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JRC-IDEES: Integrated Database of the European Energy Sector

Methodological note

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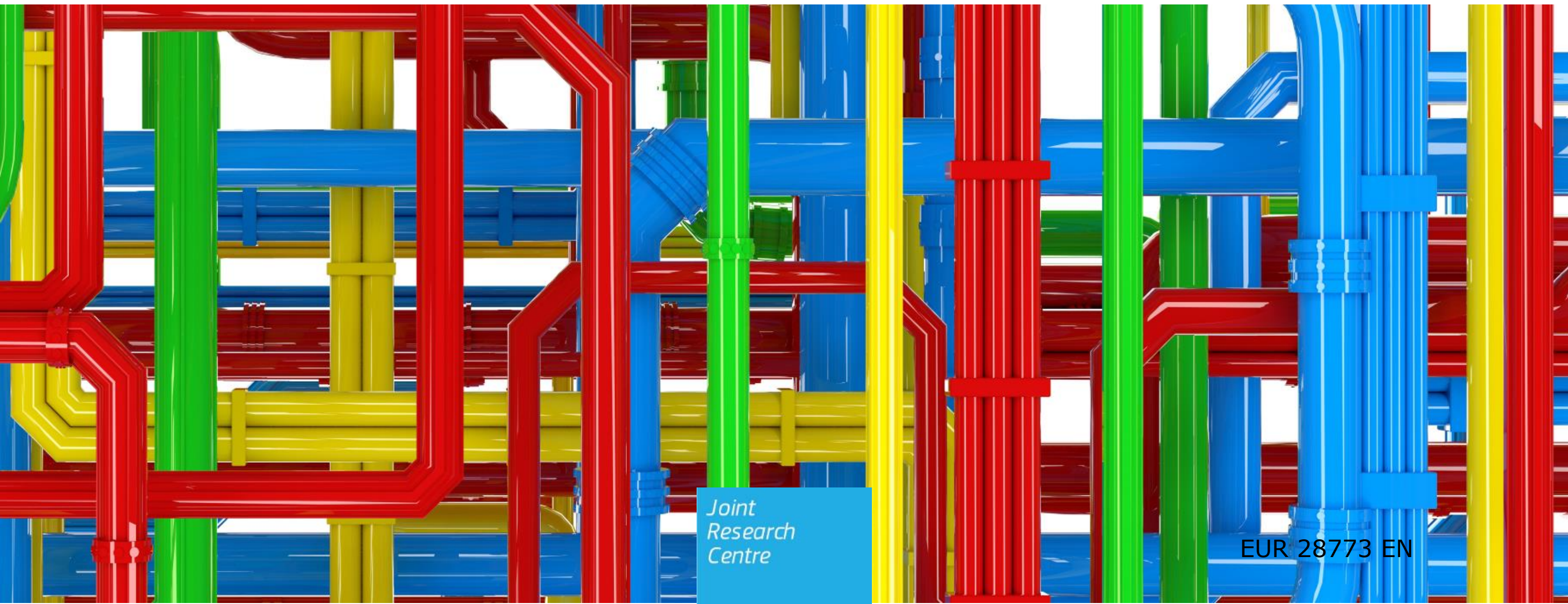

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Abstract

The "Integrated Database of the European Energy Sector" (JRC-IDEES) is a one-stop data-box that incorporates in a single database all information necessary for a deep understanding of the dynamics of the European energy system, so as to better analyse the past and to create a robust basis for future policy assessments. JRC-IDEES offers a consistent set of disaggregated energy-economy-environment data, compliant with the EUROSTAT energy balances, as well as widely acknowledged data on existing technologies. It provides a plausible decomposition of energy consumption, allocating it to specific processes and end-uses. Throughout all sectors it quantifies in a vintage-specific manner the characteristics of the energy (and non-energy related) equipment in use, along with the stock's average operation, identifies different drivers and provides insights on their role by sector, fully acknowledging structural differences across countries.

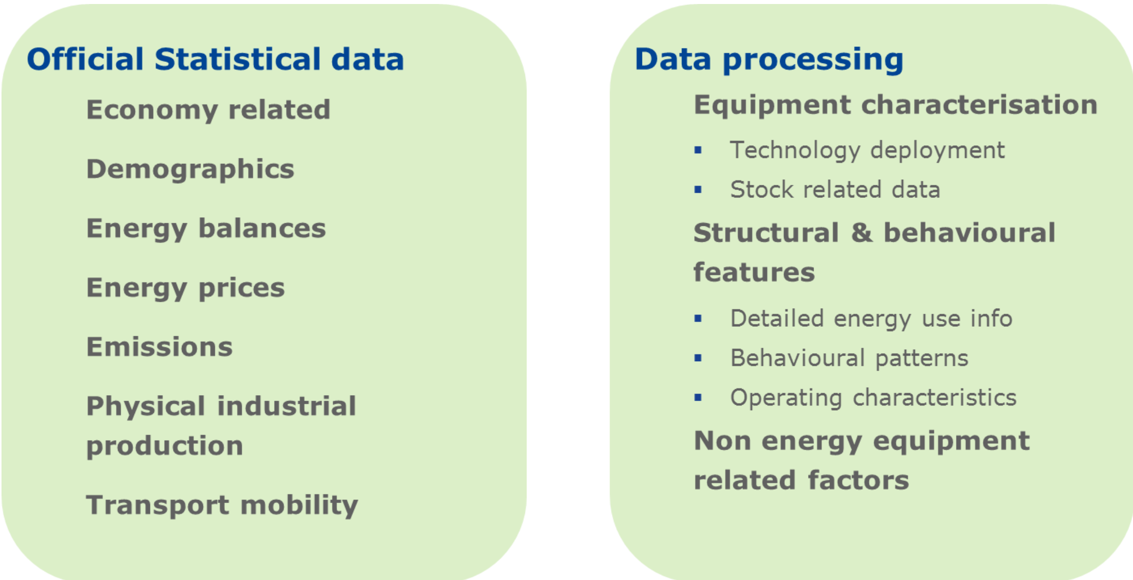
The complete output of JRC-IDEES is accessible to the general public, facilitating its use further by offering an inter-active visualisation tool. An iterative consultation process aims at further improving the data reliability. By making JRC-IDEES publicly available and revise it periodically in order to address experts' and stakeholders' comments, it can become a cost-free common reference point for energy futures assessments, thereby also avoiding redundant work.

JRC-IDEES is developed and maintained by the European Commission's Joint Research Centre.

1 Overview

The "Integrated Database of the European Energy Sector" (JRC-IDEES) is a one-stop data-box of all information relevant to the energy system. It provides information for all 28 EU Member States in annual time steps starting from the year 2000 up to the last year for which officially reported data are available (as of writing: 2015). Following a consistent structure throughout all energy sectors, the database contains two major, interlinked parts (see Figure 1).

Figure 1. Scope of JRC-IDEES



Source: JRC, 2017.

On the one side, JRC-IDEES brings together all statistical data that are relevant to the energy system, combining the energy balances with macro-economic, demographic, activity (e.g. industrial output; mobility) and climatic data. It draws on the Eurostat energy balances, power generation statistics, transport statistics, pocketbooks, macroeconomic and demographic data, as well as, information from UN databases (UNFCC National GHG Inventory Submissions, FAOSTAT etc.), the U.S. Geological Survey and the British Geological Survey. In doing so, it provides information on the factors that influence a sector's energy demand at the aggregate level.

On the other side, JRC-IDEES offers processed data that aim at deepening the understanding of the energy system's historic evolution and their underlying drivers, and thereby also creates a robust basis for the assessment of energy policy futures. To this end, the database makes available a detailed decomposition of historical time series of energy consumption and production that at the aggregate level match the official statistics.

This information assists in

- a better understanding of the observed variations in energy intensities across countries, caused by structural differences;
- quantifying the contribution of individual processes and end-uses in a sector's overall energy demand;
- singling out the role of technical improvements vis-à-vis consumers' behaviour in driving energy demand;
- pointing to the contribution of non-energy equipment related factors in meeting the energy service needs;
- identifying the effect of policies implemented; and
- determining the existing domain for further policy action

The decomposition is based on the available historical data series and assumptions made for the structural parameters of each sector. Energy consumption is allocated to individual processes and end-uses, acknowledging country-specific features with regard to both the installed energy equipment and their use, and to the non-energy equipment and sector-specific structures.

Energy consumption is further decomposed down to the level of a representative "consumption unit" (e.g. household, tonne of output, vehicle, appliance), distinguishing between technical properties and consumer-behavioural features.

The stock of the installed energy equipment is identified throughout all sectors, explicitly accounting for the vintages and further differentiating between existing and newly installed equipment in each year. The related techno-economic characteristics of the energy equipment are provided vintage-specific for the new equipment, and for the stock as a total; here, they evolve over time as a function of the commissioning and decommissioning of equipment.

The output of JRC-IDEES consists for each Member State and in annual time steps of:

- a comprehensive description of each sector's macro-economic and activity framework and aggregate energy demand;
- a detailed decomposition of energy use (both final and useful[1]) into processes and end-uses, and down to the level of one representative unit (e.g. per tonne of output, vehicle, household);
- comprehensive information on the related installed energy equipment (including conversion efficiency, installed capacities); this information is available for individual vintages, distinguishing in every vintage between the stock and new equipment;

JRC-IDEES offers

Full transparency…

- ✓ accessible to the general public
- ✓ iterative consultation process allowing continuous improvements

The possibility to…

- ➢ identify drivers for past energy system evolution
- ➢ analyse the role of implemented policies
- ➢ set a common reference for future energy policy assessment within the Energy Union

- explicit information on the hours of operation of the installed energy equipment;
- a consistent picture of the power generation sector that harmonises information on the installed capacities by plant type with the transformation input and the transformation output;
- enhanced energy balances that match the Eurostat energy balances at the level of sectors;
- the corresponding decomposition of CO_2 emissions and the related CO_2 emission balances[2].

[1] Useful energy refers to the energy service available to a user through a process (for example the heat output of a boiler)

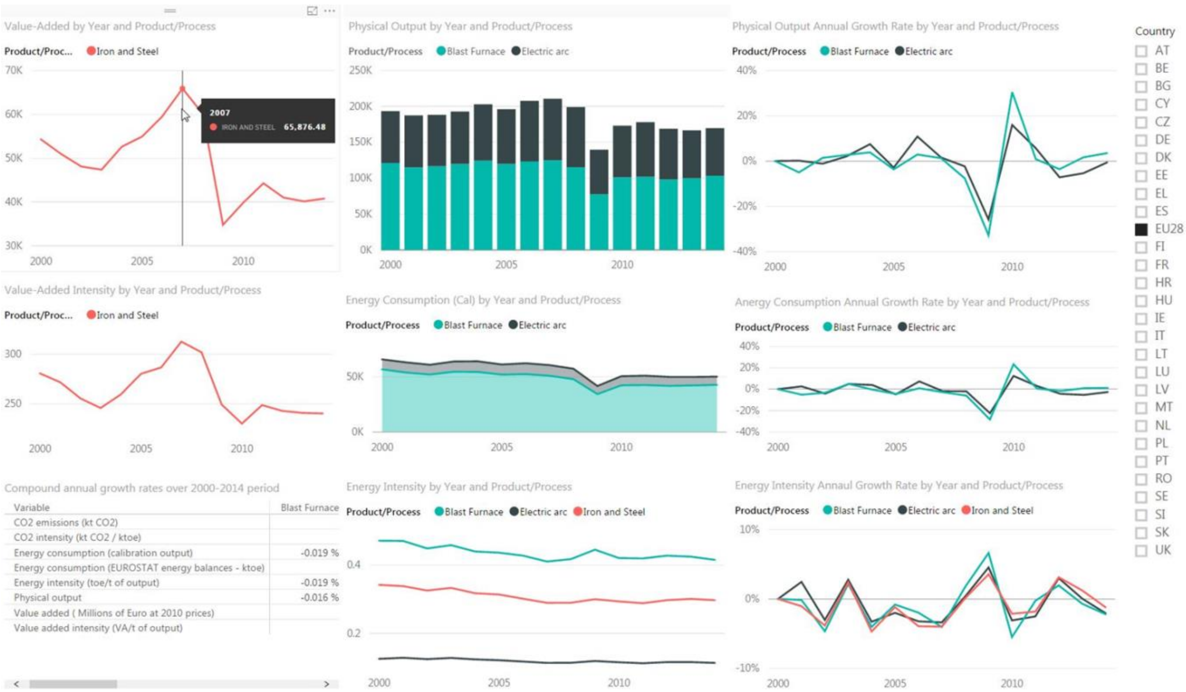
[2] These are generated using CO_2 emission factors in line with the Commission Decision 2007/589/EC.

JRC-IDEES also constitutes a helpful tool to detect data anomalies in the primary statistics used. In a first place, the combination of energy statistics with other statistical information (and the creation of relevant indicators) can support the identification of statistical outliers. In a second place, the results of the data decomposition process can offer further insights, narrowing down the outliers to a certain sub-sector or process, while respecting the constraints imposed by the installed stock of equipment. This makes it easier for the owner of the data or other analysts to explain a statistical outlier either by hidden explanatory variables not captured in JRC-IDEES or evident in the official statistics, by changes in the reporting methodology, or by an error in the data reporting.

As mentioned, the bulk of the figures in JRC-IDEES are own estimates based on available historical data series (statistics) and assumptions made for the structural parameters of each sector, based on studies, projects and surveys. Since most of the estimated values correspond to non-observable features of the energy systems or technologies,[3] alternative quantifications of structural parameters may provide equivalently valid decompositions of data.

In order to further assist users in undertaking analyses based on JRC-IDEES, an interactive interface is offered. This contains a predefined set of visualisations that are ready to use (see Figure 2). In addition, users have the option to create tailor-made visualisations to facilitate assessment of specific sectors etc.

Figure 2. Visualisation tool – an example



Source: JRC, 2017.

The complete output of JRC-IDEES is accessible to the general public. An iterative consultation process with Member States experts, stakeholders and academia has been initiated with a view towards further improving the data reliability. In addition, making this data-box publicly available creates a transparent basis for energy policy assessments within the Energy Union, both concerning analyses of the past as well as those of the future.

[3] Even though such values can be provided on a technical basis for specific energy equipment under certain well defined conditions, they are not known at the level of the overall energy system.

2 Approach

Throughout all sectors considered on the demand side, as well as for power generation, JRC-IDEES provides a consistent dataset that matches Eurostat energy balances with official information on activity indicators (e.g. value added, demographics, physical production output, transport activity).

These data are then decomposed in a consistent manner across all sectors, taking into account Member States and sectors' specificities. This means that the data decomposition within each sector is tailor-made for each Member State and sector, using a wide variety of different sources of information. Hence, by construction JRC-IDEES matches EUROSTAT energy balances.

Table 1 provides an overview of the main data sources used.

The "Challenges"

- Putting together fragmented, incomplete and inconsistent statistics
- Performing a detailed decomposition of energy use
- Keeping track of the evolution of the infrastructure
- Identifying the role of non-energy related factors
- Dealing with the lack of transparency

… while respecting the energy balances statistics and accounting for country specificities

Table 1. Main sources of information used in JRC-IDEES

Main data sources used in JRC-IDEES
EUROSTAT: Energy balances Power generation statistics Transport statistics Pocketbook publications Macroeconomic data (nama_nace and structural business statistics) Demographic data Energy consumption in households by type of end use Energy from renewable sources (SHARES tool)
UN databases (UNFCC National GHG Inventory Submissions, FAOSTAT etc.)
U.S. Geological Survey (USGS) (Minerals Information Commodity Statistics and Information)
British Geological Survey (European Minerals Statistics)
EURELECTRIC
ENTSO-E
EPIC database (Installed power plants capacities)
EurObserv'ER (Renewable energy forms)
Official national surveys and statistics
EC supported projects and studies, including: 'Survey on Energy Consumption in Households' (SECH 2010) EU Building Observatory, BPIE, TABULA, ENTRANZE, EPISCOPE on buildings characteristics TRACCS study Preparatory studies of the eco-design for energy using products ODYSSEE-MURE database JRC studies and reports
IEA reports
U.S. DOE studies and reports
Industry associations statistics, studies and reports

Source: JRC, 2017.

2.1 Demand side

In order to generate for each sector (i) a consistent set of official statistical data and (ii) processed data that contain information on equipment characteristics, structural and behavioural features and non-energy equipment related features, several distinct (but partially interlinked) steps are followed.

2.1.1 Link official statistical data relevant to the energy sector in a consistent manner

In a first step, the Eurostat energy balances are being brought together with official statistics that relate to energy-relevant drivers for the respective sectors. The activity data taken into consideration include

- Production volumes and value added for the industrial sectors;
- Demographic data, consumption expenditure and climatic data for the residential sector;
- Macro-economic data for the tertiary sectors;
- Mobility for the different transport modes (expressed in terms of passengers (pkm) or tons transported (tkm); as well as km driven, load factors, number of trips when available and/or applicable).

For each subsector considered, a consistent dataset is produced that matches information on activity indicators and energy consumption over the entire time period considered. This process may involve a further breakdown of some activity data into subsectors, using additional sources of information. Specifically in industry, country-specific structural characteristics that largely influence the subsectors' energy consumption are quantified.

In addition, for individual time series data gaps may need to be filled through interpolation and extrapolation processes, which may be modified on a case-by-case basis following a judgmental approach.

Note that Eurostat energy balances are never altered at the level of sectors; however, at lower levels and in a limited number of cases adjustments were introduced in order to correct for evident errors. Minor inconsistencies that are corrected include

- Singular misplacements of data in time series;
- Discrepancies relative to activity data;
- Allocation of unspecified energy consumption to the best-matching sectors.

2.1.2 Decomposition of the energy consumption

The aggregate energy demand of a subsector is then further decomposed on a year-by-year basis through a series of highly interlinked steps:

- For each subsector, the energy-relevant structure in terms of processes and end-uses (e.g. space heating) is identified based on a review of existing literature.
- For each end-use, the installed energy equipment is identified (in terms of number of installations and their size) in a vintage-specific manner, distinguishing between the stock and new installations, explicitly providing also data on retired equipment. In order to render the energy equipment more comparable across countries and over time, the concept of representative installations[4] is introduced. For both the stock and the newly invested energy equipment, technical characteristics are identified.
- The operation of the installed energy equipment is quantified. Hence, an explicit distinction is made between technology dynamics on the one side and the behaviour of energy consumers.
- For each end-use, the final and useful energy needs can then be quantified, both the total and at the level of a representative consumption unit (e.g. a representative household, a representative appliance, a representative vehicle, a representative unit of industrial output).

[4] A representative installation is defined for the EU28 for a given year; it relates to a certain (portfolio of) energy equipment with a given size and performance.

To the extent possible, the contribution of non-energy using equipment in satisfying energy demand is captured. For example in industry, the useful energy demand relates to a reference output (e.g. one tonne of steel of a certain quality, which is referenced to the EU28 average in a given year), rather than the actual physical output of a given country. By introducing the concept of identical production output characteristics, the useful energy demand per unit of reference output becomes comparable across countries, i.e. making it possible to interpret the remaining variations by means of useful energy needs as differences in the installed infrastructure equipment characteristics (reflecting the non-energy using equipment components) and/or product specificities.

"The Role of Installations"

Stock of energy installations explicitly identified:

- vintage-specific
- explicit replacement of equipment
- idle equipment quantified
- new equipment is assumed to have better technical characteristics compared to the stock (on a country basis)

Installations prevail over operation

… to better capture existing constraints

… to disentangle technical improvements from consumers' behaviour

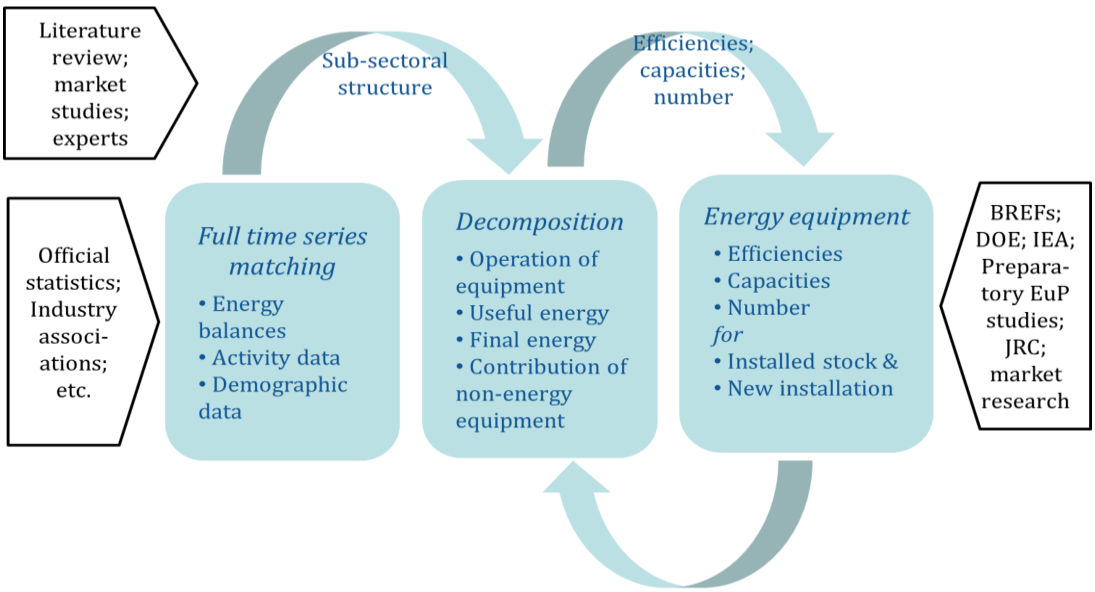
With the subsectoral structures defined and the input data gathered, the decomposition is performed as to allocate the energy consumption throughout all levels of detail, in each country and in each sector, between 2000 and 2015. In this process, several hard requirements have to be respected; these are

- the energy balance by fuel *without any exception*;
- activity data *without any exception*;
- limits imposed by the – explicitly quantified – stock of the installed energy equipment and the new equipment invested on in each year (to replace retired ones and satisfy potential additional needs); such limits refer, for example, to improvements in energy efficiency,[5] or drastic changes in the fuel mix;
- if available, official country-specific information

It should be noted here, however, that the decomposition process often requires a manual intervention for specific years, countries and/or technologies so as to match all requirements introduced throughout all points of the database and to address the statistical anomalies that might appear in the official data.

The general decomposition process can be illustrated as follows:

Figure 3. Schematics of the decomposition process



Source: JRC, 2017.

[5] Note that by default it is assumed that the energy efficiency of new installations is above that of the existing stock in any given country.

2.1.3 The mathematical problem

The technology/end use level decomposition performed in JRC-IDEES – along with the limits of the exercise – may be well illustrated as a constraint satisfaction problem (CSP).[6] In a CSP, a set of N variables $\{X_i\}_{i\in[\![1,N]\!]}$, along with their domains of definition $\{D_i\}_{i\in[\![1,N]\!]}$, need to be assigned within their domain. These may be energy consumption of residential technologies, activities of transport technologies, or value-added of different industrial pathways within the same sector (for example, integrated steelworks and electric arc in the iron and steel industry). All these need to be performed simultaneously, so that the energy and economic balances of each sector, for each country, match for every year. Therefore, we need to account for the existence of M constraints restricting the possible values taken by the variables, $\{C_j : f_j(A_j, X_i) = 0\}_{j\in[\![1,M]\!]}$. Hence, each assignment of a value to a variable must be consistent: it must not violate any of the constraints.

As a first step, assume that the variables of the problem are the fuel consumptions of each technology, and for each year. What we search is a set of annual fuel consumptions for each technology, $\{X_{t^g,y}\}_{(t^g,y)\in g\times Y}$, and activity levels $\{Z_{t^g,y}\}_{(t^g,y)\in g\times Y}$ such that:

- The energy balance of each final energy is respected, $\{\sum_{t^g|e(t^g)=f} X_{t^g,y} = E_{f,y}\}_{(f,y)\in F\times Y}$, meaning that the energy consumed by all technologies using fuel f *must* sum up to the energy balance, at any time.

It is clear that without further information, this problem admits an infinite number of solutions; as such, *there is no unique way of performing such a disaggregation*. At the extremes, one may assume that 100% of the gasoline is consumed by cars, 85% of the diesel is consumed by trucks etc. and obtain a feasible allocation. We might however end up with a skyrocketing unit fuel consumption of gasoline cars, and this is a major issue when performing the allocation solely based on *absolute activities and fuel consumptions*.

Actually, it is the *addition of intensities* (fuel efficiencies, annual mileage driven by technology) that have a higher meaning in physical and economical terms and will help narrow down the problem thanks to:

- A knowledge of technology characteristics, extracted from existing literature and databases;
- An observation of some behavioural variables, such as technology-level use intensities (km/year).

The introduction of these quantities as additional variables will make the solution more acceptable, by relying on existing pieces of evidence to establish reasonable guesses on their values. Even though - for a specific vehicle or boiler type and under certain well defined conditions – such values can be provided on a technical basis, they are not known at the level of the overall energy system, and thus remain *statistically not observable*. This means that this further disaggregation is useful to obtain a decomposition that presents *plausible storylines*, but no uniqueness. Another group may perform a similar decomposition and obtain other results that would be just as arguable.

Therefore, the approach undertaken for JRC-IDEES cannot rely on any defined mathematical program. Rather, its allocation process may be defined as follows:

- Define a set of rules that will allow to derive (almost) automatically an initial allocation solution for each country and each sector:
- Perform an ex-post adjustment process to end up with plausible estimates that do not violate any of the exogenous constraints.

Consistency is ensured across countries and sectors by applying the same generic rules in the problem definition.

[6] Another approach, called Positive Mathematical Programming (PMP), is sometimes used by modellers to estimate past, unobservable data. A (series of) mathematical program is used to calibrate a mathematical programming model against observed values for a base year, or averaged values of past years. The approach dates back to at least Kasnakoglu and Bauer (1988) and was brought to the forefront by Howitt (1995). Since then, it attracted some attention (see e.g. Heckelei et al, 2012).

2.2 Power sector

The power sector is described comprehensively for each Member States through a consistent dataset concerning its transformation input, transformation output and the related installed capacities.

The decomposition of the power generation sector provides a full picture of existing and under construction stock at unit level. The underlying data of existing power plant unit are derived from the EPIC database and was cross-checked on a unit-by-unit level; at the aggregate level it is consistent with information from EUROSTAT, EURELECTRIC and EurObserv'ER.

For most power plants, up to four typical size classes for each type of power unit with flexible classification are provided, making a total of 272 different power plant types. For each plant type, the number of units and their average unit size (which is variable on an annual basis reflecting unit commissioning and decommissioning) are provided, alongside the explicit net & gross capacities.

The database includes a consistent decomposition of historical data on energy consumption and electricity/steam production. CHP electricity is identified and contributions from co-firing are explicitly quantified.

3 Concluding remarks

JRC-IDEES is an Integrated Database of the European Energy Sector that brings together in a consistent manner throughout all sectors all statistical information related to the energy sector, and complements this with processed data that further decomposes energy consumption. JRC-IDEES quantifies the characteristics of the energy (and non-energy related) equipment in use in a vintage-specific manner, identifies different drivers and provides insights on their role by sector while at the same time respecting specific national structures.

The enhanced knowledge base provided by JRC-IDEES yields a better insight into the factors behind the energy sector's evolution. In particular, it makes it possible to disentangle technology dynamics, behavioural patterns and structural changes, and can therefore also hint to the impact of related policies. The differentiation between structural factors that influence the energy consumption and the installed energy equipment, together with the explicit tracking of the capacities and efficiencies of energy installations, offers an adequate basis on which to assess the scope for improvement that may be triggered by different types of policies. For example, it is possible to estimate the room for policy action that sets standards affecting the efficiency of new installations. Of course it needs to be stressed that the bulk of JRC-IDEES is processed data.

JRC-IDEES is publicly available and the exchange with national experts and stakeholders has been initiated. It can become a cost-free reference data-box that defines a common (and flexible) basis for the EU energy system analysis, helping to better analyse the past and to create a robust basis for future policy assessments.

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