of the non-thermosensitive end-uses. It thus also captures the demand of all other non-thermosensitive end-uses and includes typical outliers and peculiarities from the historical 2015 profile.

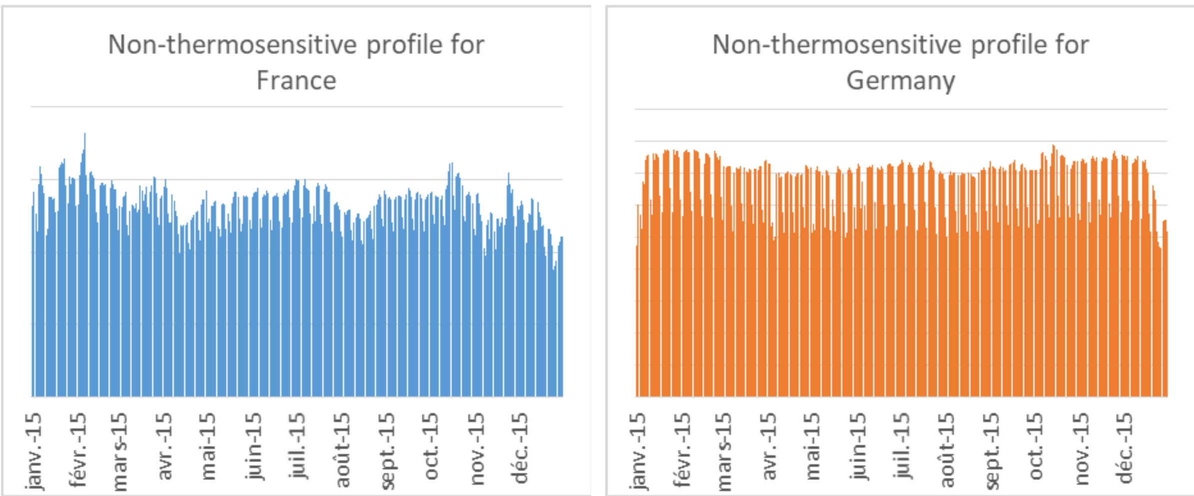


Figure 10: Non-thermosensitive profile in the year 2015 in France and Germany

Load curve projection

The last step is to calculate the scenario projections. This step may be realised by the METIS user in order to generate future load curves that are in line with his assumptions about the evolution of annual (end-us specific) electricity demand. The load curves by end-uses are multiplied with the different annual demand volumes and deliver all loads curve by end-uses, by test case, by scenario and by country, which then serve as basis to determine the overall aggregated curve.

Figure 11 and Figure 12 show the overall aggregated load curve for the base year and the three scenarios for Germany and France, respectively.

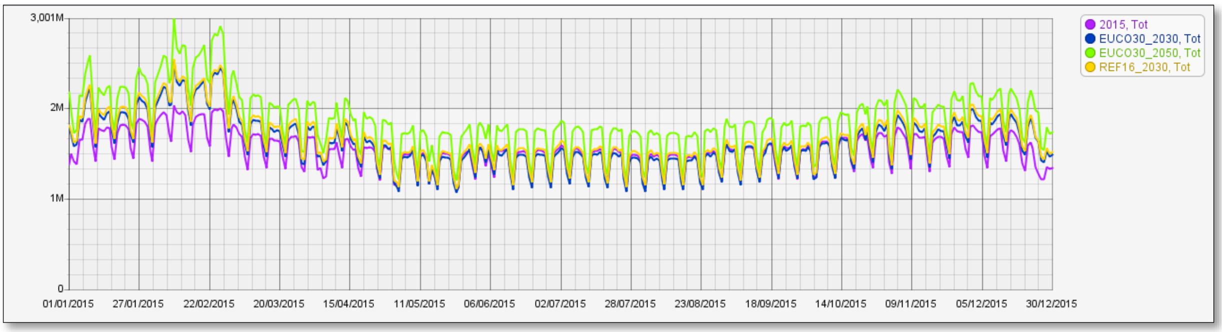


Figure 11: Comparison by scenarios for Germany (day aggregation)

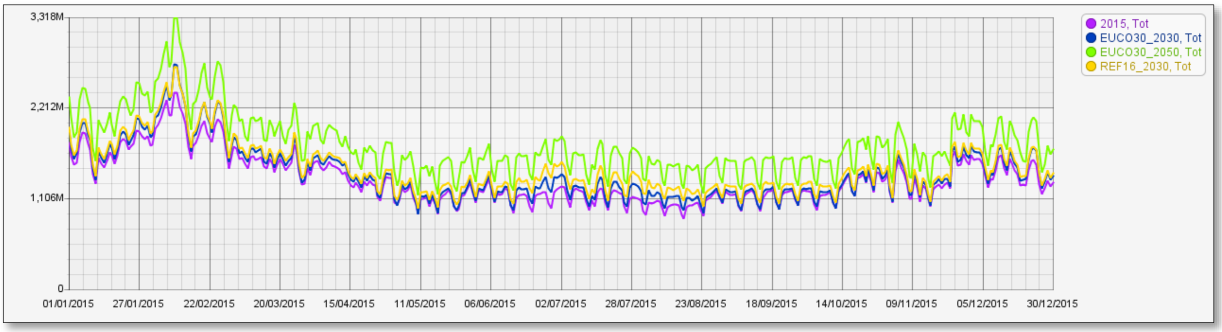
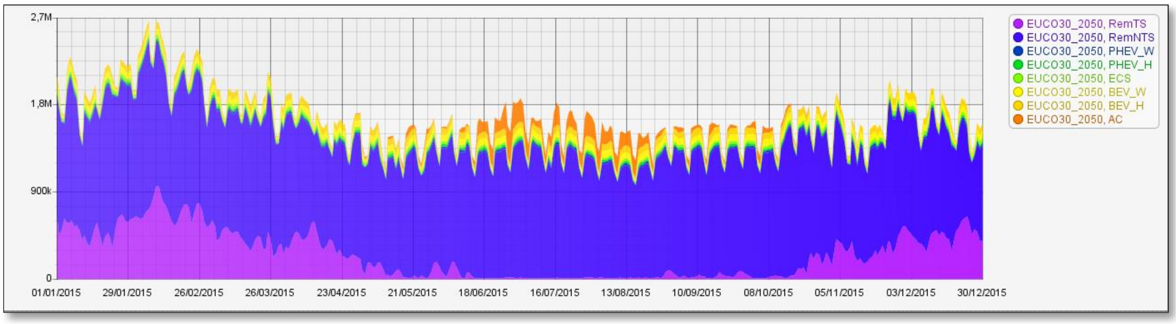
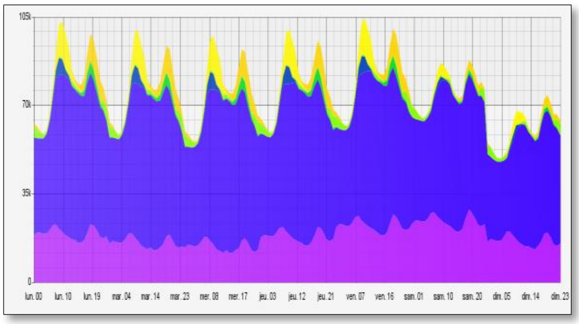


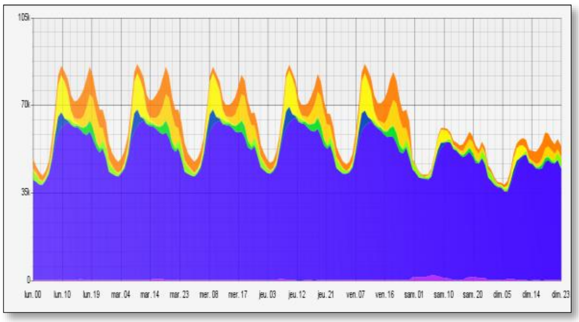
Figure 12: Comparison by scenarios for France (day aggregation)

Figure 13 shows the load curve from France projected under the EUCO30-2050 scenario, exhibiting the contribution of the individual end-uses.



a) Annual load curve, distinguished by end-use, aggregated on a daily basis.





b) Decomposition by end-use for a winter week (hours of week)

c) Decomposition by end-use for a summer week (hours of week)

Figure 13: France's load curve under the EUCO30-2050 scenario, distinguished by end-use.

Figure 14 illustrates Germany's load curve under the EUCO30-2050 scenario (aggregated on a daily basis) for five different test cases. Figure 15 depicts the variation in load for the two different EV charging scenarios, *immediate* and *smart+immediate* charging.

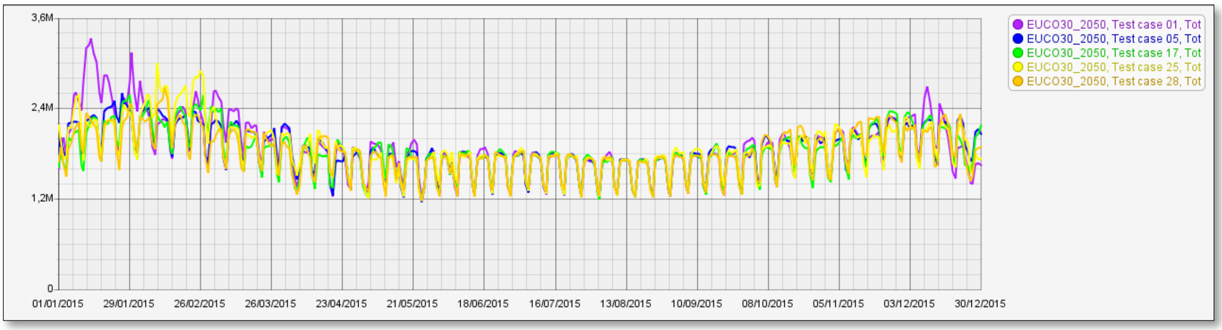


Figure 14: Comparison for five test cases for Germany (day-wise aggregation).

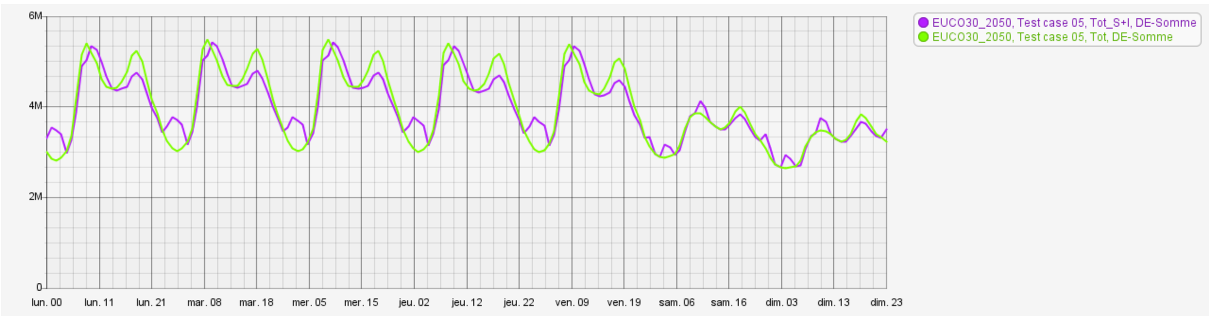


Figure 15: Comparison between immediate charging and smart+immediate charging for electric vehicles in Germany, EUCO30-2050 scenario (hourly one-week excerpt).

The determined disaggregated load curves for the different prospective scenarios are directly available in the METIS demand module. Starting from this data, the user may change the demand volume or the demand profile of the individual end-uses. The updated end-use load curve is then automatically incorporated in the national system load curve. The demand characteristics of the individual end-use assets may by selecting the respective end-use asset (cf. Figure 16).

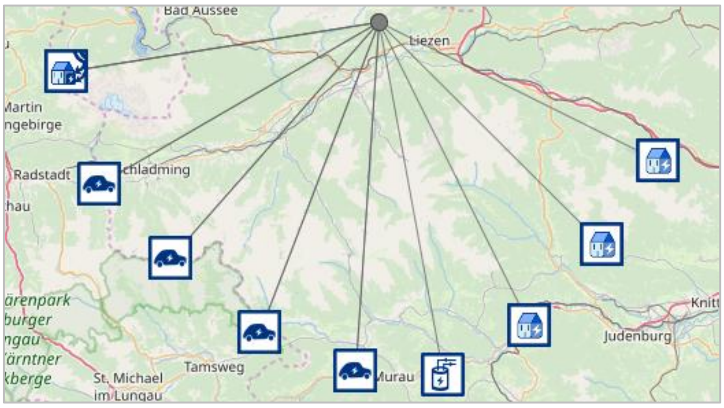


Figure 16: Illustration of the individual end-use demand assets in the METIS user interface

3.3. MODELLING THE GAS DEMAND

The approach for gas modelling is similar to the one for electricity. The major differences consist of the disaggregation by end-uses and the fact that gas demand curves exhibit a daily and not an hourly granularity.

3.3.1. *DEFINITION OF SCOPE*

Available data

Different datasets are used for the gas load projection:

- The basis for the decomposition of the load curve consists of historic ENTSO-G load curves (with daily granularity) [6]. For some countries data is available for the years 2014 and 2015, for others the data is only accessible for a single year or not at all (cf. Table 3).
- Annual demand data are available for all EU MSs for the year 2015 from the IDEES database [2] and for the years 2030 and 2050 from the European Commission scenarios [3, 4]
- Hourly temperature between 1986 and 2015 (average daily temperature is calculated) [7]
- Calendar: National public holidays, summer and winter holidays

Table 3: Availability of historical ENTSO-G data

Available year	Countries
2014	ES, NL
2015	EE, EL
2014 and 2015	BE, BG, DE, FR, HR, HU, IT, PL, PT, RO, SE, SI, GB
No data	AT, CZ, DK, FI, IE, LT, LU, LV, SK, NO, CH, BA, MK, RS

Countries
Demand data are provided at a country level and covers the same countries than the electricity demand modelling. The following three countries do not consume gas and are thus not considered in the modelling: Montenegro (ME), Malta (MT) and Cyprus (CY).

End-uses
Given the data availability in the IDEES database as well as in the scenario data from the European Commission, the following gas end-uses are explicitly considered:

- gas for (electricity-only) power plants
- gas for CHP plants
- gas for DH heating plants
- gas for final energy demand

Demand of all four end-uses is further subdivided into a TS and a nTS part.

Scenarios
The load curve projection builds upon the year 2015 and is realised for three European Commission scenarios: REF16-2030, EUCO30-2030 and EUCO30-2050.

Testcases
The thermal end-uses are simulated for 30 different test cases. Each test case represents the climatic conditions for one weather year between 1986 and 2015.

3.3.2. *ANNUAL DEMAND PROJECTION*

As basis for the load curve projection it is necessary to determine the annual gas demand by country and by end-use for the base year. The historical gas demand listed in the IDEES database is allocated to the four end-use categories as follows[10]:

- Gas for electric-only thermal power plants (G2P)
- Gas for CHP thermal power plants (G2CHP)
- Gas for district heat (G2DH)
- Gas for final energy demand (G2FED):
  - Transport
  - Industry: gas needed for steam processes and other processes such as low enthalpy heat
  - Residential: gas needed for space heating and cooling, cooking and water heating
  - Services: like residential sector, gas is needed for space heating and cooling, cooking and water heating
  - Agriculture

The IDEES database only contains information for EU MSs. For non-EU countries, data from Eurostat is used (see Section 3.3.3 for further information).

For the projection of gas demand, annual demand data relies on the European Commission scenarios[11]. Between the data structures of the IDEES database and the European Commission scenario data, only one difference has been identified. While the IDEES database distinguishes gas demand for power(-only) generation and for the use in CHP plants, the EC scenario data provides annual gas demand for power production (from G2P and G2CHP) and for heat production from CHPs (G2CHP only). To ensure consistency

[10] The detailed allocation of the different elements from the IDEES database to the four end-uses is given in Annex 9.1.

[11] The detailed allocation of the different elements from the EC scenario data to the four end-uses is shown in Annex 9.2.

between both data sources, a simplified correction of the scenario data is carried out. Gas demand related to power production in CHP plants is disentangled from the overall gas demand for power generation. By assuming a CHP plant produces heat and electricity with a 2:1 ratio, gas demand for CHP is increased by 50% while gas demand for power generation is reduced respectively. For some countries and scenarios, this hypothesis does not match PRIMES data. In that case, a new factor is computed, assuming that all gas demand for power production is used for CHP plant.
Apart from that, G2FED incorporates all demand related to industry, residential heating, tertiary heating, transport and agriculture.

Figure 17 illustrates the 2015 and EUCO30-2050 annual gas demand for all EU MS by end-use.

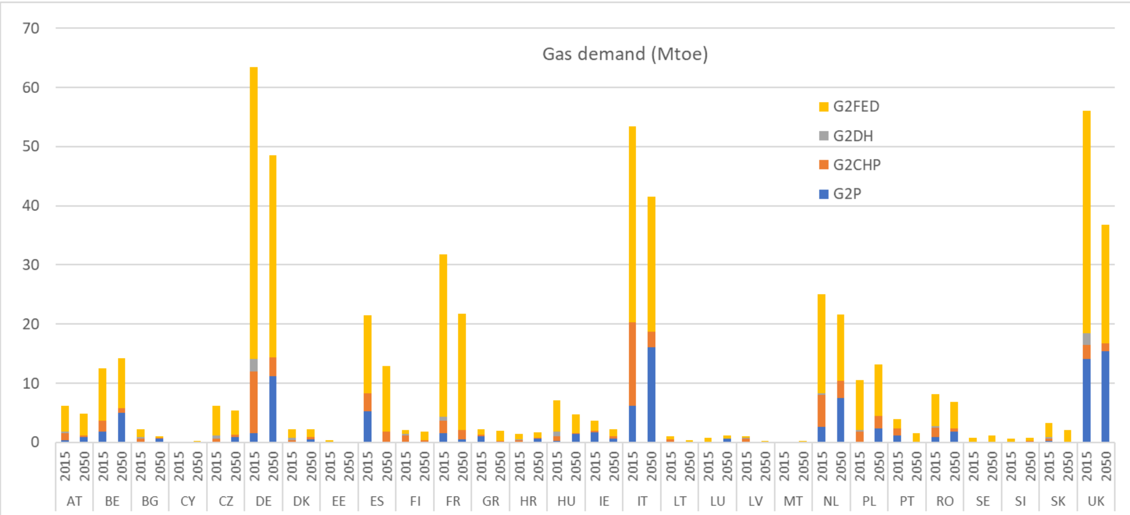


Figure 17: IDEES 2015 and EUCO30-2050 annual gas demand by end-use. Source: based on [2, 4]

3.3.3. *Load curve projection*

Based on the evolution of the annual demand by end-use and country, the actual load curve projection may be realised, following the general approach introduced in Section 3.1.

Calibration of the historical load curve

Prior to the decomposition of the historical load curve, the final gas consumption profile from ENTSO-G requires validation and calibration. If the country profile in the ENTSO-G database does not exist or exhibits incoherencies, the profile from a neighbouring country is chosen. Further, a scaling of the daily profile is realised with Eurostat data on a month-by-month level. Subsequently, consumption volumes of IDEES (EU MS) or Eurostat (others countries) are applied to the updated profiles for the purpose of calibration. Table 4 summarises the assumptions used for each country.

Table 4: Overview of reference country for gas demand profile and applied calibration approach

Code	Country	Other country profile used	Calibration approach
AT	Austria	Slovenia	Eurostat by month and IDEES on the year
BE	Belgium	/	
BG	Bulgaria	/	
CZ	Czech Republic	Romania	
DE	Germany	Netherlands	
DK	Denmark	Sweden	
EE	Estonia	/	
GR	Greece	/	
ES	Spain	/	
FI	Finland	Sweden	
FR	France	/	
HR	Croatia	/	
HU	Hungary	/	
IE	Ireland	Portugal	
IT	Italia	/	
LT	Lithuania	Estonia	
LU	Luxembourg	Belgium	
LV	Latvia	Estonia	
NL	Netherlands	/	
PL	Poland	/	
PT	Portugal	/	
RO	Romania	/	
SE	Sweden	/	
SI	Slovenia	/	
SK	Slovakia	Hungary	No scaling by month and IDEES on the year
GB	United Kingdom	/	Eurostat by month and IDEES on the year
NO	Norway	Sweden	Scaling by month from reference country and Eurostat on the year
CH	Switzerland	France	
BA	Bosnia Herzegovina	Croatia	
MK	Macedonia	Romania	
RS	Serbia	Croatia	

Load curve decomposition into TS and nTS part

The decomposition of the calibrated historical load curve into a TS and a nTS part is similar to the one for the electricity load curves. The learning algorithm uses historic load curves from the years 2014 and 2015 (if the data is available, cf. Table 5). A statistical model is calibrated to fit the thermosensitive part with reference temperatures. The statistical model used is a GAM model (Generalized additive model). The model (one for each country) depends on the calendar days, the *exceptional days* (public holidays, summer holiday period and winter holiday period) and the daily temperatures.

Table 5: Overview of the available historical gas load curves

Available year	Countries
2014	DE, ES, HR, IE, NL, PT, BA, RS
2015	EE, EL, FI, LT, LV, NO
2014 and 2015	AT, BE, BG, CZ, DK, FR, HU, IT, LU, PL, RO, SE, SI, SK, GB, CH, MK

Figure 18 illustrates the split of the 2015 gas load curve from France into the two parts. Similar to the approach applied for electricity, the nTS part of the load curve equals the overall system load less the TS part. It thus also captures typical outliers and peculiarities from the historical 2015 profile, which are important to preserve in order to obtain a realistic description of load variation and load peaks.

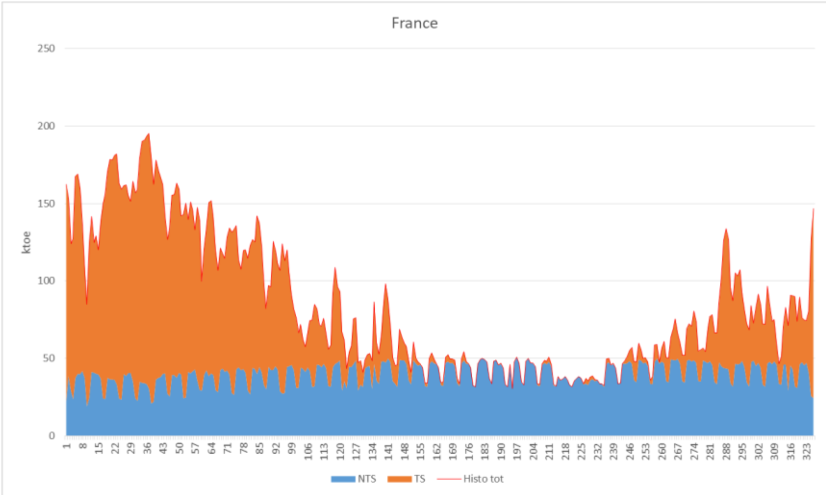


Figure 18: Decomposition of France's 2015 load curve into thermosensitive and non-thermosensitive part

Decomposition into end-uses

The approach applied for electricity (i.e. further decomposition of the TS and the nTS part of the load curve into distinct end-uses, applying specific load profiles, and remainders) may not be applied to the gas demand for want of country specific profiles of the individual end-use categories. Instead, it is assumed that all four end-use categories consist to varying degrees of a TS and an nTS part. Thus, based on the available information on the annual TS and nTS demand volumes, as well as the information about the demand by the four end-use categories, so-called split factors are determined that describe the share of each end-use in the TS and nTS part of the annual demand (and thus the respective parts of the load curve).

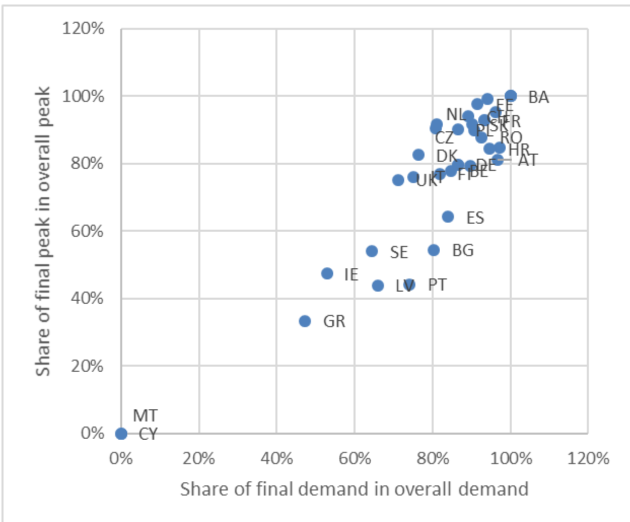


Figure 19: Ratio between share of final energy gas demand in overall gas demand and in overall gas peak load. Source: based on data from the 2020 Best Estimate Scenario, [12]

Additional orientation about the match between end-uses and the TS/nTS parts is derived from information included in ENTSO-G's TYNDP 2018 [12]. ENTSO-G provides data on annual and peak volume for final gas demand (i.e. industry, services, residential and transport, corresponding to G2FED and G2DH categories, in the following referred to as G2DH+FED) and gas-for-power demand (corresponding to G2P and G2CHP categories, in the following referred to as G2P+CHP). For the *2020 Best Estimate Scenario*, the TYNDP reveals the contribution of final energy demand (G2DH+FED) to the annual gas demand (sh_E) and the 14-day peak demand (sh_P), distinguished by country (cf. Figure 19). These values are used as an indicator to determine to what extent G2DH+FED contributes to the nTS/TS demand volumes. The following equation system determines the share of G2DH+FED in TS/nTS demand, sh_{TS}, shn_{TS}. It builds upon the assumption that the sum of G2DH+FED -based TS and nTS energy demand equal the total demand for G2DH+FED (i.e. the share of G2DH+FED, sh_E, given by ENTSO-G, multiplied with the total gas demand, E_{Total}, cf. Equation 1). Idem for peak demand (cf. Equation 2).

$$sh_{TS} \times E_{TS} + sh_{nTS} \times E_{nTS} = sh_E \times E_{Total} \quad (Equ.\ 1)$$

$$sh_{TS} \times P_{TS} + sh_{nTS} \times P_{nTS} = sh_P \times P_{Total} \quad (Equ.\ 2)$$

The determined shares of G2DH+FED in the TS and the nTS part allow then to allocate G2DH+FED to the TS and nTS part, and similar for G2P+CHP, cf. Figure 20.

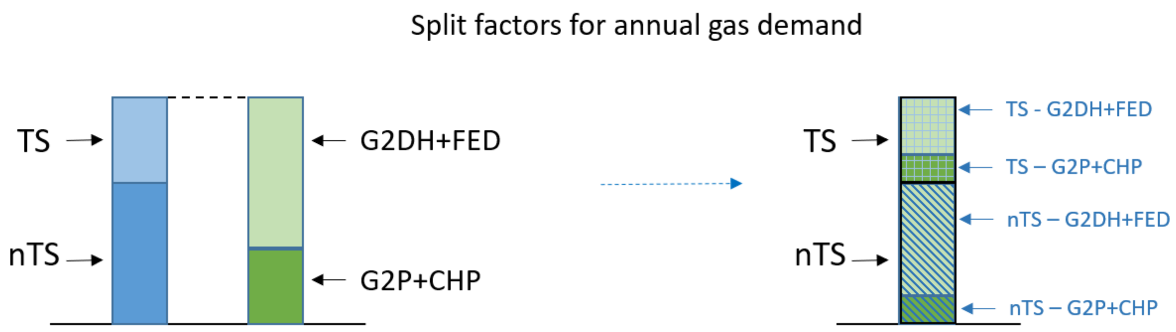


Figure 20: Matching gas demand split by end-use with the demand split by thermosensitivity

Given that the demand categories from ENTSO-G comprise several of the end-uses considered in the METIS methodology, a further breakdown to the level of the four end-uses is necessary. Thus, in a subsequent step the IDEES demand volumes are further split (following the logic shown in Table 6):

- The TS and nTS parts of G2DH+FED and G2P+CHP are allocated two the subcategories (G2DH, G2FED, G2P, G2CHP) by applying the ratios provided by the IDEES database
- In addition, if gas demand for space heating and cooling is allocated to TS-G2FED
- If space heating and cooling from IDEES exceeds the admissible TS-G2FED volume, the difference is allocated to the nTS–G2FED category. The same reasoning is performed for all other categories.
- Gas demand for water heating and cooling is allocated to the nTS-G2FED part.
- A final verification is carried out to ensure a correct balance between the overall TS and nTS parts.

In the end, the approach provides eight split factors that are fully coherent with the IDEES data and the determined TS and nTS volumes. They may be directly applied to the TS and nTS parts determined in the previous step.

Table 6: Allocation of IDEES end-uses to the TS and nTS categories

TS				**nTS**			
TS-G2P+CHP		**TS-G2DH+FED**		**nTS-G2P+CHP**		**nTS-G2DH+FED**	
TS – G2P	TS – G2CHP	TS – G2DH	TS – G2FED	nTS – G2P	nTS – G2CHP	nTS – G2DH	nTS – G2FED

Figure 21 shows the decomposition of the 2015 gas load curve from Austria, highlighting the individual end-uses.

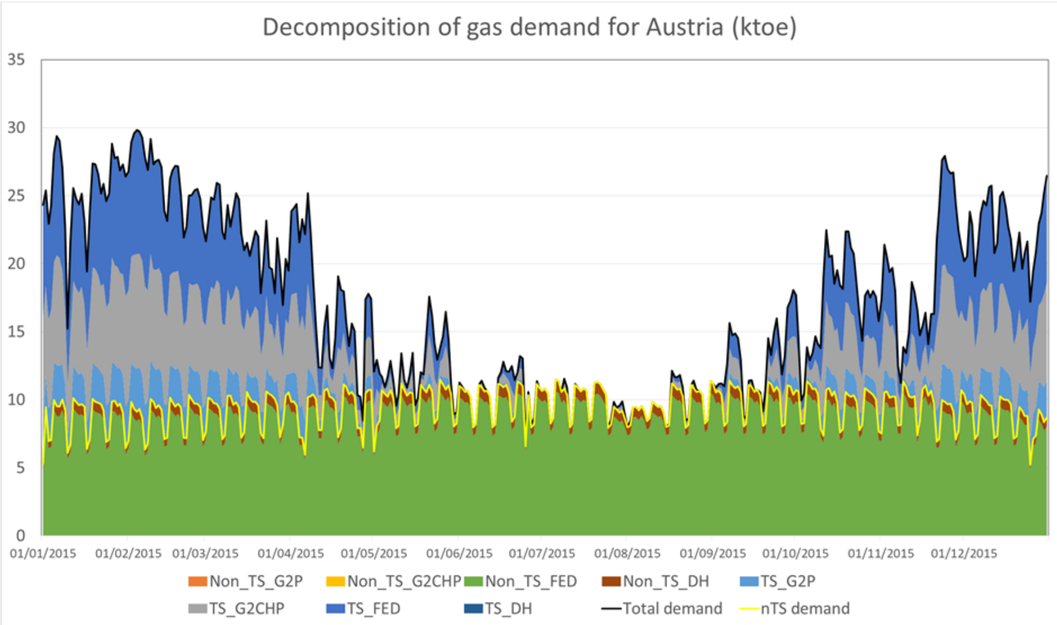


Figure 21: Decomposition of 2015 gas demand curve of Austria, applying the eight split factors

Load curve projection
The decomposed load curve of the base year is projected into the future by multiplying the individual parts of the decomposed load curve with the growth factors that describe the evolution in annual demand between the base year and the projection year. This step may be repeated by the METIS user to make future demand curves math his own assumptions about the evolution of gas demand. By default, the load curves were projected according to the EC scenario data for each of the four end-uses. These factors are likewise applied to the TS and the nTS part. Figure 22 shows the projected load curve for Austria. Comparing the black line (indicating the total load by 2050) with the red line (2015 load curve) highlights the change in the shape of the profile, with a more important reduction in demand in winter time compared to the summer months.

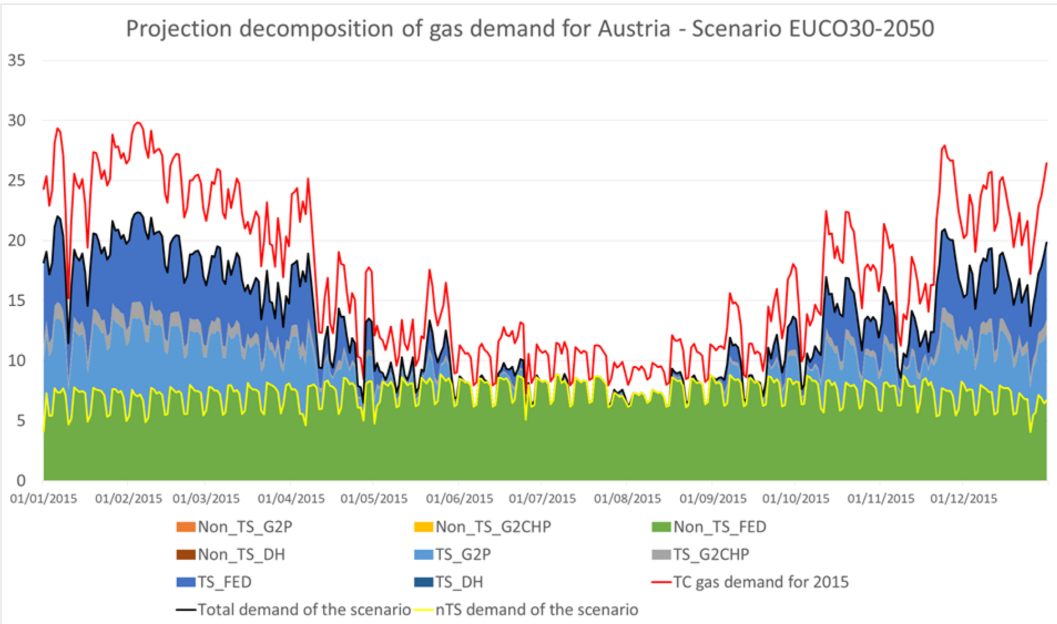


Figure 22: Projected gas load curve for Austria, EUCO30-2050 scenario

However, this general procedure does not work for country whose end-use specific demand is null for the year 2015 (according to the IDEES database) but non-zero for the projected years under the EC scenarios. For example, G2P volume for Denmark (DK) is null for IDEES 2015 but equals 490 ktoe in the EUCO30-2050 scenario. Thus, we cannot project G2P demand into the year 2050 based on 2015 data. It is to be noted that these situations only appear for G2P and G2DH. In these specific cases, we compute the TS or nTS gas demand of the category by using the same TS/nTS split than the adjacent category, i.e. we use the TS/nTS split of G2CHP (respectively G2FED) to compute the split factors of G2P (respectively G2DH). Countries with more restricted data availability undergo a specific treatment, which is outlined in detail in Annex 9.1.

The determined disaggregated load curves for the eight end-uses under the different prospective scenarios are directly available in the METIS demand module. Starting from this data, the user may change the demand volume or the demand profile of the individual end-uses. The updated end-use load curve is then automatically incorporated in the national system load curve. The demand characteristics of the individual end-use assets may by selecting the respective end-use asset (cf. house-like demand icons in Figure 23).

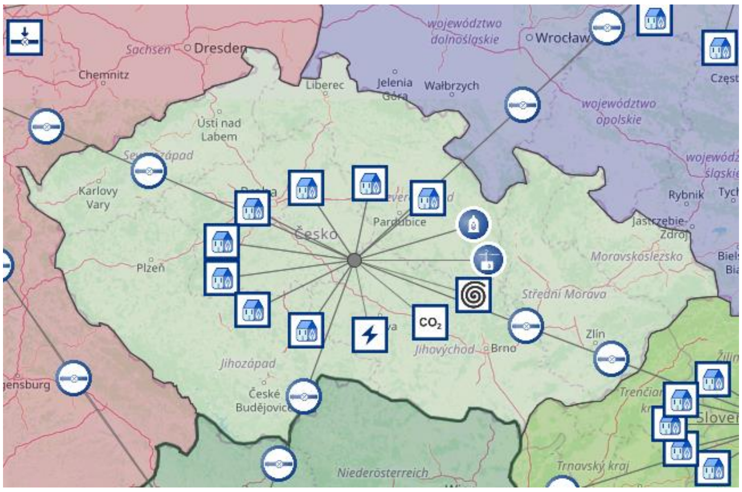


Figure 23: Overview of gas assets in the METIS user interface

4. FLEXIBLE POWER DEMAND ASSET LIBRARY IN THE METIS DEMAND MODULE

The decomposition of the electricity load curve does not only facilitate estimating the shape of the future load curve. It further allows to optimise the electricity consumption of selected consumers in response to market price signals (also referred to as demand side response, DSR). The METIS Demand Module contains a library of assets for different types of consumers that can be attached to each node of the network and whose DSR behaviour can be adapted according to the respective research subject. The flexible power demand assets are explained in more detail in the following:

- Electric vehicles
- Heat pumps
- Sanitary hot water
- Power-to-x

Detailed information about the equations used to describe the behaviour of the individual assets is available in the METIS html documentation [13].

4.1. ELECTRIC VEHICLES

The modelling of electric vehicles in METIS focusses on private electric road passenger cars. Four types of electric vehicle assets are distinguished, representing battery as well as plug-in hybrid electric vehicles that may be charged at home or at work. Each electric vehicle asset represents the national fleet of vehicles of the respective category.

Two different charging behaviours are considered for electric vehicles:

1) Immediate charging (i.e. the flag *Non-flexible demand* is set on *True*) implies that vehicles are charged immediately after their arrival at the charging infrastructure (which may be at home or at work).
2) Optimised charging (i.e. the flag *Non-flexible demand* is set on *False*) enables that the scheduling of the EV charging is jointly optimised with the overall power system dispatch. That is, EV charging reacts to the endogenously determined market price and contributes to the actual price setting. Upon selection, the optimised charging may include grid-reinjection into the grid, in the following referred to as vehicle-to-grid (V2G) behaviour.

Figure 24 gives an overview of the major input parameters of the METIS electric vehicle asset. The functioning of the asset under the two charging behaviours is explained in the following. Further details about the potential configuration of the EV asset and concrete use cases are available in METIS study S13 [11].

Parameter	Value	Unit
Total number of EV	1 677 546.98	EV
Percentage of connected EV at t=0	71	%
Percentage of EV arriving at terminal	Battery EV ...	%
Percentage of EV leaving from terminal	Battery EV ...	%
EV storage capacity	13	kWh
Average journey discharge	12.71	kWh
Average charging capacity	3.18	kW
EV charging efficiency	100	%
Storage cost	-1E-5	€/MWh/h

Generic parameters

Parameter	Value	Unit
Average V2G discharging capacity	3.18	kW
EV discharging efficiency	90	%
Production cost	1E-3	€/MWh

V2G parameters

Figure 24: Overview of major input parameters of the METIS electric vehicle asset

4.1.1. *Immediate charging*

The electricity load profile related to immediate EV charging is primarily driven by the overall vehicle stock (*total number of EV*), the arrival timeseries (*percentage of EV arriving at terminal*, which states which share of the vehicle stock arrives at the charging infrastructure at every hour of the year), the *average charging capacity* (in kW/EV) and the mean charging duration (in h/cycle). Figure 25 illustrates how EV arrivals translate into a load curve for Germany in the EUCO30-2030 scenario.

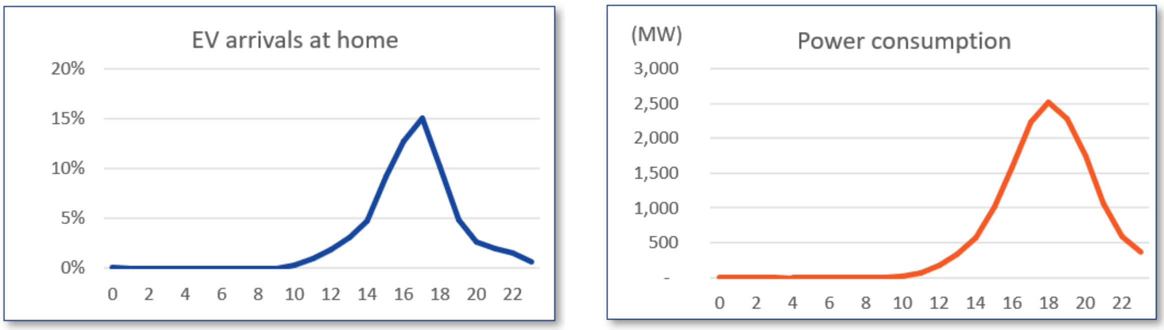


Figure 25: Translation of EV arrivals (at home) into power consumption, for Germany, EUCO-2030 scenario

In the scenarios delivered with the METIS demand module, data on vehicle stock and overall annual EV demand builds upon the EC scenario data [11]. This results in a mean daily electricity demand per vehicle (*Average journey discharge*).[12] The charging duration depends on the assumed charging capacity. For the charging capacity, a conservative estimate of less than 4 kW was made, avoiding additional system stress for distribution grid infrastructure and assuming that charging may take place via (potentially reinforced) household connections. The time series for EV arrival and departure for charging at home and at work are based on [14]. Based on the previous assumptions, the arrival time series may be translated into hourly national EV load profiles.

4.1.2. *Optimised charging*

Optimised charging is subject to a number of constraints. Upon arrival at the charging infrastructure, each vehicle is discharged by a constant level of energy, the *average journey discharge*. Each vehicle must be totally charged before leaving the charging infrastructure. Vehicle charging may not exceed the charging capacity of the individual vehicle. This implies that the charging moment of a vehicle may be freely scheduled

[12] It is assumed that compared to weekdays, during weekend days only two-third of all vehicles are circulating.

between the moment of arrival and the moment of departure.[13] Figure 26 illustrates that the electric load from optimal charging may differ substantially from immediate charging.

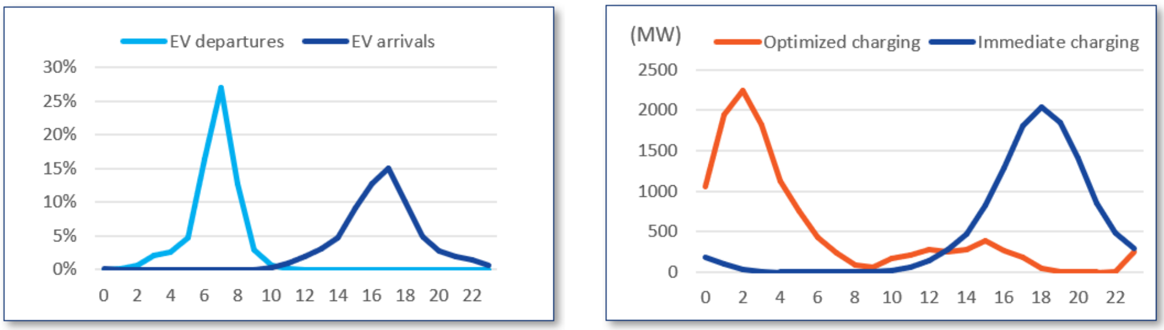


Figure 26: Optimal vs immediate charging (right) considering the arrival and departure time series (left) for Germany, EUCO30-2030 scenario

In addition, EVs may optionally reinject electricity into the grid (behaviour *Vehicle to grid* needs to be activated). In this case the EV batteries may be used as storage facility for the power system. The V2G utilisation is constrained by the *average discharging capacity* (which is supposed to equal the charging capacity), the maximum discharging level (limited to the level of the average journey discharge, meaning that the batterie charging level should never be below the level at the return of EVs to the charging infrastructure), the *EV discharging efficiency* (reflecting conversion losses, in the present case 90% based on [15]) and costs related to V2G (which may also reflect costs related to accelerated battery ageing).

4.2. HEAT PUMPS

The functioning of the heat pumps is simulated by optimising the hourly operation of the nationally aggregated heat pumps and related back-up capacities in order to meet the hourly heat demand at lowest costs, taking into account that heat demand and the heat pump's coefficient of performance (COP) vary in function of the ambient temperature. The operation of the heat pump systems is jointly co-optimised with the hourly dispatch of all European power generation, transmission and storage assets. In the following, the major input parameters of the heat pump asset (cf. Figure 27) as well as the general functioning of the asset are explained.

Parameters

Parameter	Value	Unit
Heating demand	Heat Pumps_AT_...	MW.h
Bivalent temperature	-6	°C
HP capacity	1 895	MW
Heat source temperature	Heat Pumps_AT_...	°C
Coefficient of performance	[1.0:4.0]	MW.h
Backup heater efficiency	1	
Storage discharge time	2	h
Storage cost	1E-3	€/MW.h/h
Loss rate	6.3	%/h

Figure 27: Major input parameters of the METIS heat pump asset

[13] The model does not track the precise arrival and departure times of individual cars but only considers the total number of cars being connected to the charging infrastructure and their level of charging.

Heating demand

The model assumes a linear relation between the heating demand and the outside air temperature. When the outdoor temperature drops below 16°C, the useful heat demand increases linearly with the decrease of the temperature. At temperatures above 16°C, the heating demand is supposed to be equal to zero (cf. Figure 28).[14] The hourly heat demand represents an exogenous input parameter to the heat pump asset. It is calculated in the way that the related heat pump electricity demand equals the demand provided in the European Commission scenarios. Part of the electricity demand data for heat pumps was updated. A detailed description of the realised data treatment and a use case of the heat pump asset are given in METIS study S6 [8].

Heat pump capacity

The thermal cycle performed by a heat pump system relies on various components (compressor, thermal fluid, heat exchangers etc.) whose characteristics vary with the temperature of the heat source and the desired output temperature. The thermal power available for a given system then varies according to the heat source temperature[15]. In METIS, the heat pump asset assumes a linear relation between the heat pump capacity and the source temperature. The heat pump capacity is null below -26°C, and all heat is generated via the back-up heater [15]. The METIS user may enter the overall installed heat pump capacity of a country.

Back-up heater

Since the heat pump's capacity decreases with lower temperatures, the overall system has to be dimensioned accordingly to ensure that the heating demand is even met at the lowest temperature. This leads to an oversized system, because extreme temperatures are reached only for a couple of hours each year. To avoid over-investments in expensive heat pump systems, typically installations combine a heat pump with a back-up heater (a simple electric boiler or a fossil-fuel boiler) to supplement the heat pump at the lowest temperature. The sizing of this back-up heater is realised in order to cover most of the heat demand by the heat pump, and only use the back-up heater during the coldest days (see explanations further below). The threshold temperature below which the back-up heater has to supplement the heat pump is called the bivalent temperature.

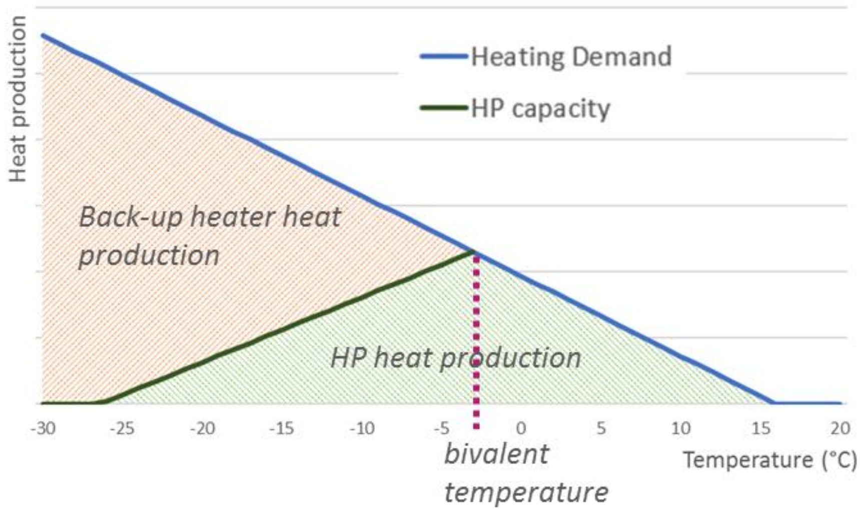


Figure 28: Decomposition of the heat production between the (air-source) heat pump and the back-up heater in function of the outdoor temperature (i.e. temperature of the heat source)

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[14] The threshold temperature of 16°C is applied to all countries, based on [14].

[15] The heat source temperature corresponds to the outdoor temperature in case of an air-source heat pump.

Heat pump coefficient of performance

The main advantage of heat pump systems is their high efficiency. This efficiency (coefficient of performance, COP) however depends on the difference of temperature between the heat source and the output temperature at the heat sink: the greater the difference, the lower the efficiency (cf. Figure 29).

The COP values used in the heat pump asset are based on [15] and correspond to air-source heat pump systems. They are in line with current heat pump characteristics across Europe. These values could significantly change in the future with improvement of heat pump technologies, leading to more efficient systems and consequently then lower electricity consumption. Yet, as the technical evolution remains uncertain, the present assumption represents a conservative assessment with respect to efficiency improvements, assuming current values for the years 2030 and 2050.

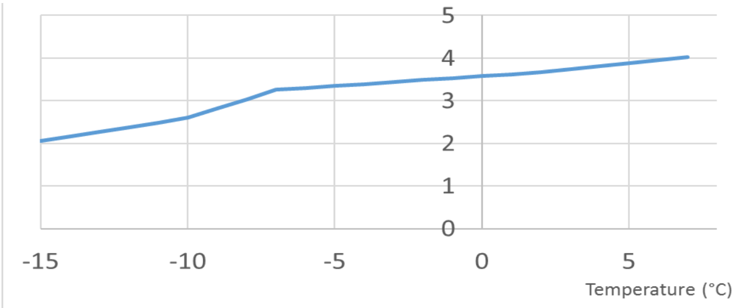

Figure 29 - Heat pump coefficient of performance [15]

Since the COP is always greater than 1, and around 3 on average, heat pumps are always more efficient than a back-up heater, whose efficiency is lower than 1. Thus, the efficiency of the whole system (i.e. heat pump + back-up heater) significantly decreases with a rising contribution of the back-up heater to the heat supply. This is illustrated in Figure 30, where the electricity consumption of the back-up heater is significantly higher than the heat pump consumption due to the lower efficiency.

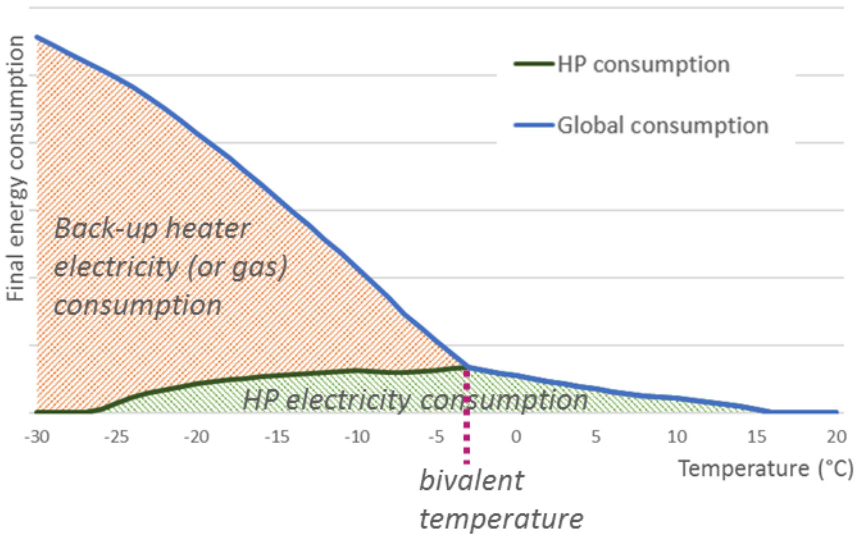

Figure 30 - Decomposition of the final energy consumption between the heat pump and the back-up heater with the temperature

This efficiency drop at very low temperatures can also be noted when analysing the temporal evolution of the power consumption[16] of the whole system (heat pump + electric back-up heater), cf. Figure 31. In the illustrated example of heat pump electricity demand in Austria, electricity consumption is close to zero during summer (since the outside temperature is on average above 16°C). In winter, as long as the outside temperature remains above the bivalent temperature, the heat pump can satisfy the whole heating demand. But for the coldest days, when the back-up heater has to supplement the heat pump, power consumption soars, leading to significant power demand peaks during a few days per year.

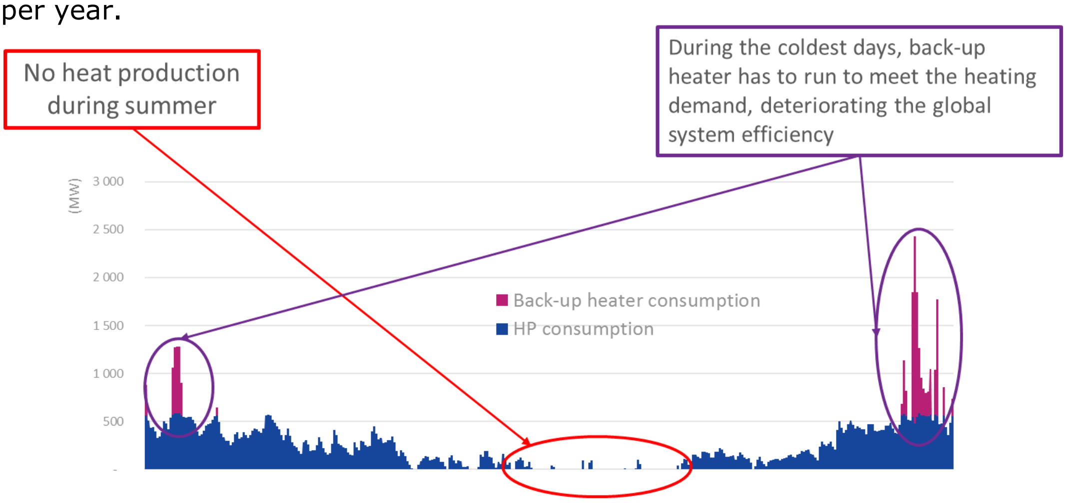

Figure 31 - Hourly heat pump power consumption in Austria in the REF16-2030 scenario

Back-up heater sizing

As explained before, the sizing of the heat pump system is a trade-off between the CAPEX and the OPEX of the two technologies. A heat pump is a rather expensive system, but due to its very high efficiency it ensures heat production at a reasonable price. On the other hand, an electric or gas boiler has lower investment costs but much more important variable costs (in particular fuel costs).

Currently, the sizing differs between monoenergetic and bivalent heat pumps. Given that currently the price for gas is lower than for electricity, the back-up heater of a bivalent heat pump is used more often than the one of a monoenergetic heat pump. Assuming that this price ratio persists in the future, the current back-up sizing rules applied (based on [16]). The METIS user may choose between two types of back-up heater configurations:

- *Monoenergetic heat pump*: 95% of the useful heat demand are covered by the HP and the remaining 5% by the electric back-up heater
- *Bivalent heat pump*: 60% of the useful heat demand are covered by the HP and the remaining 40% by the gas back-up heater

This sizing of the back-up heater was performed individually for each European country, using thirty years of historical temperature data. The result of this sizing is the bivalent temperature for each country for the two types of heat pump (monoenergetic and bivalent). Colder countries have lower bivalent temperatures, meaning that back-up heaters are used at lower temperatures than in warmer countries.

Thermal storage

A water tank is often used as a buffer between the output of the heat pump and the household's central heating system, in order to provide a more reliable heat and to smooth the heat pump operation. Combined with smart meters and time-varying electricity prices, a storage device can provide flexibility with respect to the operation of the heat pump which allows consuming electricity in advance (and at lower prices), store the heat and

[16] And gas consumption in case of a gas bivalent heat pump.

then release it when required. The user may optionally activate the consideration of a heat storage, which results in a more dynamic heat pump management (cf. Figure 32).

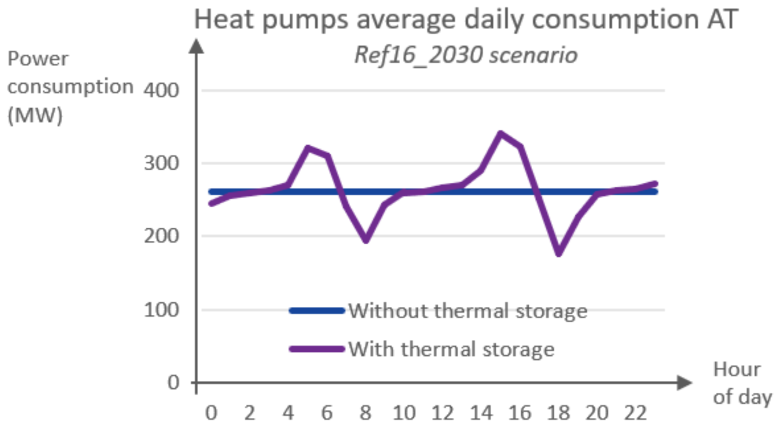

Figure 32: Mean daily heat pump power consumption with/without storage utilisation in Austria, REF16-2030 scenario

In METIS, the storage of the heat pump asset is dimensioned with the objective to store the equivalent of two hours of heat production at full capacity, according to current practices [16].

In normal operation mode, the thermal storage temperature is rather constant over time, but the temperature slightly changes depending on the ambient temperature. In order to store energy, a signal is sent to increase the working temperature of this storage. During this time when the storage temperature is above normal, thermal losses increase.
In the METIS tool, these losses are represented with a loss rate per hour. Its value has been determined based on a literature review [16]:

$$\textit{Heat loss rate} = 6\%/\textit{hour}$$

The heat loss is expressed as a percentage of the stored thermal energy. Since the stored energy is proportional to the temperature of the water tank, thermal losses vary as a function of the storage temperature.

4.3. Sanitary hot water

The METIS sanitary hot water asset represents a specific application of the underlying (generic) load shifting asset. The asset is modelled as a storage device (i.e. a hot water tank in the case of sanitary hot water). It features two behaviours. If non-flexible demand is assumed, the power consumption is exogenously fixed and follows a predefined hourly timeseries (cf. the entry *Raw demand* in the overview of all input parameters in Figure 33).

In the case of flexible demand, the electricity demand may be shifted within a specific time range (*Demand cycle duration*) that starts at a specific time (*Demand first hour*). That is, the actual load is endogenously optimised, taking into account that the instantaneous power demand must not exceed the installed capacity (*Pmax In*) and that shifting energy is penalised with a cost factor for each unit of energy being shifted by one hour (*Storage cost*).

Parameter	Value	Unit
Raw demand	Sanitary hot…	MW
Demand cycle duration	24	h
Demand first hour	6	h
Pmax In	23 074.89	MW
Storage cost	1E-4	€/MW.h/h

Figure 33: Major input parameters of the METIS sanitary hot water asset

In METIS, this asset is so far exclusively used to model the flexible power demand from electric sanitary hot water (SHW) end-uses being equipped with a thermal storage. It is assumed that only in France and the UK the bulk of SHW installations is equipped with a thermal storage unit. Hence, the use of this asset is limited to these two countries. The electricity demand for domestic SHW from the EC scenarios in conjunction with an hourly DHW electricity demand profile (based on [10]) are used to generate the raw demand time series. The maximum installed capacity is determined by assuming that the maximum daily electricity demand can be met within 3 hours.[17] Demand optimisation needs take place within 24 hours, starting every day at 6.00 am in the morning. Figure 34 illustrates the difference in electricity demand for France's SHW electricity demand during 48 hours, considering non-flexible and optimised demand.

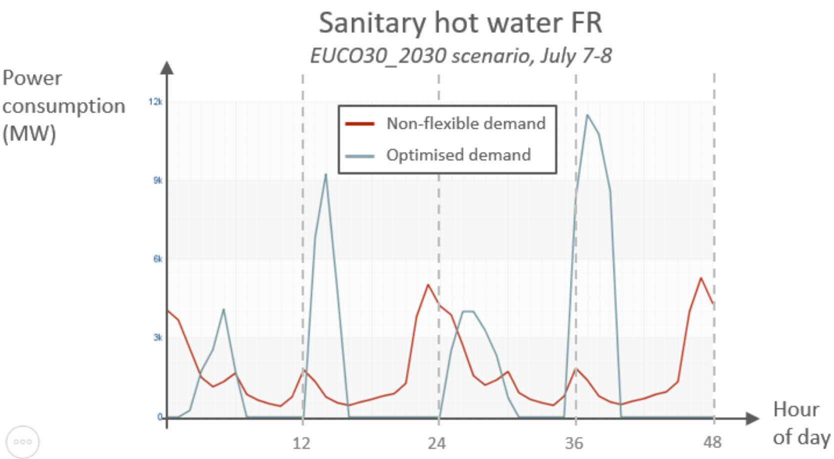

Figure 34: 48h excerpt of non-flexible and optimised electricity demand for sanitary hot water in France, EUCO30-2030

4.4. Power-to-X

The METIS power-to-x asset represents typically electrolysers generate electricity-based hydrogen. The power-to-x asset may be complemented by additional assets that reflect the subsequent energy conversion chain to generate synthetic gases or fuels.

The functioning of the power-to-x asset is driven by an exogenous hydrogen demand (to which the power-to-x asset is connected). The hydrogen demand is only considered in terms of the annual demand volume, implying that the hourly variation in hydrogen demand does not matter due to sufficient hydrogen storage capacities. The output of the

[17] Three hours is assumed to be an average value featuring charging times of sanitary hot water installations being equipped with differently dimensioned storage volumes. This assumption is supported by the fact that current hot water power consumption is scheduled in a more distributed manner to avoid demand peaks (cf. [24]), whereas in the future a joint charging might be envisaged.

power-to-x asset (and its related electricity consumption) depend on the specific electricity demand per unit of product output (i.e. the *yield w.r.t. production*, listed among the main input parameters in Figure 35) and the *consumption costs* as well as the installed power-to-x capacity (*Pmax*). The latter may be entered as an exogenous input parameter (i.e. simulation mode) or be determined endogenously via capacity optimisation, taking into account the technology's *CAPEX* and *fixed operation costs*.

Parameters

Parameter	Value	Unit
CAPEX	65 088	€/MW/Year
Fixed Operating Costs	24 500	€/MW/Year
Pmax	6 671.28	MW
Availability	100	%
Consumption cost	0	€/MW.h
Yield w.r.t production	0.82	MW.h/MW.h PCS

Figure 35: Major input parameters of the METIS power-to-x asset

Power demand is typically scheduled during the hours with low electricity prices, aiming at a least-cost hydrogen generation. Figure 36 illustrates the correlation of power-to-x activity with low residual load periods for 5 days in June in Greece under the METIS-S1-2050 scenario. This graph as well as further information about the power-to-x asset and exemplary use cases of the asset are available in the METIS study S1 [17].

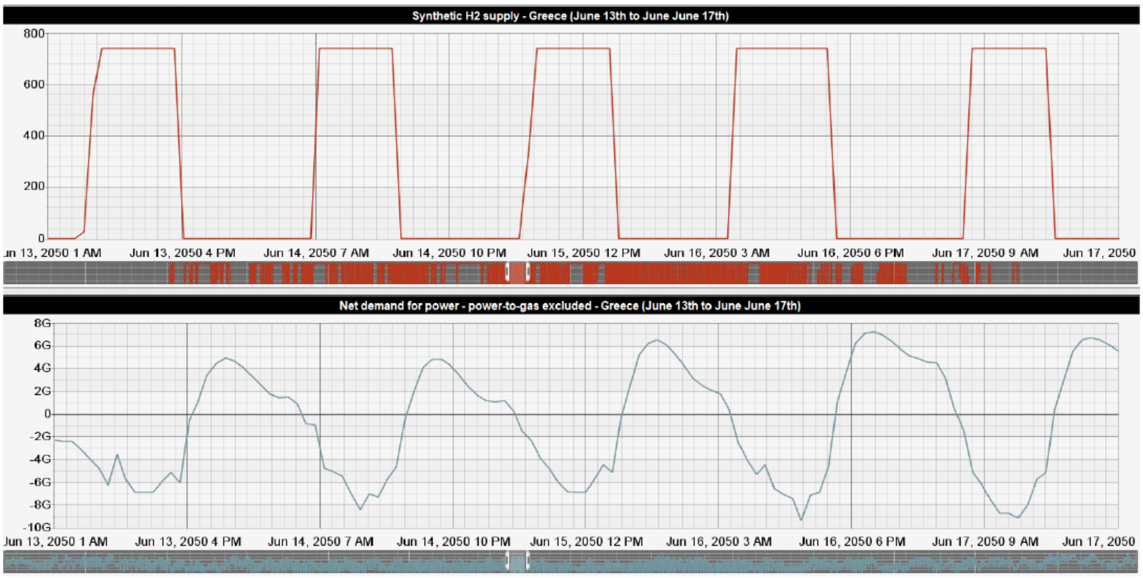

Figure 36: Power-to-x electricity demand (upper graph) and residual load (lower graph) during 5 days in June, Greece, METIS-S1-2050 scenario. Source: [17]

5. Visualisation and indicators in the METIS demand module

In addition to the enhanced technological granularity in energy demand modelling, the METIS demand model also incorporates additional indicators with respect to the assessment of results. The most relevant new key performance indicators are introduced in the following.

Cumulative demand

The indicator cumulative demand allows to display the load curve distinguished by end-use. This indicator is available for electricity and gas demand. Figure 37 shows the ample cumulative demand of France under the EUCO30-2050 scenario. The energy demand profile of flexible power demand assets depicts the updated load schedule after optimisation.

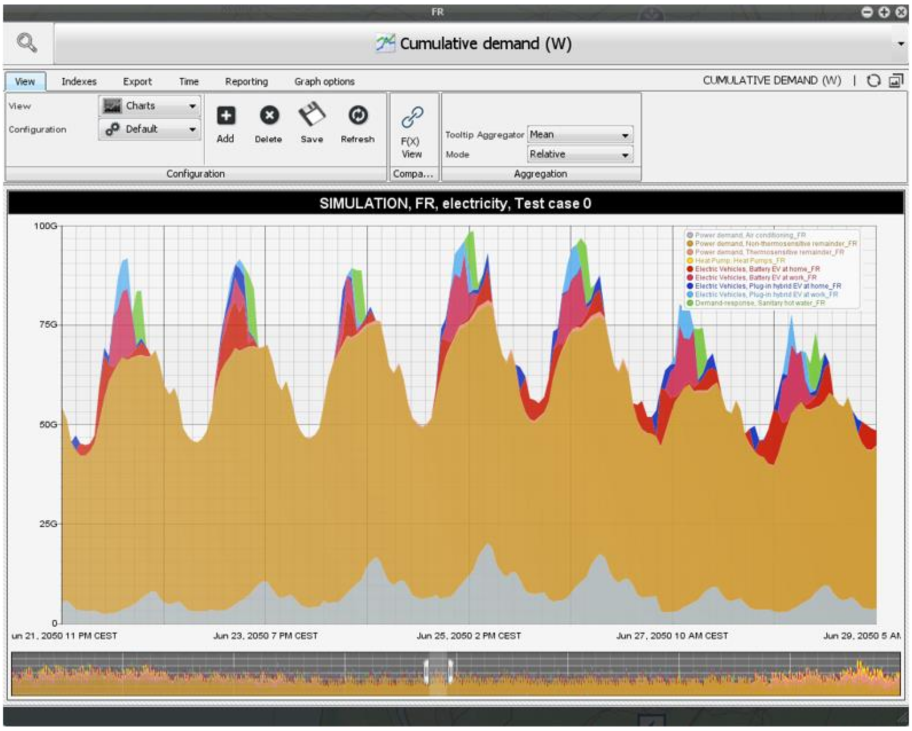

Figure 37: Cumulative electricity demand indicator, France, EUCO30-2050 scenario

Comparative view of non-flexible and optimised demand

As motivated in Section 3.2 and illustrated in Figure 37, flexible demand assets may have a significant impact on a power system's peak load and load variation. Given the related effect on the use of peak power generation capacities and power system infrastructure, a new indicator is added that allows to compare a country's system load before and after demand side optimisation. This view helps to identify the benefits from demand side response activities and quantify the net change in peak demand and load pattern.

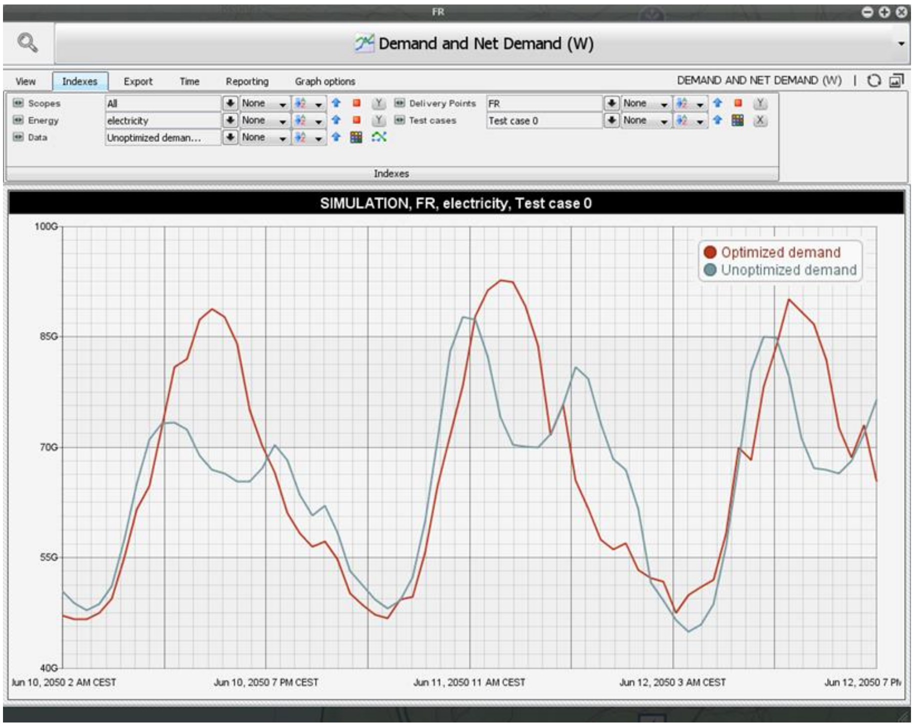

Figure 38: Comparative view of non-flexible and optimised demand, France, EUCO30-2050 scenario

Comparative view of non-flexible and optimised residual demand

Similar to the comparison of the total demand, a comparative view is available for the residual demand. The residual load is defined as the total load less the generation from renewable energy sources, that is the part that needs to be met by dispatchable power generation assets. Contrasting the residual load with and without the contribution of flexible demand assets indicates the extent to which the latter may reduce flexibility needs. Figure 39 shows the average residual loads before and after demand side optimisation for France under the EUCO30-2050 scenario and highlights the contribution of demand side flexibility to smoothen the residual load.

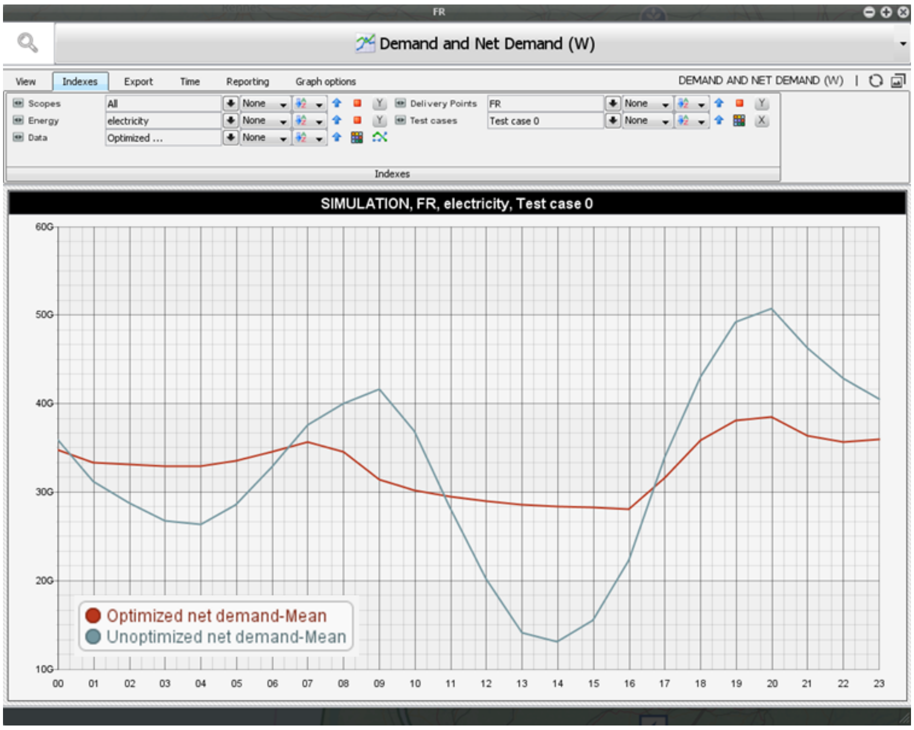

Figure 39: Comparative view of average non-flexible and optimised residual demand, France, EUCO30-2050 scenario

6. THE METIS HEAT MODULE

The METIS heat module has for objective to reproduce the hourly functioning of different, generic DH network archetypes (i.e. the hourly dispatch of the different connected heat sources to meet demand) that could potentially be installed in different countries of the EU in the future. The module is split in two parts. The first part allows to configure the individual future archetypes. The second one enables a modelling at a country level, by capturing the distribution of the archetypes at the national level, generating a national picture of district heating.

6.1. HEAT NETWORK ARCHETYPES

The configuration of the individual heat network archetypes takes place in a dedicated environment, which is typically call a *METIS study*. Inside this study, each archetype is represented by an individual *METIS context*. They allow to simulate each archetype individually. Table 8 gives an overview of all DH network archetypes so far incorporated in the METIS heat module. A detailed description of each archetype as well as additional information about the utilisation of the heat module is provided in METIS study S9 [18].

Table 7: Overview of the existing district heating network archetypes in the METIS heat module

Archetype short names	Archetype description
SOLAR	Biomass, gas, solar thermal and storage
HEAT_PUMP	Heat pump, biomass, gas
GEOTHERMAL	Geothermal base load
BIOMASS_ONLY	Only biomass (boiler and CHP)
GAS_ONLY	Only gas technologies
WASTE_AND_BIOMASS	Waste and biomass
BUSINESS_AS_USUAL	Coal and gas
GETTING_GREEN	Waste, biomass and gas
BIOMASS_AND_OIL	Biomass and oil
BIOMASS_AND_GAS	Biomass and gas
INDUSTRY_COAL	Industry Coal
INDUSTRY_GAS_ONLY	Industry gas only

In the archetype contexts, each archetype is described by a set of elements (that follow the common METIS philosophy):

- *Physical assets* describe different heat generation and storage technologies, such as boilers, heat pumps or storage assets
- *Financial assets* describe the demand asset (featuring an hourly heat demand profile), resource assets (exhibiting a specific price for fuels, like biomass, gas or electricity, and CO_2 emissions) and a loss-of-load asset (in case demand cannot be met by the supply capacities).

All elements are depicted for a sample archetype (the *Heat pump* archetype) in Figure 40. The archetype contexts allow to carry out two calculations at a time: (1) The optimisation of peak and storage capacities for each pre-configured archetype with given hourly demand and a given set of base-load and mid-merit capacities. (2) The hourly dispatch of all heat generation and storage assets to meet the archetype's heat demand at lowest costs.

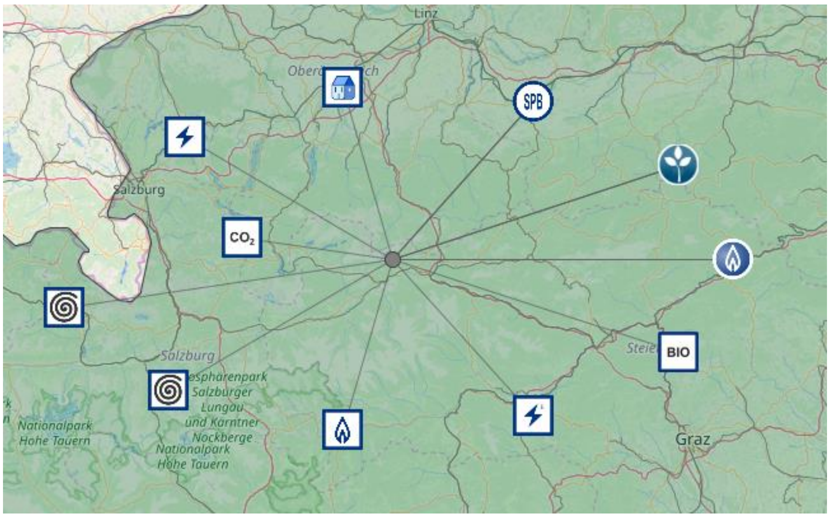

Figure 40: Overview of the different assets considered in the context for the Heat pump archetype.

Hourly heat demand profiles

Each archetype has been defined to serve either residential and commercial or industrial heat demand, which determines the heat load profile. Residential and commercial consumers use DH networks mainly for space heating and in addition for sanitary hot water supply which results in a high temperature sensitivity of the heat demand, peaking typically in winter months (cf. Figure 41). The heat demand profile for residential and commercial archetypes is derived from historic data of a French DH network operator, considering the French hourly temperature from 2015.

Industrial heat consumption is substantially dedicated to manufacturing, which explains its much more constant profile over the year, with slightly higher levels on working days than on weekend days. The hourly annual industrial heat demand profile was inspired by the 2015 electricity demand profile of the French industry sector, as published by the French transmission system operator RTE [19].

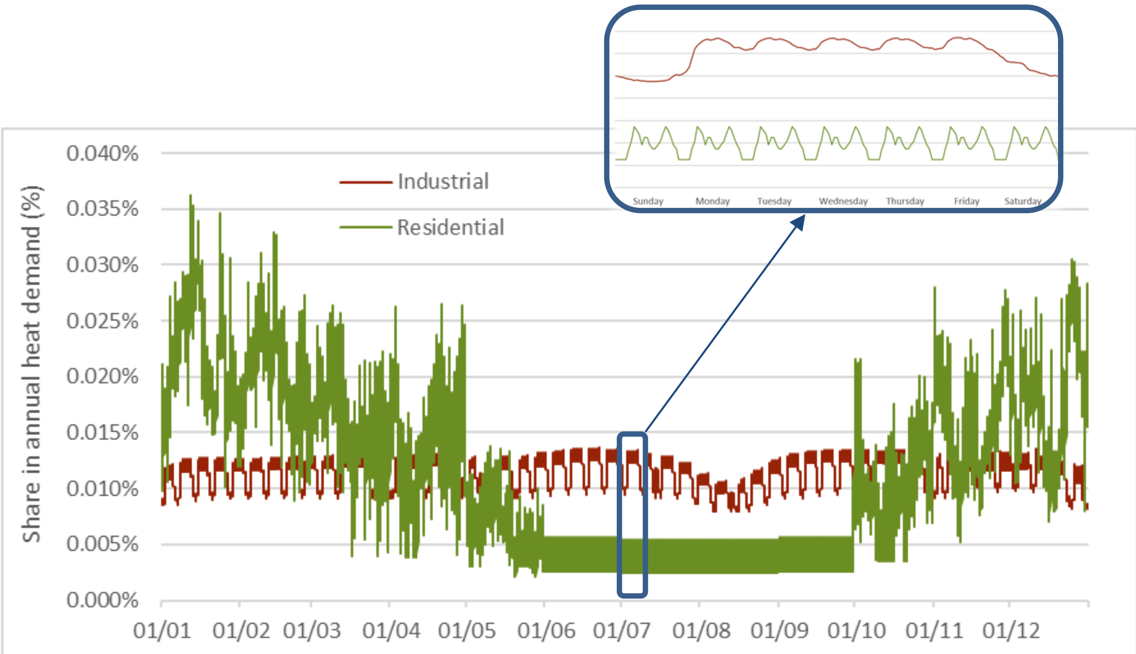

Figure 41 - Hourly heat demand profile for the industrial and the residential sector. Source: French DH network operator, (RTE, 2018)

Peak capacity investment and dispatch optimisation

For each archetype, the annual heat demand plus a set of baseload and mid-merit capacities are predefined by the user (including their individual capacities). In the framework of the METIS study S9, this configuration was based on the analysis of existing networks and future network configurations (see [18]).

The annual heat demand is applied to the respective hourly heat profile (residential or industrial). Based on this pre-configuration, the METIS heat module jointly determines the cost-optimal dimensioning of the peak assets (and storage if considered available) and the hourly dispatch of all heat generation (and storage) technologies. The capacity dimensioning takes into account the capital expenditures (CAPEX) and fixed operation and maintenance costs (FOC) of the peak technology, while the dispatch optimisation is merely based on variable heat generation costs, including fuel costs, operational costs and CO_2-related costs. Figure 42 illustrates the major input parameters of two sample heat generation assets, a biomass boiler and a CHP asset. Two types of CHP assets are distinguished, a CHP asset dedicated to meet residential heat demand and thus only operating during six months per year, and an industrial CHP asset that is operating throughout the entire year (given the continuous availability of heat demand).

Parameters

Parameter	Value	Unit
CAPEX	19 813.65	€/MW/Year
Fixed Operating Costs	5 000	€/MW/Year
Pmax	15	MW
Availability	100	%
Variable cost	0.2	€/MW.h
Fuel yield w.r.t produc...	0.84	MW.h/MW.h PCS
Fuel CO2 emissions	0	t/MW.h PCS
Fleet min load	0	%

Consommation/Production

Consommation		Production	
biomass	AT	heat	AT
		co2	AT
		electricity	AT

Paramètres

Paramètre	Valeur	Unité	Consis...	Validat...
CAPEX	98 560.43	€/MW...		
Fixed Operating Costs	14 400	€/MW...		
Pmax	15	MW		
Availability	Biomass CHP_...	%		
Variable cost	0.6	€/MW.h		
Fuel yield w.r.t production	0.25	MW.h...		
Fuel yield w.r.t heat production	0.59	MW.h...		
Fuel CO2 emissions	0	t/MW....		
Fleet min load	0	%		

Biomass boiler *CHP asset*

Figure 42: Major input parameters of heat generation assets

Figure 43 illustrates a typical result generated by the optimisation. The upper graph provides a year-long overview about the hourly dispatch of the individual heat generation and storage assets (stacked chart) to meet the hourly heat demand (red line). The excerpts in the lower part of Figure 43 highlight the use of the optimised peak generation capacities (in the given case gas boilers) and the use of heat storage (which in the given case is dimensioned to facilitate the integration of solar thermal heat generation). Upon completion of the optimisation, this information is available for all archetypes.

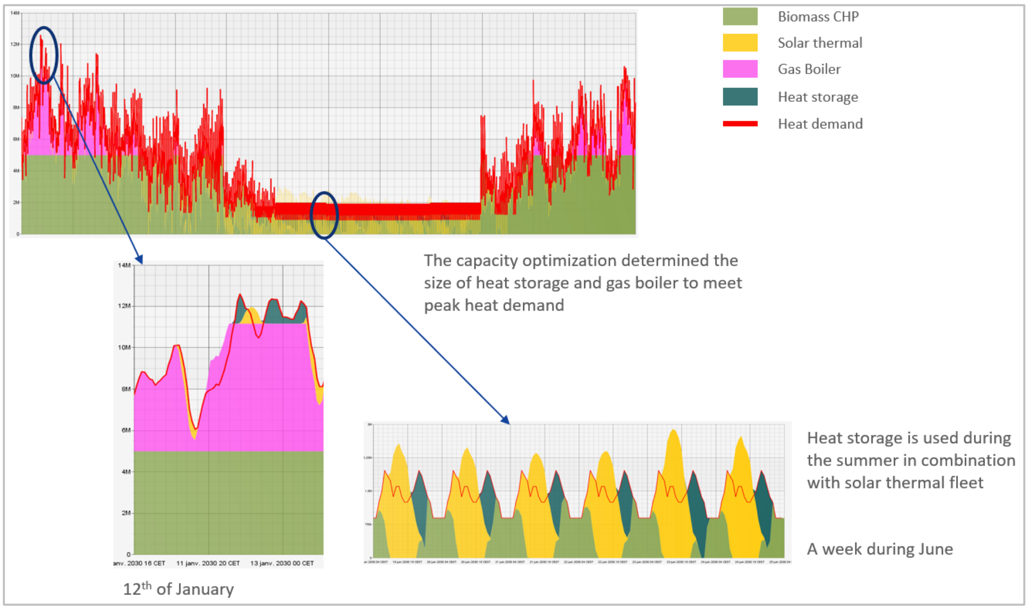

Figure 43: Cumulative hourly heat generation of the Solar archetype

6.2. ARCHETYPE AGGREGATION AT THE NATIONAL LEVEL

To obtain a national view of a country's district heating sector, it is necessary to consider the distribution of DH networks in a country across the different archetypes. This aggregation is realised in the second part of the METIS heat module. Based on an allocation matrix indicating the number of networks per archetype in each country, the module prepares an aggregated overview of all physical and financial assets (cf. Figure 44).

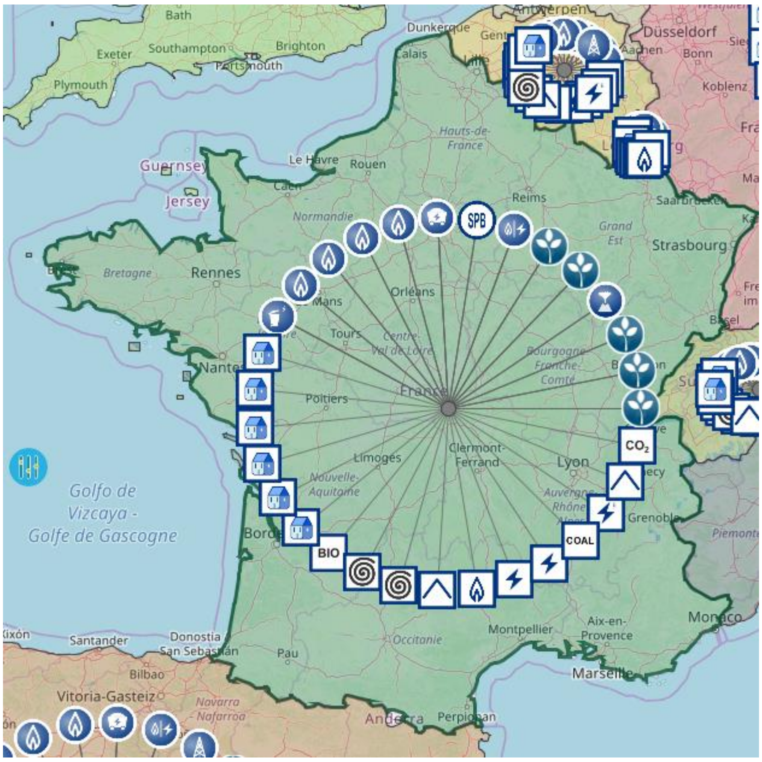

Figure 44: National overview of all available physical and financial assets

The METIS heat demand module comes with an allocation matrix that was prepared in the context of the METIS study S9. For an exogenous European 2030 DH supply mix given by the *Mapping EU heat supply* [20]. In order to match the supply mix with the archetypes available in the METIS heat module to the best extent possible, a simplified optimisation approach is applied. See METIS study S9 for further details.

Aggregating the information from the individual archetypes at the national level provides an overview of the utilisation of the available technologies and energy carriers (see for instance the cumulative heat generation in Italy, 2030, distinguished by heat generation technology in Figure 45).

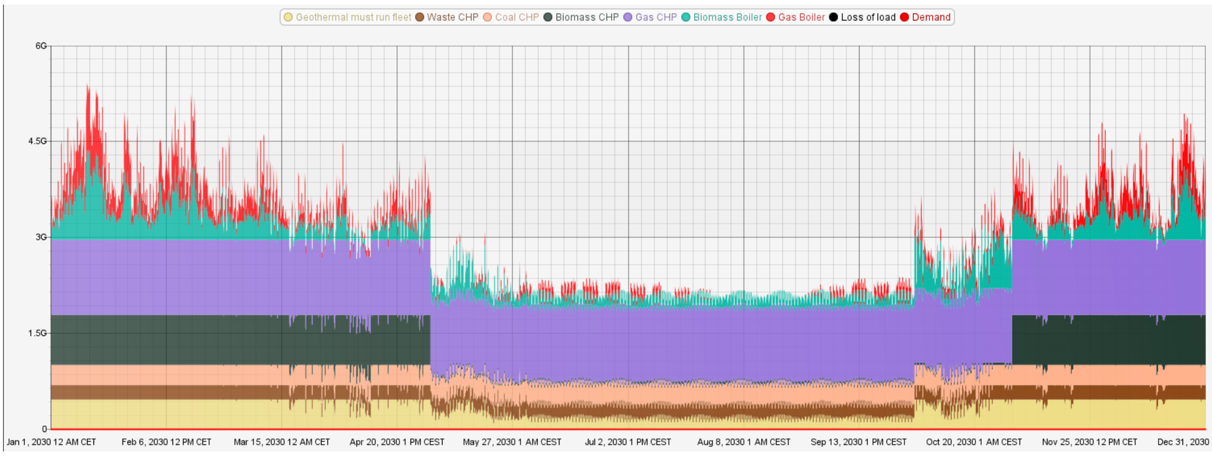

Figure 45: Cumulative heat generation at the national level, Italy, 2030. Source: [18]

Further information available at the national scale via a set of preconfigured key performance indicators include the heat generation costs, the heat related emissions, the heat-related power output (from CHP) or the overall energy demand (distinguished by fuel).

7. SCENARIOS USED IN THE METIS HEAT AND DEMAND MODULES

7.1. SCENARIOS AVAILABLE IN THE METIS DEMAND MODULE

The METIS demand module contains the following European Commission scenarios:

- European Commission **REF16 scenario** (reference scenario published in 2016) for the year 2030 [3]
- European Commission **EUCO30 scenario** for the years 2030 and 2050 [4]

The METIS scenarios contain the information for all EU Member States, plus Switzerland, Bosnia-Herzegovina, Serbia, FYROM, Montenegro and Norway.

The general integration of the EC scenario data into METIS (apart from the demand module) is described in the METIS Technical Note T1 [1].

7.2. SCENARIO USED IN THE METIS HEAT MODULE

The heat module comes with a preconfigured 2030 scenario. This scenario is calibrated to the 2030 heat supply mix from the *Mapping EU heat supply* project [20].

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9. ANNEX

9.1. MATCHING GAS DEMAND DATA FROM IDEES WITH THE FOUR END-USES

The following elements of the IDEES database [2] have been used to compile the gas demand of the four end-use categories considered in the gas load curve projection.

METIS end-uses		Excel file	Worksheet	Label 1	Label 2	Label 3
G2FED	Industry	Industry	Ind_Summary_fec	Industry Summary / final energy consumption	Low enthalpy heat	Natural gas
					Other processes	Natural gas
					Steam processes	Natural gas
	Residential	Energy Balance	cres	Residential (ktoe)	Natural gas	
			cressc	Residential: Space cooling (ktoe)	Natural gas	
			cressh	Residential: Space heating (ktoe)	Natural gas	
	Services	Energy Balance	cser	Services (ktoe)	Natural gas	
			csersc	Services: Space cooling (ktoe)	Natural gas	
			csersh	Services: Space heating (ktoe)	Natural gas	
	Transport	Energy Balance	CTR	Final Energy Consumption - Transport (ktoe)	Natural gas	
	Agriculture	Energy Balance	cagr	Agriculture/Forestry/Fishing (ktoe)	Natural gas	
G2P	G2P	PowerGen	Thermal_ElecOnly	Overview of electricity only thermal power plants	Transformation input - Eurostat structure (ktoe)	Natural gas
G2CHP	G2CHP	PowerGen	Thermal_CHP	Overview of CHP thermal power plants	Transformation input - Eurostat structure (ktoe)	Natural gas
G2DH	G2DH	PowerGen	DistHeat	Overview of district heating plants	Transformation input (ktoe)	Natural gas

9.2. MATCHING GAS DEMAND FROM EC SCENARIOS WITH THE FOUR END-USES

The following elements of the EC scenario data have been used to compile the gas demand of the four end-use categories considered in the gas load curve projection.

METIS category		Excel	Label 1	Label 2	Label 3	Label 4
G2FED	Industry	Additional PRIMES data for calibration	INDUSTRY - Iron and steel	Final Energy Demand (in ktoe)	natural gas	
			INDUSTRY - Non Ferrous Metals	Final Energy Demand (in ktoe)	natural gas	
			INDUSTRY - Chemicals	Final Energy Demand (in ktoe)	natural gas	
			INDUSTRY - Non Metallic Minerals	Final Energy Demand (in ktoe)	natural gas	
			INDUSTRY - Pulp and Paper	Final Energy Demand (in ktoe)	natural gas	
			INDUSTRY - Food, drink, tobacco	Final Energy Demand (in ktoe)	natural gas	
			INDUSTRY - Engineering	Final Energy Demand (in ktoe)	natural gas	
			INDUSTRY - Textiles	Final Energy Demand (in ktoe)	natural gas	
			INDUSTRY - Other Industries	Final Energy Demand (in ktoe)	natural gas	
			INDUSTRIAL BOILERS (C)	Energy Consumed in Boilers (in ktoe)	Gas	
	Residential	New additional PRIMES data for calibration	RESIDENTIAL	Final Energy per energy use (Ktoe)	Heating and cooling	Gas
					Other heat uses	Gas
	Services	New additional PRIMES data for calibration	SERVICES	Final Energy per energy use (Ktoe)	Heating and cooling	Gas
					Other heat uses	Gas
	Transport	New additional PRIMES data for calibration	Transport activity	Final Energy Demand (ktoe)	Total Natural Gas	
	Agriculture	New additional PRIMES data for calibration	AGRICULTURE	Final Energy per energy use (Ktoe)	Gas	
G2P	G2P	Additional PRIMES data for calibration	Power generation	Fuel input in thermal power plants (2) (in ktoe)	Natural Gas	
G2CHP	G2CHP	Additional PRIMES data for calibration	Power generation	Fuel input for On Site CHP steam generation (in ktoe) (A)	Natural Gas	
G2DH	G2DH	Additional PRIMES data for calibration	Power generation	Fuel input in boilers (in ktoe) - DISTRICT HEAT	Natural Gas	

9.3. METHODOLOGIES FOR COUNTRIES WITH LIMITED GAS DATA AVAILABILITY

This general procedure works for countries with IDEES and PRIMES data (EU countries), except Cyprus (CY) and Malta (MT). These two countries have null volume of gas demand in 2015, and split factors can thus not be computed. Non-EU countries (BA, CH, ME, MK, NO, RS) have neither IDEES nor PRIMES data so split factors cannot be calculated neither. Among these eight countries, for some of them TS and nTS load curves are available, but not for all of them (CY, ME, MT). Consequently, for these eight countries split factors cannot be computed. Thus, three types of methods are set up to determine the split factors depending on the data availability.

Method 1: Applies to countries which have TS and nTS profiles for 2015 but neither IDEES nor EC scenario data for annual gas volumes. Projection coefficients are assumed to be equal to a nearby country. Then these coefficients are applied on the TS and nTS load curves of 2015.

Method 2: Applies to countries which do not have TS and nTS profiles for 2015 and null volume for 2015, thus no split factors for 2015 but the annual gas demand in the EC scenarios is non-zero. Projection coefficients are assumed to be equal to a nearby country with a scaling in order to recover annual volume of PRIMES data. Then these coefficients are applied to the TS and nTS load curves of 2015.

Method 3: Countries which do not have any data and load curves. Projection coefficients are assumed to be equal to a nearby country with a scaling by the population. Then these coefficients are applied to the TS and nTS load curves.

Table 8 summarises the approach for the specific countries.

Table 8: Overview of applied methodologies for countries with limited data availability

		Data availability			**Projection coefficient computation**	
Code	**Country**	**Load curves TS and NTS 2015**	**IDEES / EC scenario data**	**ENTSO-G TYNDP data for**	**Used method**	**Country for scaling or analogy**
BA	Bosnia-H.	X		X	1	Croatia
CH	Switzerland	X		X	1	France
CY	Cyprus		X	X	2	Greece
ME	Montenegro				3	Macedonia
MK	Macedonia	X		X	1	Romania
MT	Malta		X	X	2	Italia
NO	Norway	X			1	Sweden
RS	Serbia	X		X	1	Croatia