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# POTEnCIA model description
## Version 0.9


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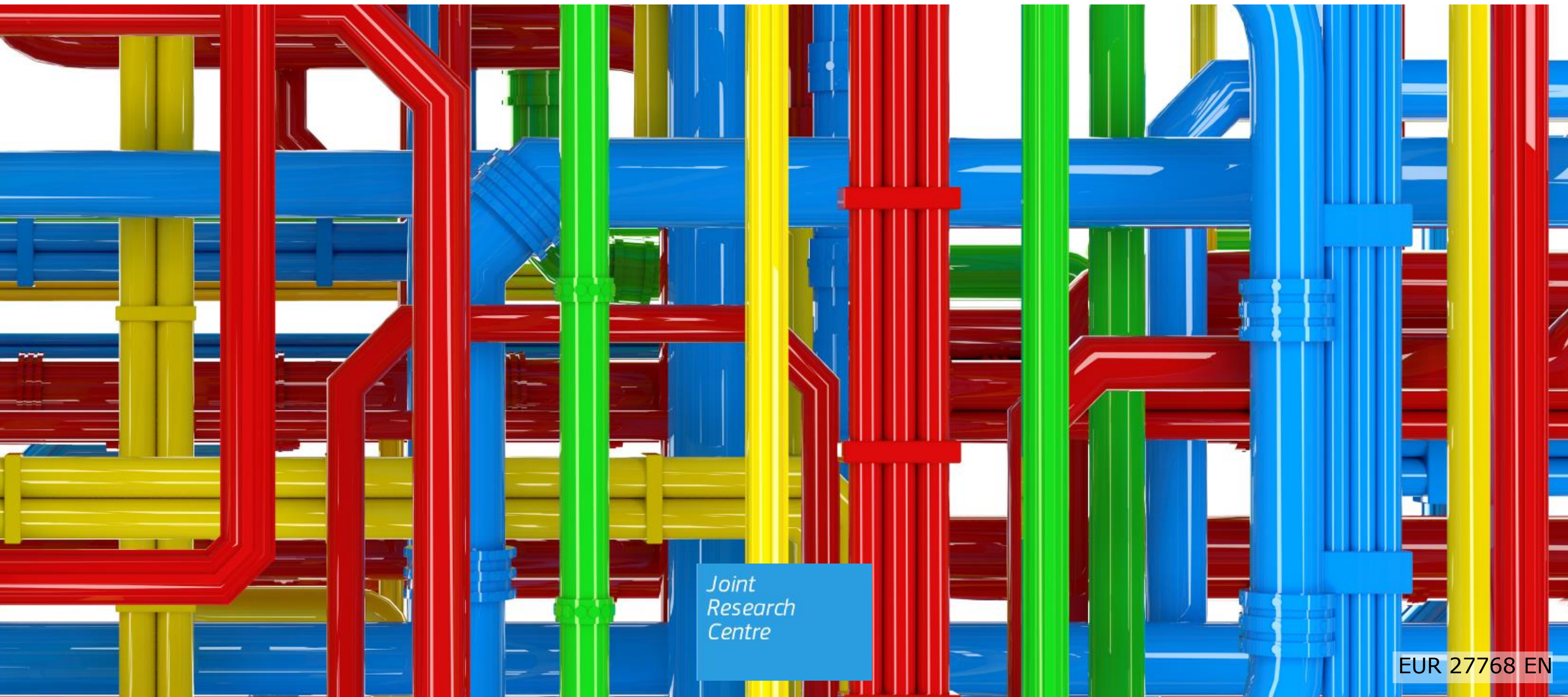

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- 'Improved Modelling of Energy Efficiency' (ENER C3)
- 'Enhanced JRC Modelling of Renewable Energies' (ENER C1)
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# Abstract

This report lays out the modelling approach that is implemented in the POTEnCIA modelling tool (Policy Oriented Tool for Energy and Climate Change Impact Assessment) and describes its analytical capabilities. POTEnCIA is a modelling tool for the EU energy system that follows a hybrid partial equilibrium approach. It combines behavioural decisions with detailed techno-economic data, therefore allowing for an analysis of both technology-oriented policies and of those addressing behavioural change. Special features and mechanisms are introduced in POTEnCIA in order to appropriately reflect the implications of an uptake of novel energy technologies and of changing market structures, allowing for the robust assessment of ambitious policy futures for the EU energy system. The model runs on an annual basis with a typical projection timeline to 2050.

# 1. Introduction

### *Motivation*

The European energy sector has entered a phase of rapid and substantial changes, with important consequences over the decades to come. Challenges arise from environmental concerns including increasingly ambitious greenhouse gas emission reductions, the pursuance of policies striving towards the more rational and efficient use of energy, market transformations such as the liberalisation of the European energy supply sectors and the creation of a single European energy market, the advent of innovative – partially fluctuating – power generation technologies that would change the simplistic industrial pattern of centralised producers and decentralised consumers, as well as increasing concerns about energy security of supply.

An energy model that is suitable for the analysis of impacts of policies on the EU energy markets needs to appropriately reflect these trends and address the mechanisms that explain them. Novel technologies are required to be accurately represented, both on the supply and on the demand side. At the same time, the implications of moving an important part of the generation capacities to decentralised production need to be captured, including possible impacts on networks. In such a dynamically changing environment, a high level of technological disaggregation and the appropriate representation of technology dynamics, in the context of different policy regimes, need to be adequately captured by the model both for energy consumers and suppliers. Finally, as policy-induced accelerated changes can lead to premature replacement of equipment the model should be able to explicitly address the corresponding stranded investment costs.

In order to address these major changes of the energy system, the Institute for Prospective Technological Studies of the European Commission's Joint Research Centre (ECCET unit) has developed a new energy sector economic model named POTEnCIA (Policy-Oriented Tool for Energy and Climate Change Impact Assessment).

### *Application scope*

POTEnCIA is designed to assess the impacts of alternative energy and climate policies on the energy sector, under different hypotheses about surrounding conditions within the energy markets. The model covers each EU Member State separately, while offering, in addition, the option of addressing the EU28 energy system as a whole. The typical projection period that can be analysed by POTEnCIA is up to year 2050 in annual steps.[1] Special mechanisms and features are implemented in the model as to appropriately represent the transformation of today's energy systems and to assess a variety of current and future energy related policies and measures. As an annual-step model, it can also be used to examine the short-term impact of new energy programs and policies.

The main use of such an instrument is for comparative scenario analysis. In other words, the projections produced by the model are not to be seen as statements of what will most likely happen (a forecast) under certain assumptions and with a certain degree of probability. They rather act as an assessment of what might be the impact of a given specific set of assumptions (defining a certain variant scenario) with respect to a plausible central (or reference) scenario, given the formulation and the methodological characteristics of the specific tool.

POTEnCIA is designed to represent the economically driven operation of the European energy markets and the corresponding interactions of supply and demand. In that

[1] It is possible, however, to extend the projection period beyond that year, as the model incorporates robust mechanisms allowing doing so.

context it incorporates a large variety of instruments that can be used to analyse the effects of:

- existing and proposed legislation (EU wide and/or Member State specific) related to energy production and use;
- policies accelerating or delaying technology progress and deployment, as well as introducing standards and/or labelling;
- greenhouse gases reduction policies;
- policies aiming at the increased use of renewable energy sources;
- policies focusing on increased efficiency of energy use;
- policies promoting the use of alternative fuels;
- different pricing regimes and taxation policies;
- price peaks caused by scarcity of certain energy carriers;
- different regimes for the electricity market related to decentralisation and liberalisation;
- alternative behaviours of representative agents (both energy suppliers and consumers) affecting both their investment decisions and use of equipment;
- policies related to the development of energy networks (including the impact of modifications in the cross-country interconnection capacities).

The subsequent changes in the structure and characteristics of the energy system, including its costs and prices, are not purely based on economic grounds, but are also affected by decisions of extra-economic nature (lifestyle, etc.). To account for this, POTEnCIA represents the economic behaviour of the energy suppliers and consumers, with the appropriate level of detail, taking into account such (observed) market imperfections rather than seeking a pure cost-optimisation reaction under perfect market conditions. Comparing the effects of the introduction of different policy assumptions to the projection of the main scenario (which only reflects current policies in place) allows quantifying their impact on the evolution of the energy system.

There are also a number of applications that go beyond the scope and the boundaries of the model and therefore cannot be addressed explicitly:

- Engineering analysis that refers to explicit technological options beyond the level of detail present in the model cannot be carried out. For instance, policies related to specific eco-design and/or labelling are addressed in an implicit manner at the level of disaggregation present in the model. However, information on the evolution of the overall characteristics of technology groups can be provided; for this purpose these groups were defined in line with eco-design definitions.
- Phenomena that occur in fractions of an annual step, such as random fluctuation in intermittent renewable energy sources supply, cannot explicitly be modelled. However, the impact of such fluctuations on the energy system can be analysed through specific snapshots, that can subsequently be incorporated in a Monte-Carlo analysis framework, contributing in this way to the assessment of the impact of alternative scenarios on given future structures (as derived from a policy scenario under default settings).
- By construction, the model cannot assess energy policy impacts on the economy unless when linked to a general equilibrium model. POTEnCIA can nevertheless provide quantified information on the impact of such policies at the level of activity for the various sectors within the energy system.

Issues relating to a higher spatial resolution than the one used in POTEnCIA (Member State level), including for example the electricity and gas grids infrastructure, locations of wind parks etc., cannot be addressed. However, the model can implicitly capture the volume and investment cost for networks capacity expansions at country level. It also performs a dynamic update of the resource potential (re-powering) for renewable energies.

# 2. POTEnCIA OVERVIEW

POTEnCIA is a modelling tool for the EU energy system that follows a hybrid partial equilibrium approach. It combines behavioural decisions with detailed techno-economic data, therefore allowing for an analysis of both technology-oriented policies and of those addressing behavioural change. The model runs on an annual basis, based on historic time series and with a typical projection timeline to 2050.

Each country is modelled separately as to appropriately capture the existing differences in energy system structures, levels of energy service, technology characteristics, resources availability etc. Vintage equipment characteristics are explicitly considered, allowing for an accurate representation of the features of the energy system at each point in time. Thus, the tool provides a consistent framework for representing the complex interactions of the energy system and its response to a wide variety of alternative assumptions and policies or policy initiatives.

Each demand and supply sector in POTEnCIA is formulated by means of a representative agent that implicitly seeks to minimise its cost and/or to maximise its benefit (profit, utility, etc.) under constraints related to behavioural preferences, technology availability, level of activity desired, degree of comfort sought, equipment installed, fuel availability and environmental considerations.

The behaviour of the representative agents within POTEnCIA is captured by causational equations (in many cases highly non-linear). Other non-linear relationships are introduced in the model as to represent the scarcity of resources, the level of exploitation of existing infrastructure and technology dynamics.

A variety of sector-specific assumptions are applied within the model. These concern the different planning horizons, the formation of expectations about prices, technologies, resources, etc., and the role of those expectations in economic decision making. Expectations about future markets are also accounted for.

At the level of the overall energy system, the model determines the equilibrium across the different sectors by means of price signals (equivalent to Lagrange multipliers in a purely optimizing modelling context) for all scarce resources (not only the traditional energy carriers, but also renewable energy, other efficiency and environmental –$CO_2$ related- costs in relation to their potentials). In this process different agents act as price-takers, price makers or simultaneously both. The equilibrium for network supplied energy forms (i.e. electricity, distributed steam/heat and natural gas) is treated by means of chronological load curves (at the level of representative days). These curves are computed by the model following a bottom-up approach that links the exogenously defined load profiles at the level of individual energy uses to the corresponding energy requirements. The equilibrium is static (determined on an annual basis) and repeated in a time-forward path while incorporating dynamic relationships as to reflect the previous decisions of each economic agent from one year to the next. Given the complexity of the problem as such and taking advantage of the annual time steps in which the model solves, POTEnCIA makes use of the equilibrium prices with a one year lag. This approach is adequate considering the (observed) delays with which price signals pass to economic agents.

POTEnCIA, though a partial equilibrium model, can also contribute to analyse, in an implicit manner, the effects that the implementation of policies may generate for the economy as a whole. Changes in the foreseen levels of production, induced as a response to the implementation of policies, may either be interpreted as equivalent reductions in the economic activity of the corresponding sector or as shifts towards products with different value added characteristics.

# 3. KEY FEATURES OF POTEnCIA

## 3.1 Generic model features

### 3.1.1 Annual time steps and vintage characterisation

POTEnCIA solves in annual time steps. This permits the explicit identification of vintages (both by means of number of installations as well as with regards to vintage equipment characteristics), allowing for an accurate representation of the energy system structures and characteristics at each point in time. Existing vintages dynamically evolve over time in relation to possible scrapping and/or premature replacement of energy use related equipment, as well as the adoption of non-energy related measures (permanent or temporary ones) that affect the operating characteristics of the vintages.

The overall stock characteristics are updated on an annual basis taking into account the investment performed in each specific year, the scrapping of equipment and the updated characteristics of previous vintages, according to a vintage-specific perpetual inventory model. In that context a realistic assessment of the energy savings and $CO_2$ emission reduction potentials in the energy system can be undertaken.

### 3.1.2 Subjective financing capability

For the investment decisions a subjective financing capability rate is used. Assuming unlimited access to financing capital and no risk aversion, the discount rate applied in the investment decision for an agent, reasoning on pure economic grounds, should be equal to the interest rate the agent has to pay for a credit (cost of capital financing). However, budgetary constraints, risk factors and/or asymmetric information apply and therefore the perceived cost of capital for the energy consumer may be higher than the nominal capital costs annuities. In order to capture these deviations from optimality, POTEnCIA assumes the existence of a subjective financing capability that reflects a kind of 'perceived' risk premium for the investor. Thus, in POTEnCIA the investment decisions are performed with discount rates that are the sum of the nominal one and the subjective financing capability.

The inclusion of budgetary constraints in the subjective financing capability rate allows for a differentiation of the investment related discount rates not only across sectors, but also across Member States. Whereas budgetary constraints have a limited impact on the investment decision for large industrial investors and power generators, they affect individual choices to a much larger extent. Hence, the subjective financing capability rates applied in investment decision making for households or private transport can differ largely across Member States, linked to the level of income. However, under the typical assumption of an economic convergence in the EU these differences would dynamically decrease in the long run.[2]

The subjective financial capability rate is taken into account only in the context of performing investment decisions. This means that when calculating the energy system costs nominal discount rates apply. Furthermore, the default setting of POTEnCIA does not involve any change in discount rates as to assess the impact of policies, since it incorporates a number of mechanisms that endogenously change the decision making parameters as a function of the policies in place.

### 3.1.3 Capturing behavioural changes

The introduction of policies generates a response in the decision-making of the representative agent as regards the investment in new equipment and/or the use of the

[2] Such economic convergence is typically reflected in the long-term macroeconomic assumptions that align to existing EU policies and constitute an input to POTEnCIA.

installed equipment. This response is multifaceted and includes, beyond pure price-driven changes, reactions in the agent's behaviour. To this end, in POTEnCIA a number of features are introduced that endogenously capture policy-induced changes in the behaviour of energy consumers and suppliers.

The market acceptance factor reflects the investor's preferences that result in investment choices which deviate from economic optimality as defined if only engineering costs were taken into account. Such preferences, however, may change as a function of the prevailing policy conditions. For example, within a policy framework that strongly supports a certain technology type, the representative agent may perceive signals of a collective 'societal' appreciation of such technology, thereby favouring it beyond pure economic criteria. This is captured through a policy-dependent element of the market acceptance factor in POTEnCIA.

The introduction of a strict policy framework may also result in a better understanding of the costs of different option when performing an investment-decision. In consequence, the choice made by the representative agent would become more economically optimal rather than being influenced by non-economic considerations. To this end, POTEnCIA introduces the possibility of a policy driven (endogenously derived) change in the elasticity of substitution of the market sharing function.

Concerning the operation of the installed energy equipment, the representative agent can react to changes in the prevailing policies through adapting the related rate of use of the equipment, and its behaviour temporarily so as to use the equipment in a more (or less) rational way. The latter includes reactions such as a change in the driving style, different settings of the thermostat, etc. These behavioural changes, which are of temporary nature, are captured in POTEnCIA through the behavioural response parameter (BRP).

The explicit consideration of behaviour-related policy responses, which are reflected through the above-described endogenous mechanisms, limit the need for exogenous interventions when addressing specific policies in the POTEnCIA model.

## 3.2 Key features and concepts in the demand side

### *3.2.1 Investment in and operation of installed equipment*

The majority of traditional energy system models determine the total energy service requirements of a sector through a behavioural standard demand equation, based on observed consumption patterns. This approach has a major shortcoming. Since it starts from the total energy service requirements, instead of the unit ones, existing equipment can be inappropriately allocated to new agents. For example, in a scenario where the total energy service requirements of households decrease (e.g. due to a price shock) while the number of households increases the existing equipment could, under certain conditions, be sufficient to satisfy the total energy service requirements of the sector. In reality however, new equipment would still need to be installed as a new household cannot use the neighbour's central heating system. In this case, the traditional modelling approach may lead to an inaccurate underestimation of the investment needs.

In order to adequately cope with this issue POTEnCIA makes use of the concept of the above-mentioned 'Representative economic agent'. Within each sector, the representative economic agent summarises the individual choices of various decision makers under different conditions. This yields a 'representative' consumption profile in the sector in terms of energy related equipment in use, consumer preferences, etc. The notion of the representative economic agent has a different physical meaning in each sector. In the residential sector it represents a household or an appliance whereas in the transport sector it represents a mean of transport and in industry the production volume. In the corresponding sections of this report, an accurate characterisation of the representative economic agent chosen will be given, as well as a description of its choice-making decision as formulated in the model.

In POTEnCIA, each sector-specific representative economic agent implicitly optimises an objective function (by means of profit/utility maximisation and/or cost minimisation). The optimisation takes place through adjustments in the level of activity within the sector, the level of unit energy requirements (i.e. per unit of activity), the level of use of installed equipment (i.e. involving possible premature replacement and/or under-utilisation), and investment choices under constraints that refer to behavioural preferences, activity levels, comfort standards, technology options, environmental concerns and fuel availability. Consequently, although the decision is assumed to be economic, many of the constraints and possibilities reflect engineering feasibility and restrictions. At the same time non-energy related issues (e.g. budgetary constraints, policy perception) are also taken into account. Therefore, the model combines economics with engineering in a consistent way.

Moreover, a clear distinction is made between the energy related equipment that needs to be installed when making an investment decision and the rate of use of the installed equipment. For that purpose the concepts of "desired" and "realised" energy service requirements at the level of the representative agent are introduced.

Desired energy-related service requirement represents a notion of the "welfare target" of a new representative agent at each moment in time. It depends on standard drivers for energy demand (i.e. economic and demographic assumptions) and on the evolution of technical and comfort standards incorporating saturation effects. The desired energy related service is used for calculating the investment needed at the level of the representative agent when acting as an investor so as to satisfy its foreseen energy needs.

On the other hand the realised energy related service requirement is used to calculate the energy consumption of the existing representative agents in a given year and the level of utilisation of installed equipment, not only taking into account the evolving welfare target but also the cost of the energy service, i.e. fuel prices, effects of policies in place etc.

Through this approach, energy consumption and installed capacities of the energy related equipment are calculated independently the one from the other; they are matched through endogenously calculated utilisation rates.

In POTEnCIA the number of agents operating in a sector represents the activity level of the sector, depending on the evolution of macroeconomic and demographic assumptions. Therefore, for each year the model explicitly identifies the number of agents performing investment and those that are operating their already installed equipment. Furthermore, through the explicit representation of the number of agents on an annual basis it is possible to identify cases in which the number of existing installations from previous years is higher than the ones needed to be operated in the current year. This is extremely important for industrial sectors that exhibit fluctuations in their activity levels over time. For example in POTEnCIA the existence of installations that were underutilised in the period 2008-2012 in the iron and steel industries of the EU (as a result of the economic downturn) is fully captured, thus limiting the need for new investment when activity resumes.

The total investment in new equipment is explicitly calculated as the product of the agent-specific unit investment decision with the number of agents that need to purchase new equipment in order to satisfy their energy needs. This number of agents is the sum of the following:

- "New" agents entering in the sector (e.g. increase in the number of households; increase in the tons of steel produced relative to the available installations capacity);
- Existing agents that perform normal replacement for their existing equipment when it reaches the end of its technical lifetime; and
- Existing agents that driven by prevailing policy assumptions decide to prematurely replace their installed energy related equipment (scrapping it or putting it in "cold" reserve).

The actual, realised energy service is computed as the product of the rate of use of the installed equipment and its corresponding size and characteristics. At the same time possible non-energy equipment related actions from the side of the agents (again vintage dependent) that may lead to a decrease or even an increase of these requirements are taken into account. These actions are simultaneously vintage and end-use specific. Thus, the behaviour of the agents is endogenously differentiated depending on the type of equipment in use and its technical characteristics. For example in the presence of an ambitious energy efficiency policy consumers with inefficient installations for space heating will be strongly affected whereas those that satisfy their needs through (for instance) a heat pump will continue satisfying their comfort needs without performing additional investment. At the same time, in the presence of a price shock differences in the response of consumers depending on the energy use can be captured (e.g. high responsiveness in the rate of use of space heating equipment but a lower one for cooking).

The total installed energy related equipment capacities consist of the existing stock including capacities that have been prematurely replaced or put into cold reserve. The decision about whether a capacity of the cold reserve can be reactivated at a later point in time varies between demand sectors and the type of equipment. For example, a decision taken in a certain year to put into cold reserve an integrated steelwork unit can be made reversible in another year. Similarly, improvements in thermal insulation may lead to the underutilisation of a domestic boiler. However the full capacity of the boiler is maintained and can be used when necessary. On the contrary, a decision to prematurely replace a household's space heating system as such is not reversible and the replaced capacity cannot be reactivated.

### 3.2.2 Vintage stock representation in POTEnCIA

A detailed capital stock ageing approach is adopted in POTEnCIA in order to keep track of the techno-economic characteristics of the installed capital stock in a given sector over time. The capital vintage model adopted assumes a given, vintage-specific (but not stochastic), standard lifetime for each capital good category. Accounting for the techno-economic characteristics and the corresponding capacities for both the investments undertaken and the equipment that leaves the stock in each year a detailed representation of the capital stock dynamics is achieved.

This model architecture allows differentiating the rate of use of the installed equipment for the representative agents that fall into different vintages, explicitly taking into account the vintage specific techno-economic characteristics and, consequently leads to a more accurate calculation of the final energy demand, $CO_2$ emissions and costs related to the fulfilment of the energy service needs in comparison to models that follow an approach of 'average' equipment characteristics.

In addition, many technology-oriented policies, and in particular those for consumer goods, set standards for new equipment. For example, eco-design policies for energy-related equipment usually set minimum efficiency standards for newly installed equipment. Hence, the explicit identification of vintages allows to appropriately identifying the domain for new equipment, thereby better assessing the impacts of such types of policies. The same applies for policies that aim to accelerate the equipment turnover (e.g. scrapping subsidies for old cars) as the domain for (premature) replacement under changing policy conditions can be assessed across vintages.

### 3.2.3 Endogenous technology dynamics

For each of the technology options defined in POTEnCIA consumers choose to invest in an 'almost ordinary' (T1), an 'advanced' (T2) or a 'state of the art' (T3) technology. The techno-economic characteristics of these alternatives are defined endogenously and evolve dynamically over time as a function of the average characteristics of the existing stock for that specific option and a theoretical optimum technology (the 'backstop' technology).

The 'ordinary' technology initially represents the average country specific technological characteristics of the existing stock in the base year of the analysis for which statistical data (energy balances) are available. These 'ordinary' technology characteristics are calculated through a calibration process which entails the decomposition of aggregate energy demand (as available in EUROSTAT energy balances) to the level of detail introduced in the model, in combination to reference techno-economic data for the different equipment types. For each projection year the characteristics of the 'ordinary' technology are updated accumulating the effects of investment choices made by consumers in the previous year and the scrapping of equipment.

On the other hand, the 'backstop' represents the technical optimum that a technology converges towards in the future. It is the same across all countries and, to a great extent, reflects the physical limit of potential efficiency improvements.

The efficiency characteristics of the technologies T1, T2 and T3 in each projection year are calculated by using exogenous ratios which may dynamically change over time depending on prevailing scenario assumptions, e.g. strength of emission reduction policies, energy efficiency support policies etc. These ratios apply to the gap between the 'backstop' and the 'ordinary' technology in identifying the updated equipment efficiency characteristics. The capital, fixed O&M and variable O&M costs of the competing technologies are calculated endogenously as a non-linear function of their distance by means of efficiency to the backstop and the pace of the efficiency improvement. The formulation applied in the model allows distinguishing between radical and more progressive technology changes and their impact on equipment costs, while capturing at the same time endogenous learning effects that offset (partly or fully) over time the additional costs incurred by technology progress. This means that the model mimics historically observed trends of many consumer products that have experienced continuous improvements in their technical efficiencies whilst these improvements were not followed by an increase in their end user prices.

Furthermore, the approach retained with regards to technology dynamics allows differentiating between the characteristics of the technologies available in different countries as they depend on the gap described above. According to this, for instance, it allows for a faster deployment of efficiency improvements in inefficient energy systems compared to efficient ones; in other words, a gradual convergence of available technologies across countries takes place. Similarly the costs of the installed equipment vary across countries, better reflecting the fact that countries with less efficient equipment face lower equipment costs.

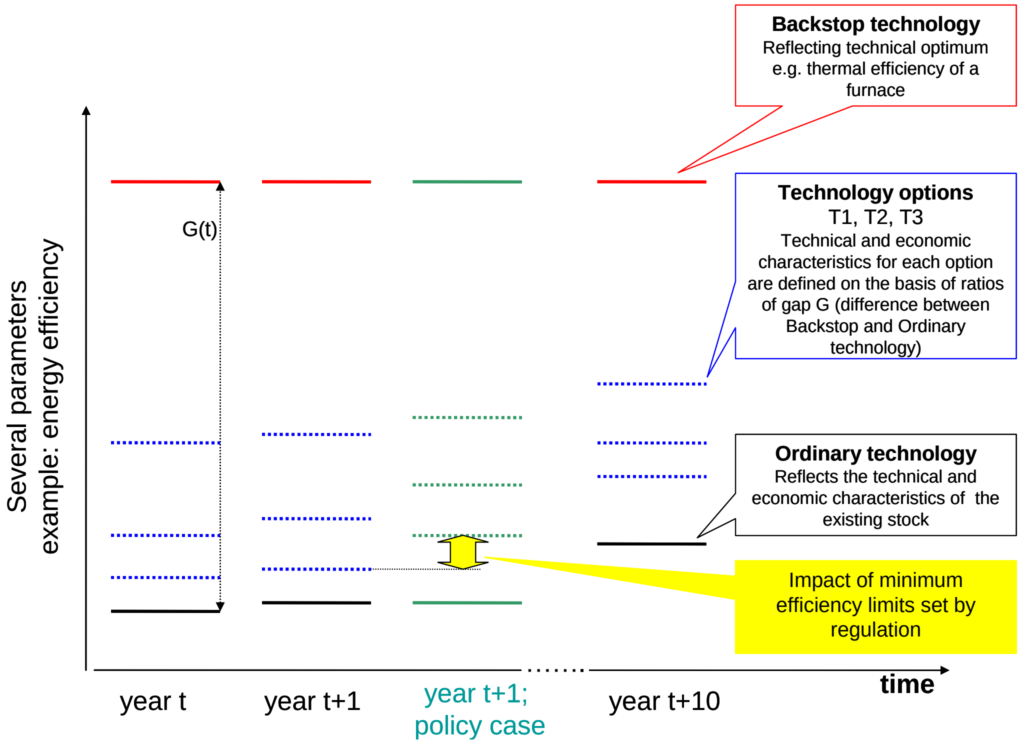


**Figure 1 Description of technologies on the energy demand side**

Moreover, the mechanism establishes a link between technology dynamics and policies. In the presence of policies that lead to a faster deployment of more efficient options the model further reflects the observed tendency of making even better options available in the market, thus, allowing for a faster evolution over time towards the 'backstop' technology (compared to a scenario in which such policies are absent).

Imposed minimum efficiency standards, e.g. by eco-design policies, can also be explicitly modelled. Such policies directly influence the techno-economic characteristics of the 'worst-performing' investment option (technology T1). This leads to a mandatory change of the gap between the technology T1 and the "backstop" technology which in turn affects the techno-economic characteristics of the technologies T2 and T3. Hence, both the primary and the secondary impact of such type of legislation can be modelled. However, for policies that address technologies at a level of detail that goes beyond the one of the technology groups of POTEnCIA an ex-ante analysis is necessary.

### 3.2.4 Non-energy equipment parameters

#### *Production Structure Parameter (PSP)*

The actual composition of the energy system sectors varies largely across the EU Member States. For example throughout most industrial sectors, the portfolio of output produced, the primary input feed used and the infrastructure as such is very heterogeneous, and has an important impact on the energy intensity of the sector. Hence, for an energy model it is crucial to identify the impact of the sector's underlying structure on its energy consumption, and distinguish it from the technical efficiency of the installed energy equipment and the exploitation of non-energy equipment options.

In that context and making use of the extensive decomposition process of historic data (the JRC-IDEES database) the impacts of these systemic differences are captured in POTEnCIA through the introduction of the Production Structure Parameter (PSP). Through this PSP a large part of the deviations observed across Member States in terms of energy intensities for the different demand side sectors are associated and allocated to structural differences, therefore limiting the discrepancies in terms of the efficiencies of the energy equipment within acceptable boundaries. For example the energy intensity of the food industry in 2010 ranged from 44 to 286 toe/M€2010 across the EU Member States –with a value of 130 toe/M€2010 for the EU28 as a whole. Such a range cannot be solely attributed to differences in the installed energy-related equipment but rather reveals the (sometimes substantially) different structural characteristics of the sector.

In the default setting POTEnCIA assumes that the PSP remains constant throughout the projection period implying that the production structure remains unchanged within each sector. However, it is possible to exogenously define different patterns for the evolution of the PSP in the future.

#### *Infrastructure efficiency parameter (IEP), structural response parameter (SRP) and behaviour related parameter (BRP)*

Since in general the energy equipment installed in the EU energy system has achieved already a high level of energy efficiency, additional energy savings will depend to an important extent on measures that are non-energy-equipment related.

To this end, POTEnCIA explicitly addresses such type of measures as an alternative option in the economic investment decision making process. At the level of end-uses an infrastructure efficiency parameter (IEP) is introduced. This IEP provides a notion of the potential and costs for optimising the entire process at an aggregate level. It relates to the structure and the use of the energy equipment.

The IEP captures measures of technical nature such as thermal insulation in buildings, heat recovery in industry, low resistance tyres in private cars, installation of sensors etc. The level of exploitation of the saving potential through the IEP and the related costs follow a non-linear formulation (usually of the type of an S-shaped curve). The representative agent takes an economic decision on the level of investment in non-energy equipment options, comparing their costs with the cost savings occurring from the lower capacity needs and lower energy consumption. The investment decision (for example improving the non-energy equipment related part of an industrial production process) takes place not only for new installations but also for existing ones. In the latter case, both, the cost of the improvement and the stranded costs arising from the induced underutilisation of installed equipment are considered.

At the same time behavioural changes that link to the more or less rational use of the energy equipment, such as the way of use of electric appliances, the setting of the thermostat in a building etc., are addressed through a sector-specific behavioural response parameter (BRP). With the BRP possible rebound effects can be addressed. For example in the case of a drastic decline in fuel prices the BRP can capture the worsening of the behaviour of the consumers. Thus, the BRP links to the level of exploitation of installed equipment and, depending on demand sectors specificities, can either complement or counterbalance changes in the rate of use of the equipment. For example a price driven reduction in the hours of use of space heating equipment is possible to be further complemented by a change in the thermostat settings.

The key difference between the IEP and the BRP lies in their nature as such. The IEP has a permanent character (a physical type of investment is needed as to be achieved and the corresponding costs are borne by consumers over time), whereas, the BRP is characterised by its temporary nature and triggers indirect changes in the variable costs of the installations. Because of the permanent nature of the IEP, decisions made for further improving such non-energy equipment characteristics within the same vintage are accumulated over time and act in a reinforcing manner.

POTEnCIA further offers the possibility of linking the level of activity in the different sectors (initially driven by macroeconomic and demographic assumptions) to the prevailing economic and policy assumptions. This is done through the introduction of the structural response parameter (SRP). A non-linear formulation, through which the SRP adjusts over time in relation to the changes in the cost of satisfying one unit of service, has been introduced in the model. Such adjustments can be interpreted as a response of the representative agents by means of altering the mix and quality of their service (and/or, depending on the sector, its productivity).

## 3.3 Key features and concepts in power generation

For the power generation sector POTEnCIA follows a non-linear, price-lagged, optimisation approach, simultaneously addressing capacity planning and power plants dispatching under:

- demand constraints (synchronised chronological load curves for electricity, and distributed steam and heat demand);
- power plants related operational constraints;
- fuel supply constraints (including chronological load curves for intermittent renewable energy forms, such as wind and solar energy, as well as for natural gas);
- system reliability and reserve margin constraints;
- grid constraints; and
- policy constraints

Both for the capacity expansion and for the unit commitment/dispatching problems the model is solved simultaneously for electricity-only and cogeneration capacities.

### 3.3.1 Addressing the chronological demand load

POTEnCIA considers the chronological demand load curve with *hourly* time segments for one representative day. This representative day is derived after clustering historically observed hourly loads over a year and is constructed as to reflect the most likely *load pattern* for annual dispatching.

### 3.3.2 Unit commitment and operating mode

The dispatching in POTEnCIA considers simultaneously both the chronological (hourly) load pattern of the demand and the different load regimes (ranging from the base load to the peak load). Power plant units are dispatched while considering the duration of the respective load regimes, therewith explicitly taking into account additional costs and fuel use that may occur as a consequence of cycling operation and spinning when operating certain power plant types within specific load regimes. At the same time, the availability pattern of intermittent renewable energies is fully respected.

Rather than following an approach that considers the total installed capacity of a given power plant type, POTEnCIA simulates the operation of (representative) units by accounting for the number of units available, their corresponding (unit-specific) size and operating constraints, including additional costs and inefficiencies that may occur when the unit is operated in part load or with frequent ramp-ups and -downs.

Thus, POTEnCIA allows for a more realistic representation of the power plants' annual dispatching by mimicking a *unit commitment* approach, which

- explicitly considers the hours of availability of each resource;
- respects the units' size and their operating conditions (minimum stable load etc.); and
- identifies the efficiency of the power plant in operating mode, taking into account the real hours of operation, as well as the cycling and spinning effects.

This approach makes it possible to distinguish, within a given load regime, between a unit's contribution to satisfy the electricity demand in terms of kWh and its contribution to meet the load in terms of power (kW). Whereas a thermal unit's contribution to electricity generation also implies a corresponding contribution to the load of the regime it is allocated to, this may not be the case throughout all load regimes for intermittent renewable energies due to constraints arising from their naturally limited hours of availability. For example, even though PV units cannot contribute to meeting the power load in the base load due to the fact that they can generate electricity only during daylight hours, they can satisfy part of the electricity generation within it.

The distinction between a unit's contribution in terms of electricity and in terms of power (load) to a certain load regime makes it possible to derive:

- the exact number of units in operation and the un-used ones (reserve);
- the actual rate of use of the units in operation, taking into account also their operation in part load conditions;
- the costs, the additional fuel consumption and related $CO_2$ emissions caused by operating units in cycling and spinning mode.

### 3.3.3 Priority dispatch and portfolio management approach

Power plants operation is treated in two consecutive steps: firstly, the mandatory production requirements and secondly, the economic dispatching in order to meet the remaining load.

In POTEnCIA the strategic considerations, such as the *priority dispatching of intermittent renewable* energy forms, the electricity generated from the cogeneration power plants, together with the specific policies and technical constraints of the system, like quotas set by policies (e.g. electricity generation from biomass), the possible operating preferences linked to the installed capacities (e.g. nuclear) or the existence of indigenous energy sources (e.g. lignite), are treated as minimum levels of electricity generation from certain technology types. This represents the first step of the simulation of the power plant units operation and satisfies partially the electricity generation and the load of different load regimes.

The remaining part of the load curve is fulfilled through the economic dispatching criteria. Instead of seeking the least cost solution for electricity generation POTEnCIA adopts a *portfolio management approach* with regard to economic decision-making both in the capacity planning and in the power plants' operation by using the "desired market shares" of the options available, as obtained through applying a multinomial logit formulation.

### 3.3.4 Independent distributed power producers

POTEnCIA can deal with independent distributed power producers in two different ways, allowing thereby the impact assessment of different policy options, such as the promotion of self-consumption of the on-site generated electricity.

On the one hand, independent distributed power producers (e.g. small PV) are allocated to the power sector and form an integral part of the dispatching problem, meaning that technologies like small PV or micro-wind compete within the power sector. On the other hand, POTEnCIA offers the option to allocate them to the demand side. In this case, POTEnCIA calculates the electricity produced in the demand sector by micro-CHP, micro-wind and micro-PV at each point in time, by means of chronological load curves using appropriate load profiles. The electricity grid – i.e. the power sector – would then see the (remaining) net demand profile of the household, which may even turn negative (representing sales of electricity to the grid). In this setting, decentralised electricity generation competes outside the power sector; it thus reflects optimality of the consumer rather than that of the power sector, as under these circumstances the burden of a more complex load-track would impact negatively centralised power generators.

### 3.3.5 Investment planning under uncertainty

A key feature of POTEnCIA is that capacity planning in power generation follows a dynamic recursive foresight with imperfect information. The investment decision in the model moves away from the perfect foresight framework and does not consider with certainty fixed, predetermined values for the policy parameters. Instead, the approach implemented seeks to mimic real world decision making under uncertainty.

To this end, POTEnCIA by default introduces *uncertainties in the investment* decision-making in the power sector, which reflect different expectations as regards the evolution of policy parameters. Each value has a specific weight calculated based on the distance to the prevailing policy condition. In other words, the different expectations take into account the reality of the prevailing policy. These dynamically evolving *asymmetric probability distributions* determine which investment options are more desirable.

### 3.3.6 Decision making considering different types of agents

In POTEnCIA the capacity planning in power generation is performed by means of considering the different behaviours for distinct types of agents' under diverse expectations as regards the future policy regime:

- *Dedicated producers* - which identify the investment solution at the level of specific parts (markets) of the load duration curve, ignoring the overall system characteristics.
- *Market agents* – which represent individual producers. Each one of them has a different perception of the stringency of future policies (e.g. one market agent evaluates its investment decision applying a carbon price of 100€/t$CO_2$, another considering a price of 50-100€/t$CO_2$ and another applying a price of 1 €/t$CO_2$). The overall investment solution is obtained by combining the individual choices through a weighted average of the number of agents likely to make this very choice, taking into account the prevailing policy conditions (e.g. the ETS price in place).
- *A central planner* - which considers different possibilities for the future of policies and weights them in order to obtain the final specific, economically driven investment choice. The central planner examines the different possible characteristics of the system by identifying the likelihood of the costs of the different investment options and based on this he identifies the most likely cost characteristics of each investment option. On this basis, the market shares of the final investment choice are derived.

The default setting that POTEnCIA applies in performing the investment decision is the one of the central planner. However, the possibility to activate the other two types of agents' behaviour is available (including a possible combination of the three types of planners using exogenous weights).

### 3.3.7 Explicit vintage characteristics

POTEnCIA runs on an annual basis and includes explicit vintage characteristics of installed equipment. To this end, the overall stock characteristics are updated on an annual basis taking into account the investment performed in each specific year and the scrapping of existing equipment. This feature enables a realistic assessment of the operating characteristics of power plants when dispatched.

### 3.3.8 Potentials

Two different types of potentials are considered for the available resources:

- *technical potentials* which impose a strict, theoretical constraint for the system; and
- *realisable potentials*, which reflect the economically exploitable resources under reference policy assumptions

In POTEnCIA a power plant option becomes less attractive when it is already exploited at levels close to the realisable one. However, this does not imply that because the economically exploitable potential is reached no further investment will materialise for that specific option. In other words, the model reflects the possibility that certain policy regimes may lead to an endogenous revision of the economically exploitable potential towards the absolute limit that is expressed by the technical potential.

### 3.3.9 System stability

In POTEnCIA the stability of the electricity system is carefully addressed, going beyond the typical notion of the reserve margin. To this end, endogenously derived signals are obtained from the power plants operation to the investment decision, which affect both the level of investment needs, and the attractiveness of competing investment options. Concerning the former, a boundary condition for the capacity in use versus the total capacity installed is introduced, ensuring that sufficient capacity is available to meet the load in all circumstances. At the same time, another system stability indicator is computed as the ratio of the capacity in operation and the peak load. This indicator reflects the bundling of power plant units and the exploitation of capacities that contribute mainly in satisfying the energy but do contribute to the load only to a very limited extent due to e.g. constraints in the availability of their primary resource (wind, PV). When this indicator reaches high levels the investment options that contribute to the reliable available capacity become more attractive compared to options that further contribute in satisfying the energy and not the load.

### 3.3.10 Endogenous treatment of electricity imports and exports

Imports and exports are explicitly modelled in POTEnCIA, taking into account the capacity constraints of interconnectors. Both their levels and their patterns of use change dynamically as a function of the evolution of the demand load pattern and the contribution of intermittent renewable energies. In a similar manner, the shape and level of pumping are not exogenously predetermined but link to the pattern of the demand load curve.

In the case of extreme scenarios, imports can also be used for closure, meaning that the parts of demand that cannot be satisfied by the system alone will then be met through increased import levels. The amounts of imports needed in order to satisfy a gap that results as a mismatch between the operation of installed capacities and demand are displayed separately, allowing therewith the identification of such situations.

### 3.3.11 Hourly pattern for electricity costs and prices

Electricity pricing in POTEnCIA assumes a full recovery of costs, including the operational costs, and the payback of fixed ones for both the capacities in operation and the capacities in reserve. In addition, mark-ups are introduced to reflect market power, and grid costs are also taken into account. Policy relevant system costs, caused by e.g. support schemes introduced for renewable energies, are assumed to be passed on fully to the consumers.

In addition, the way in which the dispatching is modelled in POTEnCIA provides the total and variable electricity generation *cost on an hourly basis*, i.e. the model identifies for each hour of the representative day how much the cost of generating electricity would be. In consequence different pricing regimes for different users can be followed, considering explicitly their demand load patterns (defined at the level of uses). Moreover, the hourly variable electricity generation costs provide a clear signal for – and the value of - load shifting through Demand Side Management policies.

# 4. DEMAND SIDE IN POTEnCIA

POTEnCIA introduces a high level of detail for the energy consumed in each demand side sector, involving the characterization of energy requirements by sub-sector, process, and end-use, as well as, the associated technological options and energy forms. For the past years, a calibration process has been applied, ensuring consistency between aggregate data for energy consumption (as available from EUROSTAT energy balances) and the detailed meta-data generated with the use of structural and technical information (as available from sector specific databases, studies and surveys). The detailed disaggregation for each sector with regards to its structure as defined in POTEnCIA is provided in ANNEX I.

## 4.1 Energy use in the demand side sectors

Energy requirements in the demand side sectors are driven by the number of representative economic agents that operate their installations/equipment. The evolution of this number links to the evolution of the macro-economic and demographic assumptions, which are exogenously introduced in POTEnCIA.

For each point in time the model explicitly quantifies the amount of new installations needed to satisfy the number of new representative agents entering into the market, while taking into account the existing installations (again expressed by means of existing representative agents) after normal and possible premature replacement of equipment which takes place in that specific year. The notion of the representative agents varies across sectors as shown in Table 1.

**Table 1 Types of representative economic agents per sector**

| Sector | Representative Economic Agent |
|---|---|
| ***Industry*** | Physical output indicator |
| ***Residential*** | Representative Household<br>Representative appliance |
| ***Services*** | Serviced area ($m^2$)<br>Representative unit |
| ***Agriculture*** | Equivalent physical output indicator |
| ***Transport*** | Mean of transport (e.g. car, train, plane, etc.) |

The characteristics of the new installations are those obtained at the various levels of the investment decision tree, as described in section 4.2 (see below). The number of new installations, alongside these characteristics, forms in POTEnCIA a specific vintage which can be explicitly tracked over its technical lifetime. It should be mentioned here that the technical lifetime of an installation, as such, is not by default equivalent to the lifetime of the various energy related components that constitute this installation. This is especially valid for the industrial sectors, but also for clusters of thermal uses in buildings. This means that at various points in time parts of the installations need and can be replaced. For this purpose, for the equipment that is replaced and for the year of its replacement, the characteristics of the corresponding level of the investment decision tree are taken into account. Consequently the characteristics of vintages in POTEnCIA evolve dynamically over time.

Furthermore, two additional features are available in the model. The first one concerns the possibility of adopting non-energy related measures that lead to a reduction of energy requirements (expressed through the ***infrastructure efficiency parameter – IEP***). In the presence of the appropriate policy incentives, non-energy equipment related investments towards energy savings, applicable at the level of end-uses, may take place for both new installations and existing vintages (for example improving the non-energy equipment related part of an industrial production process; enhancing the thermal integrity of a building shell).

The level of exploitation of the saving potential through the IEP is determined by comparing the corresponding costs (which follow a non-linear formulation) with the cost savings occurring from the lower capacity needs for energy related equipment and the lower energy consumption. Hence it is driven by prevailing economic and policy assumptions while also being vintage specific. In the case of existing installations the stranded costs arising from the induced underutilisation of installed equipment are also considered. Within a vintage, such type of investment may take place in different points in time (occurring at incremental costs). In this case investment in non-energy equipment related options accumulate on the vintage characteristics towards reaching the non-energy equipment related saving potential of the specific energy use. The age of the vintage is also taken into account when deciding for non-energy related investment options as to capture the unwillingness of agents to face additional investment expenditures in the case of an installation with a short remaining payback period. Therefore, investment in energy saving options becomes unattractive for installations reaching the end of their technical lifetime.

***Premature replacement*** of installations may also take place across all vintages in response to prevailing policy assumptions. The decision for premature replacement in POTEnCIA is based on the comparison of:

- the net present value of a new installation, assuming the current year's operating costs over its lifetime, plus the induced stranded costs of the existing vintage that would be prematurely replaced;
- the operating costs of the existing vintage for its remaining lifetime, assuming the current year's level, plus a fraction of the net present value of the new installation. This fraction is defined as the ratio between the difference of the technical lifetime of the new installation and the remaining lifetime of the existing vintage, at the nominator and the technical lifetime of the new installation at the denominator.

In the current model formulation a direct comparison between these costs takes place and in case that the new installation is less costly, premature replacement of the existing vintage is performed.[3] Specific policy initiatives may also be explicitly introduced (for example subsidising the replacement of inefficient equipment) as to accelerate the rate of premature replacement. Stranded and policy support costs are also explicitly quantified and assigned to the year in which such a replacement takes place.

The ***unit energy needs*** that a representative agent ("unit" installation) seeks to satisfy in a specific year are calculated as a product of:

- the installed capacity (size) of the equipment (vintage-specific),
- the vintage specific realised level of use (hours of operation for all sectors except for the transport sector in which the level of use corresponds to the kilometres driven per vehicle on an annual basis), and
- the behavioural response parameter (again vintage-specific)

POTEnCIA endogenously determines the ***size of the installed equipment*** across all sectors as a function of structural, technical and social characteristics. The structural characteristics reflect the level of adoption of non-energy equipment related saving options (for example, buildings insulation properties) that result in a reduction of the size of the equipment required as to meet the energy service needs. The technical characteristics refer to the possible downsizing of equipment capacities through technology progress (exogenous assumption). Social characteristics are mainly applicable to equipment used by private consumer's (linking for example to the evolution of the surface area of the representative household or to the size of the representative car). Whereas technical and social characteristics apply when performing an investment decision, with the resulting size of equipment becoming afterwards an inherited characteristic of the specific vintage, the structural characteristics may evolve over time, in relation to the exploitation of non-energy equipment related energy saving options as described above.

The ***realised level of use*** (rate of use) of the installed equipment (end-use specific) derives from the ***desired level of use*** of the equipment while also considering changes in the variable cost of operation (i.e. fuel prices and policy considerations) in conjunction with the vintage specific technical characteristics of the existing stock (equipment efficiency). The desired level of operation of an installation refers to a theoretical optimum rate of use that fulfils the consumers comfort standards. In other words it represents a notion of the "welfare target" of a representative agent at each moment in time. It is defined as a function of several standard drivers for energy demand (i.e.

[3] Alternative formulations (for example of the form of a logit function) may also apply.

prevailing economic and demographic assumptions) while taking into consideration the evolution of comfort standards and saturation effects. The desired level of operation is the one taken into account when performing investment decisions. Thus, the investment choice is made on economic grounds considering the available technology options, fuel availability, prices, policy considerations (reflecting environmental concerns, efficiency standards, renewable promoting policies etc.) and behavioural preferences, in a context of meeting the representative agent's welfare target. The flexibility for changes in the realised level of use is largely sector and end-use dependent. For example, in an industrial sector the hours of operation of an installation cannot change as the installed equipment needs to be operated in a technically driven rate as to as to produce one unit of output (however, changes in the IEP or the BRP may apply). Similarly, in the residential sector there are end-uses for which the possible change of hours of use of an installation is limited (e.g. water heating or cooking) whereas for others (e.g. space heating) a higher flexibility to adapt to prevailing policy assumptions is observed. Thus, in POTEnCIA it is possible to capture the existing differences with regards to the willingness of consumers to revise their comfort standards by addressing the realised level of use of the equipment at the level of end-uses.

Changes in the level of activity in the different sectors,[4] which may occur as a response to changing policy conditions, are reflected in POTEnCIA through the ***structural response parameter (SRP)***. The SRP links the variations in the cost of satisfying one unit of service to the induced modifications of the activity levels, making use of a non-linear formulation.

The ***behavioural response parameter (BRP)*** captures possible behavioural changes of temporary nature that link to the more or less rational use of the energy equipment as a response to prevailing economic and policy conditions at a specific point in time. Examples include changes in the driving style, possible effects from appropriate (or not) maintenance of the installed equipment, the setting of the thermostat in a building etc. Even for the heavy industry such behavioural measures could lead to energy savings in the order of 10-15% without any additional capital investment needs.[5] Thus, depending on demand sectors specificities, the BRP can either complement or counterbalance changes in the rate of use of the equipment capturing possible rebound effects.

Applying the techno-economic characteristics of the installed equipment on a representative agent's (unit installation) energy needs (per corresponding vintage) within a year, the final energy consumption, $CO_2$ emissions and system fixed and operating costs are derived.

The overall energy consumption, $CO_2$ emissions and system operating costs within a sector are then calculated as the product of the unit installation respective figures and the number of operative installations within each vintage. As regards the system fixed costs they are calculated by applying the vintage specific economic characteristics to the total installed capacities per vintage within a sector, i.e. accounting not only for the number of operative agents but also for installations (agents) that possibly remain idle in a specific year.

Due to the explicit representation of the number of agents (installations) on an annual basis and per vintage, in POTEnCIA it is possible to identify the existence of excess installations at any point in time as a result of a drop in activity levels (e.g. industrial activity slowdown, population decline etc.). In such a case, the operative installations within a vintage are obtained by applying the ratio of the total operative installations versus the total installed ones (across vintages) on the number of installations within

[4] The activity levels are initially driven by macroeconomic and demographic assumptions.

[5] ICF Consulting Limited, 2015: "Study on Energy Efficiency and Energy Saving Potential in Industry from possible Policy Mechanisms"; Contract No. ENER/C3/2012-439/S12.666002

that vintage. This means that in no competition across vintages is introduced[6] although the explicit characteristics of each vintage are quantified.

Keeping track of the total number of agents available in each year (and not only of the operative ones) also assists to appropriately address the gap for investment and therefore the domain for policy action (previously idle capacities need to be prematurely retired in order to be replaced by more efficient equipment or else they are put back in operation as to satisfy higher activity levels).

More details and clarifications on the way in which the various features discussed above are implemented for the different demand sectors can be found in their respective sections below.

[6] At least in the current formulation of the model.

## 4.2 Generalised nested decision tree structure

POTEnCIA makes use of a nested tree structure to calculate the investment decisions made by the various consumers of energy in order to satisfy their incremental needs. The decision tree, from the lowest decision level up to the sector, consists of seven levels. At each level of the tree an economic decision determines the market shares of the competing options on the basis of two factors:

1. ***The cost****:* defined as the total annual operating cost of making a specific choice on a specific level. It reflects the engineering (technical) cost of delivering a specific utility to consumers, taking into account the techno-economic characteristics of a technology option. The cost includes techno-economic parameters as capital, fixed and variable O&M costs, efficiency factors, emission factor, etc. When calculating the annuities of the capital costs a distinction is made between the reporting of costs and investment decisions with regard to the rate at which the agents discount future payoffs:
   - A common discount rate is used when reporting costs.
   - For the investment decisions a subjective financing capability rate is used (Section 3.1.2).
2. ***The market acceptance/maturity indicator:*** It reflects distortions that lead to consumer choices that deviate from optimality as defined if only engineering costs were taken into account. Such market distortions include the lack or congestion of infrastructure, structural changes that relate to consumers' behaviour as well as consumers' considerations about specific utilities (particularly for emerging ones with a limited market share). As a consequence, a difference between the perceived cost for the equipment under question and its engineering cost is observed.

Throughout all steps the techno-economic characteristics of the corresponding investment decision of a representative agent are calculated. These are summarised in Table 2.

**Table 2 Set of techno-economic characteristics and aggregates calculated in all seven levels of the decision tree**

| $cha_{tree\ level}$ | $Agg_{tree\ level}$ |
|---|---|
| Capital cost | Annual fixed cost |
| Fixed maintenance cost | Annual operating cost |
| Variable operating cost | Annual total cost |
| Fuel cost | Annual nominal cost |
| Efficiency factor | Annual useful energy |
| $CO_2$ emission factor | Annual final energy |
| Share of auxiliary fuel in use | Annual $CO_2$ emissions |
| Hours of use of the equipment | |

The subscript *tree level* (i.e. *tec, top, enu, euc, epr, sbs and ase*) denotes the level of the decision tree we are in. The definition of each one of them follows hereafter.

### *1st level (TEC): Alternative technologies competing within a technology option*

As described in Section 3.2.3, for each of the technology options defined in POTEnCIA, three alternative technologies are available when considering investment decisions. Consumers may choose to invest in an 'almost ordinary' (T1), 'advanced' (T2) or 'state of the art' (T3) technology the characteristics of which are endogenously calculated for each projection year.

The efficiency of the alternative technologies available for investment at a given point in time *t,* is given by:

$$\eta_{Ti} = \eta_{stock} + (\eta_{BS} - \eta_{stock}) * GC_{Ti}$$

$\eta_{BS}$ = efficiency of the backstop technology

$\eta_{stock}$ = efficiency of the existing stock

$GC_{Ti}$ = gap coverage ratio towards the backstop technology

The related capital, fixed O&M and variable O&M costs are then calculated endogenously as a non-linear function of the efficiency's distance to the backstop and the pace of the efficiency improvement of the existing stock. They are computed as follows:

$$cha_{Ti} = cha_{ref} * \left(\frac{\eta_{Ti}}{\eta_{ref}}\right)^{-e\_cost * f(\eta_{stock}, \eta_{BS})}$$

$\eta_{ref}$ = efficiency of the reference technology in the base year (constant over time)

$cha_{ref}$ = technical and economic characteristics of the reference technology in the base year

$e\_cost$ = cost adjustment elasticity (constant over time and common for all countries)

The annual total operating cost at the level of one representative agent for each technology is given by the sum of the annual fixed cost and the annual operating cost:

$$C_{Ti} = C_{f(Ti)} + C_{ope(Ti)}$$

$$C_{f(Ti)} = \left[C_{cap(Ti)} * \frac{1}{\sum_{t=1}^{L}(1+r)^t} + C_{fix\_om(Ti)}\right] * cap_{enu}$$

$L$ = the technical lifetime of the equipment

$C_{cap(Ti)}$ = capital cost of the equipment

$C_{fix\_om(Ti)}$ = fixed O&M costs

$cap_{enu}$ = capacity size at the energy end use level

$r$ = discount rate

$$C_{ope(Ti)} = \left[C_{var\_om(Ti)} + \left(C_{fuel} + Carb_v * em_f + pen_\eta\right) * 1/\eta_{Ti} - ren_{val}\right] * RoU * cap_{enu}$$

$C_{var\_om(Ti)}$ = variable operating and maintenance cost

$C_{fuel}$ = fuel cost

$Carb_v$ = carbon value

$em_f$ = $CO_2$ emission factor

$pen_\eta$ = penalty applied when using a less efficient technology to the best

| | | |
|---|---|---|
| | | available technology in the market |
| $ren_{val}$ | = | renewable support value |
| $RoU$ | = | desired level of operation of energy related equipment when making the investment decision (rate of use) |

The market acceptance factor is given by:

$$maf_{Ti} = maf_{exo(Ti)} * macro^{e_{ec}} * f(policy)$$

| | | |
|---|---|---|
| $maf_{exo(Ti)}$ | = | exogenous market acceptance factor at the technological level (by default assumed constant over time for the different technologies – T1 option always gets a market acceptance of 1) |
| $macro$ | = | macroeconomic activity indicator relative to the EU average |
| $e_{ec}$ | = | elasticity for the adjustment of the market acceptance of investment options in relation to changes in economic conditions |
| $f(policy)$ | = | factor expressing the possible adjustment of the market acceptance of investment options as a reaction to the introduction of policies |

Through the endogenous adaptation of the market acceptance factor, it is possible to capture changes in the consumer's behaviour that are induced by changing preferences, shifts in economic conditions and the introduction of policies. The willingness of consumers to invest in more capital-intensive options when their income increases, is captured through the link to the macroeconomic indicator. At the same time differences in the perception of technologies due to budgetary constraints are also reflected. For example this factor allows differentiating across Member States the behaviour of residential consumers in adopting different technologies as a function of their income per capita. In addition, consumers' preferences may change in the presence of policies. For example, in a strictly carbon-constrained world, the consumers' environment would provide a signal (that goes beyond the costs) to invest in more efficient options. This approach also allows for limiting the need for exogenous interventions when addressing specific policies. Of course it is also easily possible to deactivate this mechanism if behavioural responses should be disregarded.

An indicator of the investment option attractiveness is then identified using the one-factor logit approach:

$$attr_{Ti} = maf_{Ti} * f\left(C_{Ti|T1}, e_{tec}\right)$$

| | | |
|---|---|---|
| $attr_{Ti}$ | = | indicator of the attractiveness of the technology at the TEC level |
| $e_{tec}$ | = | elasticity of substitution used to determine the shares of alternative investment options (investment decision) within a technology option |

The market shares of alternative investment options at the TEC level are then simply given by:

$$msh_{Ti} = \frac{attr_{Ti}}{\sum_i attr_{Ti}}$$

### *2nd level (TOP): Characteristics of technology options*

The techno-economic characteristics of each 'representative' technology option are obtained as the weighted average of the different technologies using the corresponding market shares (from the 1st level) and their individual techno-economic characteristics. The capital costs, fixed operating cost, variable operating cost, fuel costs, efficiency factor and $CO_2$ emission factor are computed as follows:

$$cha_{top} = \sum_i msh_{Ti} * cha_{Ti}$$

The same applies for the aggregate characteristics of the technology options $Agg_{top}$ (annual fixed cost, annual operating cost, annual total cost, annual nominal cost, annual useful energy, annual final energy, and annual $CO_2$ emissions):

$$Agg_{top} = \sum_i msh_{Ti} * Agg_{Ti}$$

where $Agg_{Ti}$ represent the corresponding aggregates at the TEC level.

When addressing the investment decision at the level of technology options the corresponding infrastructure costs are also explicitly taken into account. Such costs reflect both nominal costs, i.e. those of setting up a specific infrastructure, as well as costs related to its level of maturity. The infrastructure costs are represented through a cost increase factor, $inf_f$, which in turn links to fixed cost of the technology option:

$$inf_f = inf_{f\_exo} * \left(1 + \left(1 - msh_{top_{t-1}}\right)^{e\_inf} * mat_f\right)$$

| | | |
|---|---|---|
| $inf_{f\_exo}$ | = | exogenous cost increase factor (relative to the fixed costs of equipment) for the infrastructure investment at the level of technology options when they become fully mature |
| $msh_{top_{t-1}}$ | = | market share of the technology options from the previous year |
| $e\_inf$ | = | elasticity for infrastructure cost increase relative to the market penetration of the technology options |
| $mat_f$ | = | factor reflecting the entry barriers infrastructure costs at the level of technology options (maturity cost penalty) |

$$C_{\inf\_top} = C_{f\_top} * (inf_f - 1)$$

| | | |
|---|---|---|
| $C_{f\_top}$ | = | the annual fixed cost at the TOP (technology option) level |

This formulation reflects the high infrastructure costs related to niche markets which decrease in a non-linear manner as the technology options obtain significant market shares. For example this mechanism allows reflecting the additional cost perceived by consumers when purchasing a fuel cell vehicle in the absence of a widespread refuelling network.

In line with the methodology followed at the TEC level, the market acceptance factor for alternative technology options is computed as a function of an exogenously defined one (reflecting the foreseen evolution of technology maturity and availability) and the response to the policy assumptions. In addition, a learning-by-adopting effect from the consumer's point of view is also taken into account:

$$maf_{top} = maf_{top\_exo} * f(penetration) * f(policy)$$

$maf_{top\_exo}$ = initial market acceptance factor for technology options linked to their technical maturity and their foreseen availability in the market

$f(penetration)$ = element reflecting learning-by-adopting as a function of the penetration level of a technology option

$f(policy)$ = scenario specific element that captures the effect of prevailing policies

The attractiveness of the technology option is obtained through a multinomial logit function as follows:

$$attr_{top} = maf_{top} * \left(C_{tot\_top} + C_{\inf\_top}\right)^{-e_{top}}$$

$e_{top}$ = elasticity of substitution used to determine the shares of alternative technology options (investment decision) within an end-use

The market shares of alternative investment options at the technology option level are then given by:

$$msh_{top} = \frac{attr_{top}}{\sum_{top} attr_{top}}$$

As technology options refer to the same end-use, satisfying the same type of energy service (for example the options of solids, liquids, gas and biomass fired thermal furnaces in industrial sectors), they are considered as highly substitutable, i.e. consumers, when performing their investment decision at this level, are very responsive to the prevailing economic and policy conditions.

### *3rd level (ENU): Energy end-uses*

The techno-economic characteristics of a sector's energy end-uses are defined at this level. They are calculated on the basis of the market shares of the technology options competing within a specific end-use:

$$cha_{enu} = \sum_{top} msh_{top} * cha_{top}$$

The aggregates at the level of energy end-uses are given by:

$$Agg_{enu} = \sum_{top} msh_{top} * Agg_{top}$$

The infrastructure related cost for energy end-uses is given by:

$$C_{\inf\_enu} = \sum_{top} msh_{top} * C_{\inf\_top}$$

In POTEnCIA end-uses are not considered to be competing. They add up to form the combined end-used at the 4$^{th}$ level.

### 4th level (EUC): Combined end-uses

The concept of combined end-uses is introduced in some sectors where specific end-uses form clusters *by default*. A typical example is the residential sector where the space heating and water heating end-uses are strongly interlinked. The installed space heating device has a strong impact on the investment decision made for water heating; either by utilising the same equipment for both (e.g. combi-boiler) or by limiting the options of the water heating equipment (for example it is very unlikely that a household using natural gas for space heating would use pellets for water heating).

The techno-economic characteristics of the combined end-uses are calculated by summing up the techno-economic characteristics of the stand-alone end-uses, while taking into account their respective capacities.

The capacity of the alternative combined end uses:

$$cap_{euc} = \sum_{enu} cap_{enu}$$

The aggregates at the level of the combined end use:

$$Agg_{euc} = \sum_{enu} Agg_{enu}$$

The infrastructure related cost of the combined end use:

$$C_{\inf\_euc} = \sum_{enu} C_{\inf\_enu}$$

In order to decide between the different combined end uses their attractiveness is calculated as:

$$attr_{euc} = maf_{euc} * \left(C_{tot\_euc} + C_{\inf\_euc}\right)^{-e_{attr_{euc}}},$$

where the market acceptance factor is:

$$maf_{euc} = maf_{euc\_exo} * f(policy)$$

The market shares of the alternative investment options at the EUC level are given by:

$$msh_{euc} = \frac{attr_{euc}}{\sum_{euc} attr_{euc}}$$

### 5th level (EPR): Energy processes

The techno-economic characteristics of the processes are then calculated on the basis of the market shares of the competing combined end-uses and their characteristics (4$^{th}$ level).

The capacity of the alternative energy processes:

$$cap_{epr} = \sum_{euc} msh_{euc} * cap_{euc}$$

The aggregates at the level of energy processes:

$$Agg_{epr} = \sum_{euc} msh_{euc} * Agg_{euc}$$

The infrastructure related cost for energy processes:

$$C_{\inf\_epr} = \sum\nolimits_{euc} msh_{euc} * C_{\inf\_euc}$$

### *6th level (SBS): Sub-sectors*

At the level of sub-sectors, as in the case of combined end-uses, the characteristics of the competing sub-sectors are derived as the sum of the related processes (i.e. according to the model definitions, processes form a structural characteristic of the related sub-sector and, therefore, are not substitutable).

The capacity of the alternative sub-sectors:

$$cap_{sbs} = \sum\nolimits_{epr} cap_{epr}$$

The aggregates at the sub-sector level:

$$Agg_{sbs} = \sum\nolimits_{epr} Agg_{epr}$$

The infrastructure related operating cost at the sub-sector level:

$$C_{\inf\_sbs} = \sum\nolimits_{epr} C_{\inf\_epr}$$

The market acceptance factor is given by:

$$maf_{sbs} = maf_{sbs\_exo} * f(policy)$$

and the attractiveness of the sub-sector by:

$$attr_{sbs} = maf_{sbs} * \left(C_{tot\_sbs} + C_{\inf\_sbs}\right)^{-e_{attr_{sbs}}},$$

The market shares of the alternative investment options at the sub-sector level:

$$msh_{sbs} = \frac{attr_{sbs}}{\sum_{sbs} attr_{sbs}}$$

### *Upper level (ASE): Sector characteristics*

The upper level of the decision tree represents the entire sector. From the decision making in the lower levels of the tree the detailed techno-economic characteristics of the representative agent's investment decision within a sector are obtained. These include the capital cost, fixed and variable operating costs, the representative fuel mix and the efficiency gains in comparison to previous years existing stock.

## 4.3 Industrial sectors in POTEnCIA

POTEnCIA follows the EUROSTAT energy balances nomenclature as regards energy requirements for industrial purposes. In total, eleven industrial sectors are represented in the model; five energy intensive and six non-energy intensive sectors. When appropriate and in order to better reflect distinct production processes within specific industries different sub-sectors are defined. The industrial sectors considered in POTEnCIA and their corresponding sub-sectors are summarised in Table 3.

**Table 3 Industrial sectors and corresponding sub-sectors in POTEnCIA**

| Energy Intensive | Non-energy intensive |
|---|---|
| 1. Iron and steel industry | 6. Food, Beverages and Tobacco |
| ○ Integrated steelworks | 7. Transport equipment |
| ○ Electric arc | 8. Machinery equipment |
| ○ Direct reduced iron (DRI) | 9. Textiles and Leather |
| ○ Alkaline electrolysis | 10. Wood and wood products |
| 2. Non-ferrous metals | 11. Other industrial sectors |
| ○ Alumina production | *Including:* |
| ○ Aluminium primary production | Mining and quarrying |
| ○ Aluminium secondary production | Construction |
| ○ Other non-ferrous metals | Non-specified industries |
| 3. Chemical industry | |
| ○ Basic chemicals | |
| ○ Other chemicals | |
| ○ Pharmaceutical products etc. | |
| 4. Non-metallic minerals | |
| ○ Cement | |
| ○ Ceramics & other NMM | |
| ○ Glass production | |
| 5. Paper and pulp | |
| ○ Pulp production | |
| ○ Paper production | |
| ○ Printing and media reproduction | |

For each industrial sub-sector, energy requirements are split between different processes (on the basis of its engineering characteristics) and further decomposed into different energy end-uses (competing or complementing each other within a specific production process) and the associated energy forms consumed (which in turn represent different technology options available within an energy end-use). The split of each subsector's energy requirements concerns three different types of energy uses:

- Non-process related energy uses that involve the use of cross-cutting technologies (including lighting, low enthalpy heat uses, air-compressors and motor drives). These are common across all industrial sectors;
- Process related energy uses (the specific energy uses included are differentiated on the basis of the sub-sector specific characteristics);
- Process related non-energy uses (feedstock uses).

This explicit representation of the different sub-sectors (going beyond the level of detail available in the EUROSTAT energy balances) alongside the detailed breakdown of energy use across the sector specific production processes allows better addressing the development of energy requirements in industry. In addition, through the introduction of this level of detail, the role of the EU Emission Trading Scheme on the evolution of the techno-economic and the operating characteristics of the installed equipment, for the industrial sectors that fall under this regime (as a whole or by means of specific industrial process), can be better captured.

## *Definition of the representative economic agent in industrial sectors*

The representative economic agent in industry is defined as the installation needed (combining various sector-specific processes with technically driven structural characteristics) in order to produce one unit of industrial output. This industrial output (or production volume) is dealt with in POTEnCIA by means of:

- Physical tonnes of output;
- Equivalent tonnes of output; and
- Physical output index.

An overview of the type of industrial output as addressed in POTEnCIA within each industrial sector (alongside some sector-specific key features) is provided in the following paragraphs.

For the ***iron and steel*** *industry* the production volume, in POTEnCIA, is equivalent to the physical tonnes of steel produced in the sector each year, i.e. a representative agent corresponds to the installation needed as to produce one tonne of steel per year. In addition to the two dominant production lines through which steel production takes place in the EU (integrated steelworks and electric arc furnaces), POTEnCIA also considers two additional options for steel production, the direct reduced iron (DRI) in combination with an electric arc furnace (uses natural gas as the reducing agent) and the alkaline electrolysis, an ultra-low $CO_2$ steel making future production process. Changes in the production structure that relate to the variability in the type of the final product among (rolled steel, special steels etc.) and to possible alterations in the feed are not explicitly taken into account. This means that under default settings the production structure parameter (PSP) is equal to 1 over time, implying that in the absence of specific drivers (exogenously defined ones) it is assumed in POTEnCIA that the type of the final output product retains the same characteristics (country-specific ones) over time.

The approach described above also applies in the ***non-ferrous metals*** industry. However, whereas for alumina, primary and secondary aluminium production volumes correspond to the physical output of the corresponding industrial sub-sector, in the case of other non-ferrous metals the production is expressed in tonnes of lead-equivalent per year in order to create a homogeneous reference level for the energy-intensity of this highly heterogeneous industry. This lead reference is created by weighting the observed production levels of cadmium, chromium, cobalt, copper, gold, manganese, nickel, silver, tin and zinc with their specific energy consumption per tonne produced relative to the specific energy consumption of lead production (using technical data). The share of primary and secondary production of each other non-ferrous metal and the subsequent impact on the corresponding energy intensity is also taken into account.

Furthermore, special considerations with regards to alumina and secondary aluminium production are also taken into account. As alumina production is strongly linked to the availability of the raw material (bauxite), it is assumed to be an available option for the future only for countries that possess this resource and/or have already alumina production installations in place. In addition, raw material availability (recycled aluminium/scrap) constraints apply for secondary aluminium production. This is needed both because of issues related the quality of the product (which can be quite different between primary and secondary production) and because in the absence of such a constraint new installations for aluminium production would be dominated by secondary aluminium ones, as primary aluminium production consumes about 9 times more energy per tonne.

The ***chemical sector*** is a conglomerate of a large number of heterogeneous industries with very different specific processes, outputs and inputs. The *basic chemicals* industry includes the manufacturing of plastics in primary forms, other basic organic chemicals, fertilisers and nitrogen compounds and other inorganic basic chemicals. The production of *other chemicals* refers to products with typically higher value added intensity, which do not require an energy feedstock, including industrial gases, dyes and pigments, agrochemical products, paints, varnishes and coatings, soap and detergents, etc. Finally, and despite its very low total energy consumption, the manufacture of *pharmaceuticals* is a separate sub-sector due to its distinct drivers and its very high value added intensity. In order to be able to create a basis for comparing amongst the Member States industries in terms of activity and energy consumption and to obtain some kind of reference with regards to potential energy related improvements in the sector, the production volume is expressed in POTEnCIA by means of tonnes of ethylene-equivalent.

In the ***non-metallic minerals*** *industry* the *cement sector* is the largest energy consumer. Production in the specific sub-sector is expressed by means of physical tonnes of cement per year. The *glass industry* aggregates the production of both container glass and non-container glass. Container glass encompasses a high share of recycled glass whereas non-container glass comprises a variety of glass types ranging from flat glass to technical glasses and filament fibres all of which are characterised by different energy and value added intensities. In POTEnCIA the overall activity is expressed as tonnes of container glass equivalent per year. For the *ceramics and other non-metallic minerals industry*, the concept of equivalent tonnes is also applied. The heterogeneous production output of this industry is expressed by means of equivalent tonnes of bricks per year, which can be associated to a well-defined production process and hence energy intensity. Similarly to other non-ferrous metals, the default setting in the model assumes that the mix of the various glass types and of the ceramics and other non-metallic minerals remains unchanged in the future.

It needs to be highlighted that the cement and ceramics sub-sectors are two of the few sub-sectors where biomass and waste can be used not only in boilers but also directly in kilns. This fuel option is explicitly considered in the model structure and creates an important potential niche for the use of biomass.

Energy consumption for pulping, paper production and printing falls under the ***pulp and paper industry*** category of EUROSTAT. Concerning *pulping*, the model distinguishes between mechanical (electric) and chemical pulping processes due to the important differences in the specific energy consumption and the fuels used for the various routes. Mechanical pulping is more electricity-intensive whereas chemical pulping requires large amounts of steam. In *paper* production, the paper machine is at the heart of the manufacturing process and is therefore introduced as one single process that involves the complementary use of steam and electricity. The energy consumed for stock preparation depends on the feed used, such as the share of recycled paper, related de-inking, etc., and the final paper quality. For these sub-sectors their output is expressed by means of tonnes of pulp and paper per year, respectively, accounting for the observed energy intensity differences across the EU Member States as part of the production process and/or the mix of final products. The output of *printing and reproduction of recorded media* is expressed as a proxy of tonnes of paper-equivalent. This makes it possible to create a comparable reference level as regards energy intensity across the EU Member States.

The structure of the ***non-energy intensive industries*** varies significantly across Member States as regards their inputs, outputs and production processes involved. Consequently energy intensities across Member States exhibit substantial discrepancies that is not possible to explicitly attribute to the technical characteristics of the installed energy related equipment. In order to handle this issue the notion of the physical output index is introduced in POTEnCIA. At the EU level this physical output index is equal to the value added, but corrects for each Member State as to account for country-specific structural differences in an attempt to limit energy intensity discrepancies within technically explainable barriers. The ratio of the physical output index to the value added is translated in POTEnCIA as the sector and country specific production structure parameter (PSP). The PSP is assumed, under default settings to remain constant over time (as in the case of the energy intensive sectors).

### *Energy use in industry*

Energy requirements in industrial sectors are driven by the production volume which is interpreted as the number of representative agents that operate their installations. The evolution of the production over time is calculated as the product of:

- the evolution of the value added of the industrial sectors;[7]
- the value added intensity (units of output per unit of value added); and
- the structural response parameter (SRP)

Both the value added and the value added intensity are exogenously introduced in POTEnCIA. Limited variations with regards to the evolution of the value added intensity over time may be introduced as to reflect possible changes in the mix and the quality of the output products, which in turn may affect the productivity of an industrial sector (such changes can also be interpreted -and act in exactly the same way- as corresponding changes in the PSP on a country-specific level). Furthermore, whereas for past years the physical output index in non-energy intensive industries is equal to the value added at the EU level (by construction) this is not the case for the future as economic growth in these sectors follows different patterns across the EU Member States (i.e. even if no changes are assumed for the value added intensity). The resulting PSP at the EU level provides some insight into the evolution of the structure of products towards more or less energy intensive ones within a sector.

In addition, POTEnCIA offers the option of linking the level of activity to the prevailing economic and policy assumptions, making use of the Structural Response Parameter (SRP). The SRP adjusts over time in relation to the changes in the cost of producing one unit of industrial output, following a non-linear formulation. Such adjustments can be interpreted as a response of the industrial sectors by altering the mix and quality of their output products and/or the sector's productivity. Consequently the volume of production and the value added intensity are also endogenously revised. It should be mentioned that in POTEnCIA it is not possible to explicitly translate such changes in the product's output characteristics into corresponding changes in the production structure (by means of the contribution of different processes in the overall production process).

Given the volume of production, the mechanisms described in section 4.1 apply as to calculate the final energy demand, the $CO_2$ emissions and the corresponding system costs for each industrial sector. However, in the case of industrial sectors the realised level of operation (rate of use) of the installed equipment forms a structural – production related - characteristic of the sector and therefore is, by definition, equal to the desired level of operation of the equipment. Thus, with regards to the equipment use of existing installations, industry can respond to prevailing policy assumptions only through changes in the infrastructure efficiency parameter (IEP) and/or changes in the behavioural response parameter (BRP).

[7] The definition of the industrial sectors and subsectors in relation to the economy (EUROSTAT NACE codes) can be found in ANNEX II.

## 4.4 Residential sector

A representative economic agent in the residential sector is defined in POTEnCIA as equivalent to a representative household. Table 4 summarises the energy uses that form the energy profile of such a representative household in the model. Besides the energy service needs related to buildings thermal uses and to specific electricity uses, the building shell energy related features are also taken into account. These features reflect the thermal envelope of the buildings by means of their degree of insulation, structural, architectural and physical characteristics and allow quantifying the avoided energy consumption with regards to space heating and cooling service needs of households, i.e. they can be considered as the infrastructure efficiency parameter (IEP) of buildings for the above mentioned energy uses.

**Table 4 Components of the energy profile of a representative household**

| **Representative household** |
|---|
| Building shell energy related features |
| Thermal uses |
| • Space heating<br>• Water heating<br>• Cooking<br>• Space cooling |
| Specific electricity uses |
| • Lighting<br>• White appliances<br>  ○ *refrigerators and freezers*<br>  ○ *washing machines*<br>  ○ *tumble dryers*<br>  ○ *dishwashers*<br>• TV and multimedia<br>• ICT equipment<br>• Other electric appliances |

### *Space heating, cooling, water heating and cooking*

A special feature of the sector in relation to heating/cooling energy uses is that the infrastructure in place (e.g. connection to a gas network) in combination with the energy form selected for space heating purposes defines the primary fuel type used for space and water heating, and often also cooking. To this end, POTEnCIA distinguishes, at the upper level of the decision tree, between types of households based on their form of space heating. For each household, the main energy carrier for satisfying its energy needs is defined, with limited flexibility for fuel shifts.[8] The approach allows for an accurate representation of existing infrastructure limitations (both in terms of networks and related to existing building installations) but also capturing the effects of structural changes and of changes in consumers behaviour.

The household types considered in the model are the following:

- central heating with solids
- central heating with diesel oil[9]
- central heating with natural gas[10]

[8] Especially in space heating for which only complementary use of alternative fuels is considered (e.g. the use of solar thermal as a default option for all types of space heating; the use of wood in fireplaces or use of ohmic resistors as auxiliary heating devices)
[9] Including biofuels
[10] Including biogas

- central heating with LPG
- central heating with biomass and waste
- heat pump households
- electric heating households
- district heating households
- geothermal heating households (direct geothermal heating)

The concept of combined end-use clusters of 'space heating/water heating/cooking/space cooling' is therefore introduced in the model, linking the water heating, cooking and space cooling options to the space heating one. For every household type, only a limited number of combinations are considered as rationally feasible (see ANNEX I).

Thus, investment decisions concern packages (clusters) of equipment rather than individual technology and fuel options per energy end-use. This prevents the creation of unlikely investment combinations (e.g. solids for space heating and natural gas for water heating). Moreover, using combined end-uses avoids an exaggeration of the flexibility in replacing the equipment: unless the main space heating equipment is replaced, and with this a new infrastructure is created, the options available when replacing for example a water heater (with shorter lifetime than the space heating equipment) remain linked to the main energy carrier. A change in the main energy carrier can occur when the installed equipment for space heating reaches its technical lifetime, or when a premature replacement of the equipment (for the cluster as a whole) is found cost-effective.

### *Specific electricity uses*

Specific electricity uses in the residential sector link to the use of a variety of electric appliances. Whereas with regards to lighting and white appliances the approach retained in POTEnCIA is rather straightforward this is not the case for the other electric appliances. Thus, in the case of appliances related to ICT and multimedia, representative devices are defined; these consist of a package of various appliances that belong to the specific category, taking into account their specific market penetration) are defined. The same applies for other electric appliances, a category under which many different appliances fall under (including irons, vacuum cleaners etc.).

In order to reflect the different technology dynamics of electric appliances across countries and capture the possible differences in the drivers for incremental energy needs in specific electricity uses, in POTEnCIA the following parameters are explicit:

- The number of appliances owned per representative household (e.g. number of equivalent light bulbs of 1000 lumens each)
- The technical efficiency of the device, expressed as power (Watts) per appliance. This makes it possible to explicitly consider pure technical efficiencies for a representative appliance, differentiating across Member States. This parameter can be directly associated with the expected technical evolution, taking also into account relevant policies such as Eco-design.
- The observed hours of use, which reflect the behaviour of the representative agent; they differ across countries linking to economic, demographic and cultural differences.

The distinction between these different drivers as regards the energy use of electric appliances in the residential sector allows understanding the evolution of their energy consumption in the past, and, therefore, better deals with the evolution of this energy consumption in the future.

### *Energy use in the residential sector*

The number of representative economic agents in the residential sector that need to satisfy their heating needs is defined as the number of occupied households (calculated on the basis of demographic assumptions; population and number of inhabitants per household). In the case of electric appliances the number of occupied households is further multiplied by a penetration rate (specific to each examined appliance) which reflects the number of appliances owned per occupied household. This penetration rate dynamically changes over time in relation to the evolution of the household's income (exogenously defined) under constraints with regards to saturation effects (i.e. an S-curve formulation applies towards a theoretically set maximum number of appliances per household).

Another important driver that impacts the energy needs in the residential sector is that of the size of the equipment installed as to satisfy heating energy uses. Besides the exogenously assumed technical evolution of the size of equipment (which in the case of space heating uses also links to the country-specific climatic conditions, expressed by means of degree-days), social drivers also apply for heating uses. Thus, the size of the installed equipment, as applicable at the level of investment decisions, evolves over time as a function of the useful size (expressed in terms of surface area) of the representative household, with regards to space heating and cooling uses, and of the number of inhabitants per household, with regards to water heating and cooking. Concerning electric appliances their size is assumed to remain constant over the projection period as possible changes are reflected through their penetration rate.

Investment decisions take place on the basis of the desired level of operation of the energy related equipment (i.e. the welfare target of households). This desired level of operation is end-use specific and links to:

- The evolution of the representative household's income;
- Changes in climatic conditions (if any; applicable for space heating and cooling uses);
- Changes in the penetration rate of electric appliances (applicable to electric appliances).

As already discussed, investment decisions for heat uses are applied at the level of explicit clusters of equipment, which link the technology-fuel options available for space cooling, water heating and cooking to the main energy type used for space heating, thereby capturing possible infrastructure constraints and multi-use-equipment (such as combi-boilers) operation. In POTEnCIA, the different heating related processes are assumed to complement each other (for example the equipment needs for space heating cannot be replaced by water heating and vice-versa). However, the model is designed as to handle cases in which new processes, such as cooling in the residential sector, exhibit a fast growth, gaining additional market shares to the detriment of other processes in the sector.

Prevailing economic and policy assumptions may lead to a response in the structure of the residential sector, expressed through the SRP. Such response would materialise in a change in the number of occupied households (implying a revision of the number of inhabitants per household, as the population figures cannot change) and in the number of operated electric appliances (or else a revision of the penetration rate of electric appliances).

The realised hours of operation of the installed equipment follow the evolution of the desired hours of operation of the equipment (reflecting consumers' adjustment to the evolving comfort standards) while correcting for the effect of changes in the cost of meeting their energy service and taking into account the technical characteristics of the existing stock (equipment efficiency, differentiated in POTEnCIA by vintage). It is important to note that whereas the investment decision is taken for clusters of end-uses, the actual utilisation rates are calculated for each individual end-use within these clusters and, at the same time, separately for each household type specific vintage, in order to reflect different consumer behaviour response for space heating, water heating, cooling and cooking.[11] In all cases the realised hours of operation of the installed equipment are constrained by the desired ones, i.e. even in cases that the use of existing equipment becomes very attractive as a result of prevailing policy assumptions consumers will not exceed their welfare target.

Besides adjusting the hours of operation of the installed equipment, the representative agents in the residential sector may also react to the prevailing economic and policy conditions by performing investment in non-energy related equipment as to reduce their energy needs and/or through the behavioural response parameter (BRP). Changes in the IEP mainly link to improvements of the building shell characteristics across the different vintages, thus affecting energy needs for space heating and cooling. Limited improvements of this type may also take place for water heating uses, reflecting better insulation of pipes etc. On the other hand, behavioural responses usually act towards further enhancing the effect of policies on the rate of use of the installed equipment, as consumers have the tendency to further adapt their behaviour, for example through reducing the temperature set in the space heating thermostat. By all means, further adapting the behaviour does not necessarily act towards a positive effect on the energy balance. Thus, in cases of declining costs for meeting the energy service needs, consumers may operate their equipment in a less rational manner. In that context, and through the BRP it is possible for the effective operation of the installed equipment to go beyond the desired hours of operation, which by definition reflect the level of use needed to meet the consumers comfort standards in a rational manner.

The total energy consumption, $CO_2$ emissions, energy and variable operating costs for the residential sector are then calculated as the product of the consumption of the household by vintage and household type and the corresponding total number of occupied households. As already discussed, POTEnCIA explicitly captures the possibility that the number of equipped households is larger to that of occupied ones (this, for example could happen in a country with a strongly declining population trend). Therefore, the system fixed costs are calculated by applying the vintage specific economic characteristics to the total number of equipped households. It needs to be highlighted that the number of occupied households, in that case, is proportionally attributed across vintages, thus, not taking into account issues related to the attractiveness of the different vintages.

[11] This approach makes it possible to reproduce the results of the historic data analysis, which provided evidence that for example a reduction in household income during an economic downturn affects space heating requirements to a larger extent than energy needs for cooking and water heating.

## 4.5 Services sector

The services sector is characterised by a high level of heterogeneity and comprises many different branches, each linked to different demand patterns and levels of energy requirements. Even though these branches present different energy intensities, reflecting the different nature of the services offered, their generic structure as regards energy processes is identical. In that context the services sector is modelled in POTEnCIA as a single sector. However, the energy use can be split between each of the branches in an ex-post process, taking into account their respective evolution in terms of value added, employees and (derived) square meters of useful building surface.

**Table 5 Components of the energy profile of a representative service**

| **Representative service** |
|---|
| Building shell energy related features |
| Thermal uses |
| • Space heating<br>• Space cooling<br>• Hot water services<br>• Catering |
| Specific electricity uses |
| • Ventilation and others<br>• Street lighting<br>• Building lighting<br>• Commercial Refrigeration<br>• Miscellaneous building technologies<br>• ICT and multimedia |

The energy uses that form the energy profile of a representative service in POTEnCIA are summarised in Table 5. Similarly to the residential sector, energy service requirements in the services sector can be distinguished between thermal uses which are principally related to buildings (space heating, space cooling, water heating and cooking) and specific electricity uses. Energy demand for space heating and cooling is also linked to the buildings' thermal behaviour which depends on the level of insulation, architectural, structural and physical characteristics. These elements are taken into account as to calculate the avoided energy consumption for space heating and/or cooling service needs, thus, representing the infrastructure efficiency parameter (IEP) of buildings for the above mentioned energy uses. Additionally, ventilation is also linked to the building's thermal behaviour.

The notion of the primary energy carrier, as adopted in the residential sector, is not applicable in the services sector. This is due to the fact that buildings in the services sector are characterised by high heterogeneity and variability. Furthermore, space heating uses are, in quite some cases, not the dominant thermal energy use.

Specific electricity uses in the services sector can be appliance specific (as is the case for ventilation, street and building lighting) or comprise of a variety of different types of electric equipment and appliances that in POTEnCIA are grouped under – service purpose linked – representative devices. Commercial refrigeration comprises of all types of refrigeration and freezing technologies used by the different services. Miscellaneous building technologies accumulate all possible types of equipment (ranging from vacuum cleaners, to elevators, to hospital equipment, etc.) whereas under ICT and multimedia all related office and leisure equipment is considered. An effort was made so that the characteristics of the so-defined packages that form a representative device are determined taking into account the market presentation and the techno-economic properties of the different equipment types that they consist of.[12]

Across Member States the energy equipment stock characteristics vary. Such differences are captured in POTEnCIA through the following parameters:

- The technical efficiency of a representative device, expressed as power in Watts/appliance. The technical efficiency of ventilation is expressed in Watts/$m^2$ of ventilated floor space.
- The number of representative device per service or per employee.
- The observed hours of use of a representative device which differs across the Member States due to cultural differences, population size, economic growth and market penetration factors.

The distinction between street and building lighting is introduced in POTEnCIA to capture that these two end-uses are driven by different factors (serviced area and population respectively) while incorporating different technologies.

### *Definition of the representative economic agent in the services sector*

In contrast to the residential sector in which a representative agent is defined as a household that seeks to satisfy its own energy needs, in the services sector such energy needs occur as to satisfy the needs of the users of the associated service. Thus, the representative agent in the services sector is defined in view of the nature of the service and the number of users that request that service and, therefore it is differentiated across the energy uses. More specifically:

- The number of representative building cells of the sector is considered as the representative agent for space heating and cooling service requirements, as well as, building lighting, ventilation and miscellaneous building technologies;
- The representative agent for hot water and catering services, street lighting, commercial refrigeration and ICT and multimedia services is the defined by means of the representative consumer of the respective services.

In POTEnCIA, the number of representative building cells is calculated endogenously. This is done through linking this number to the evolution of the value added of the sector.

With regards to the definition of the number of representative consumers of a service, this is service specific:

- For hot water services it is the population
- For catering services and commercial refrigeration this number is defined as the product of the population and an index that reflects the ratio of making use of this service per capita. This index is, in turn, linked to the evolution of the GDP per capita also taking into account possible saturation effects (i.e. a formulation similar to that for the penetration rate of electric appliances in the residential sector applies)
- For street lighting it is the product of the population and an index that links to the evolution of the GDP. This index represents the number of street lighting points per capita. Also in this case saturation effects apply.
- For ICT and multimedia services this number is the product of population and an index that represents the access to such a representative device per capita. This index links to the evolution of the GDP per capita

[12] A study carried out by VHK for DG ENER C3, concerning the update of Ecodesign Impacts, was used as the main input, aggregating technologies to the ones defined in POTEnCIA to the extent necessary.

The size of the installed equipment, as applicable at the level of investment decisions, per energy end-use in the services is endogenously calculated in POTEnCIA. Throughout all end-uses it links to the exogenously assumed technical evolution of the size of equipment. Social drivers that also affect the size of the (to be installed) equipment differentiates in the services sector across end uses:

- For space heating and cooling end-uses, as well as, for building lighting, ventilation and miscellaneous building technologies this relates to the evolution of the useful surface area per representative building cell. This useful surface area is a function of the value added of and the employment in the sector. Specifically for space heating and cooling the country-specific climatic conditions also affect the size of the installed equipment.
- For hot water services the size of equipment is also linked to changes in the GDP as to reflect possible changes by means of a comfort level offered to the consumers of this service.

For the remaining energy end-uses no social driver applies on the size of the installed equipment.

### *Energy use in the services sector*

In services investment decisions take place, as in the case of the residential sector, on the basis of the desired level of operation of the energy related equipment. This desired level of operation is end-use specific and links to:

- The evolution of the services sector value added (taking into account different weights for the various branches as to better reflect their impact on the desired operating hours; for example a huge increase by means of value added in the financial and insurance activities should not affect the rate of use of hot water services equipment); and
- Changes in climatic conditions (if any; applicable for space heating and cooling uses)

The structural response parameter (SRP) may also be used as to capture possible effects from prevailing economic and policy assumptions. It applies on the number of representative agents per energy end-use.

The realised hours of operation of the installed equipment are calculated as described for the residential sector. The actual utilisation rates are end-use, vintage and equipment type specific while the desired hours of operation act as an upper limit.

In the services sector the role of the infrastructure efficiency parameter (IEP), in other words the adoption of non-energy related equipment that leads to energy savings, is important with regards to space heating and cooling end-uses for which it reflects improvements of the building shell characteristics across the different vintages. Moreover, less pronounced improvements in the use of the installed equipment through the IEP may also occur in hot water services, miscellaneous building technologies, ventilation, building lighting and street lighting. As regards behavioural responses (BRP) their scope remains more limited than in the residential sector since a more rational use of the energy equipment is assumed by default in the services sector.

Finally, total energy consumption, $CO_2$ emissions, energy and variable operating costs for the services sector are then calculated as the product of the end-use specific consumption per vintage and technology type and the corresponding total number of representative agents. Again, in the services sector it is possible to have idle installations, especially by means of representative building cells, the system fixed costs of which are explicitly accounted for.

## 4.6 Agriculture sector

In POTEnCIA the treatment of the agricultural sector follows the logic of the non-energy intensive industrial sectors. The main drivers for energy requirements in agriculture is an activity indicator (indexed to macroeconomic assumptions while also making use of the PSP parameter as to limit the effects of structural differences across the EU Member States).

**Table 6 Energy related end-uses in the agriculture sector**

| **Agriculture** |
|---|
| Lighting (Electric) |
| Low enthalpy heat |
| Ventilation |
| Motor drives |
| Specific heat uses |
| Farming machine drives |
| Pumping devices |
| Specific electricity uses |

A distinction is made between non-sector specific energy uses and specific agriculture energy processes. The latter includes farming machine drives; specific heat uses, pumping devices including those used for irrigation systems and specific electricity uses (Table 6).

## 4.7 Transport sector

The transport sector in POTEnCIA comprises road, rail, aviation and water-based transport. Furthermore, bunkers are explicitly included in the model. Energy consumption as available from the EUROSTAT energy balances per transport sector is decomposed to the level of detail introduced in POTEnCIA as concerns the various modes for passengers and freight transport (see Table 7).

**Table 7 Transport sector structure**

| Passenger transport | Freight transport |
|---|---|
| 1. Road transport | |
| • Powered 2-wheelers<br>• Private cars<br>• Buses and coaches | • Light commercial vehicles<br>• Heavy goods vehicles |
| 2. Rail, metro and tram | |
| • Metro and tram, urban light rail<br>• Conventional passenger trains<br>• High speed passenger trains | • Conventional trains |
| 3. Aviation | |
| • Domestic<br>• International – Intra-EU<br>• International – Extra-EU | • Domestic and International - Intra-EU<br>• International – Extra-EU |
| 4. Coastal shipping and inland waterways<br>• Domestic coastal shipping<br>• Inland waterways | |
| 5. Bunkers<br>• Bunkers – Intra-EU<br>• Bunkers – Extra-EU | |

For each transport mode, relevant combinations of different engine architectures and fuel options are represented in the model. For example, for private cars the model distinguishes between internal combustion engine cars, full hybrid cars, plug-in hybrid cars, electric cars with and without range extender and fuel cell cars, accounting at the same time for different fuel options where applicable (see ANNEX I).

Since POTEnCIA is not a fully detailed mobility model, it does not incorporate specific features such as demand segmentation by trip purpose or a classification of activity by distance bands. Similarly, a distinction between urban and non-urban transport is challenging due to data scarcity. Therefore, the relative contribution of urban and non-urban transport is indirectly taken into account. In the longer run, the increase in activity for private cars, for example, could be attributed to an asymmetric evolution of such activities taking into account country-specific characteristics such as saturation of the urban activity for instance. This would affect the vehicles' overall efficiency.

### *Dealing with transport modes specificities in POTEnCIA*

Across Member States the technological dynamics of the various transport modes vary significantly. In order to be able to better reflect the specificities of each one of them and within each country, a number of parameters have been introduced:

- the number of vehicles, differentiated by technology,
- the average annual mileage, differentiated by technology,
- the average occupancy rate/load factor per movement performed, and
- the vehicle efficiency, again differentiated by technology

In road transport, a vehicle refers to a powered two-wheeler, a private car, a bus, a light commercial vehicle or a heavy goods vehicle. In identifying the vehicle characteristics country specific conditions and the stock structure were explicitly taken into account. It should be mentioned that the activity of heavy goods vehicles is based on the territoriality principle and as such, includes not only domestic but also international, transit and cabotage.[13]

In rail transport, the number of vehicles by technology is expressed by means of a 'representative train configuration'. Such a configuration refers to a vehicle (a train) that has a certain number of seats/cargo-capacity and operates for a specific number of hours on a daily basis at a given average speed. Maintenance considerations are also explicitly taken into account. Of course, this configuration differs across the modes considered (metro etc., conventional trains and high speed trains) and the different technology types (diesel versus electric conventional trains). Thus, the country-specific stock of the different train types is identified (reflecting the characteristics and structure of the corresponding rail network).

In aviation the number of vehicles operated (airplanes) is derived as a function of the number of flights performed per airplane per year. This number of flights depends on the average distance travelled and the corresponding time spent (including the on ground time) per *representative flight.* The time needed for the aircraft's maintenance is also considered. Passenger aviation is broken down into domestic flights, international intra-EU and extra-EU flights in order to better reflect the scope of the ETS. This breakdown also allows better representing the types of planes operated, [14] the distinct flight distances[15] and their impact on the specific fuel consumption.[16] For freight aviation only international intra-EU flights and extra-EU flights are considered.

POTEnCIA further covers water-based freight transport, distinguishing between domestic coastal shipping and inland waterways. Moreover, it explicitly addresses bunkers activity, broken down into intra-EU and extra-EU.

### *Definition of the representative agent by transport mode*

For the transport sector the representative agent is defined differently for each transport mode.

Concerning private road transport the representative agent is the corresponding vehicle. The number of vehicles is derived as the product of the population and a vehicle ownership ratio. This ratio is defined in the model as a function of income per capita and saturation effects for powered two-wheelers and private cars. Demographic assumptions, linking to the age of the population as to distinguish its part that is eligible to drive such vehicles, also apply.

For all other transport modes the representative agent is the *representative vehicle configuration*[17] defined as:

- a vehicle that has a certain number of seats/cargo capacity, and
- performs a certain annual mileage that makes its purchase and use justifiable (rational use)

The number of representative agents is implicitly driven by the evolution of the GDP for all these modes (by means of GDP per capita for passenger transport and GDP for

---

[13] It is not however within the current capabilities of the model to treat these categories in a specific fashion. Endogenously calculated load factors and annual travelled distances can incorporate autonomous trends to capture the impact of increasing cross-trade as well as other factors such as the decrease of weight-to-load ratios or the transition to a service economy.
[14] Distinct by means of number of available seats or cargo capacity.
[15] Member States specificities, including the network of destinations served and the frequency of flights per destination have been taken into account.
[16] Detailed ICAO statistics were used as to identify the impact of flight distance on the specific fuel consumption of a plane.
[17] The corresponding techno-economic characteristics are defined as to reflect the specific properties of the representative vehicle configuration.

freight). The linkage to the GDP per capita (rather than the income per capita) for passenger transport has been chosen as to better capture activity dynamics that link to business trips and/or tourism. More specifically the macroeconomic driver affects the number of flights (differently for domestic, intra- and extra-EU) performed per person per year in aviation, the number of km-service requested per person per year in busses and coaches and in the different modes of rail transport, and the level of freight activity per mode (expressed in tonne-km). Possible saturation effects are also taken into consideration. The same applies for structural changes of the economy that give rise to different needs for freight transport.

In order to translate the passenger- and tonne-km activity obtained as the product of the desired activity levels[18] and the corresponding driver (population for passenger; GDP for freight) into vehicle-km, POTEnCIA considers the average occupancy rate/load factor per movement performed for the different modes. As described in the following, the latter is on the one hand a function of economic growth and on the other dependent on the policy framework. The number of representative vehicles is then derived by considering their annual mileage (as defined above). Thus, through taking into account the realised level of use of the vehicles in identifying their number, POTEnCIA shifts the focus of the economic operation of the commercial transport modes towards the service providers rather than the service demanders (i.e. the comfort standard is not set by the demanders but is economically driven by the providers of the service).

### *Energy use in transport*

Investment decisions in the transport sector concern the purchase of new vehicles across all transport modes. The number of new vehicles is determined by the evolution of the total number of vehicles that need to be operated on the one side (i.e. the number of representative agents which derives from the transport service requested as described above), and the vehicle stock on the other, taking into account normal and premature replacements. It needs to be clarified here that the initially calculated number of representative agents (vehicles) for private transport modes is solely dependent on economic and demographic assumptions, in other words this number remains the same across all scenarios regardless of the prevailing policy assumptions unless the macroeconomic or the demographic conditions change.[19]

In the investment decision the desired level of operation in a specific transport mode corresponds to:

- The desired annual mileage of a vehicle in the cases of powered two-wheelers and private cars. This mileage links to the evolution of the income per capita and to the vehicle ownership ratio
- The desired occupancy rate or load factor for all other transport modes. The occupancy rate links to the GDP per capita.

The realised annual mileage for private road transport is derived from the evolution of the desired one while taking into account prevailing economic and policy conditions and the characteristics of the different vehicle vintages in the case of powered two-wheelers and private cars. Changes in the actual mileage also affect the occupancy rate of the vehicles (inversely) as to partly offset the impact by means of meeting the service comfort standard through these two modes.

In the case of all the other transport modes the realised occupancy rate or load factor is driven by the minimisation of the cost of the service providers. Their response to policies

[18] For aviation each representative flight has a given length (exogenously defined). Thus, from the number of flights per person and the flight distance we can obtain the requested service (in passenger-km).

[19] Thus, implicitly the model assumes that for example the car ownership ratio is not dependent on the prevailing policy conditions. However, prevailing economic and policy conditions may affect the behaviour of the demanders of the specific service through revising their comfort standards (as expressed by means of car ownership).

in place has a twofold character; on the one hand they try to optimise the operation of their vehicles fleet and on the other they try to minimise possible modal shifts from the side of the service demanders.

Such modal shifts are captured in POTEnCIA through the structural response parameter (SRP) both by means of adjusting the mobility levels demanded and by means of shifting to other modes. The SRP is calculated both as a function of changes in the cost of providing a certain service (one passenger-km or one tonne-km) in a specific mode and by comparing to the corresponding average cost of providing this service across all modes. This can induce modal shifts, taking into consideration constraints in the substitutability between modes.

In transport the infrastructure efficiency parameter (IEP), reflects the adoption of non-energy related equipment options that may lead to energy savings. Such options include the better servicing of vehicles, low resistance tyres, improved traffic control for rail and aviation etc. Behavioural responses (BRP) also apply in the transport sector including eco-driving and improved logistics.

Total energy consumption, $CO_2$ emissions, energy and variable operating costs for the transport sector are then calculated as the product of the vehicles annual consumption per vintage and technology type and the corresponding total number of operated vehicles. Also in the transport sector POTEnCIA allows for the existence of unutilised vehicles, thus the system fixed costs are calculated taking the whole vehicle stock into account.

# 5. POWER SECTOR

## 5.1 Chronological load curves in POTEnCIA

### *5.1.1 Introducing the "representative day" notion*

ENTSO-E provides detailed hourly data for past years. In POTEnCIA these data are used as to obtain the hourly chronological supply load curve of a "representative day".[20] This is achieved through the implementation of a clustering approach.[21] Different daily loads are grouped into comparable clusters of days with similar characteristics; for instance reflecting high and low demand days and seasonal patterns. In the figure below, four of such day clusters have been represented (including the number of days of occurrence for each of them), as well as two extreme day profiles (named "top day" and "valley day"), corresponding to the higher and lower daily demand (for 2010).

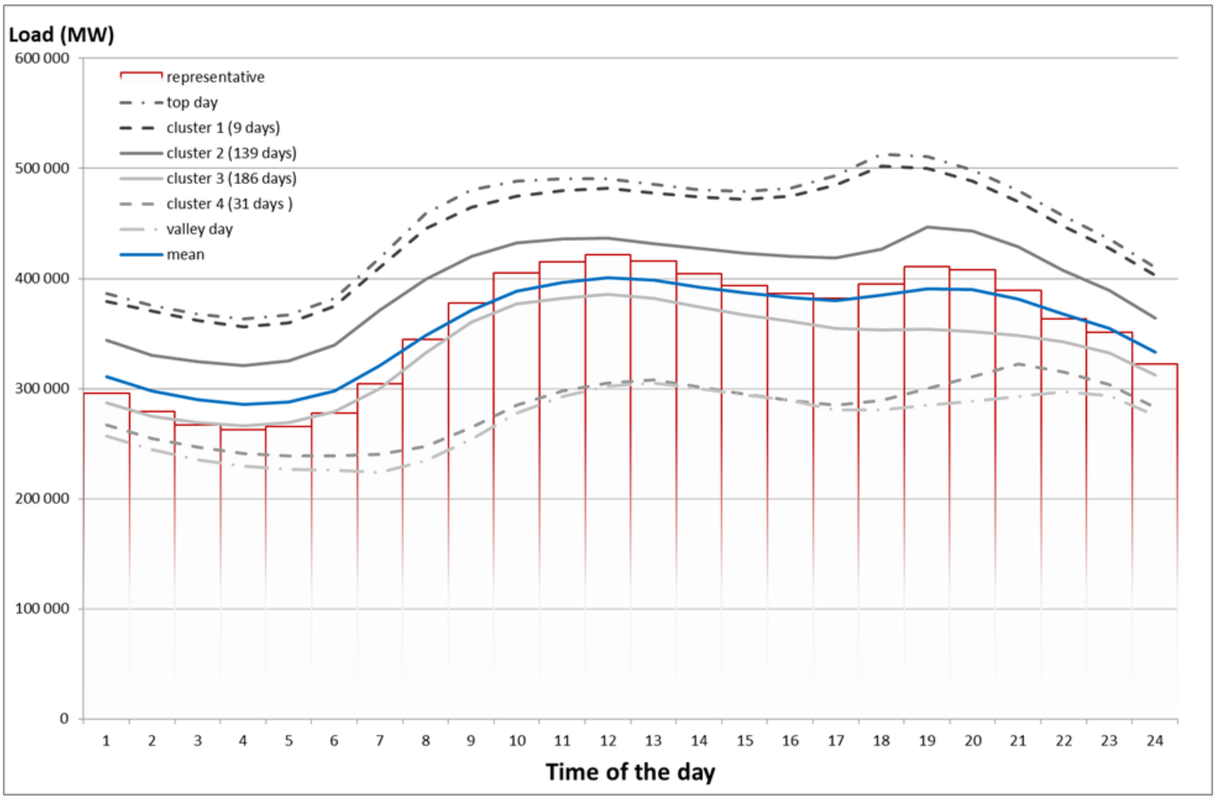


**Figure 2 Hourly chronological load curve**

These clusters are then combined taking into account their frequency of occurrence over the year in order to provide the load pattern of the representative day mentioned above. Through this process the patterns of statistically significant clusters are fully captured.

For most Member States, ENTSO-E apparently does not include (or includes only partially) the demand met from the low- and medium-voltage grid; hence the contributions from intermittent renewables (especially wind and solar) are not fully incorporated in the ENTSO-E loads and thus need to be added. For this purpose a similar approach is followed using different supply patterns for the availability of intermittent

[20] This is not to be confused with a 'typical day' load pattern that is the average of the daily load in a given year.
[21] Ward, Joe H. Jr., 1963. Hierarchical Grouping to Optimize an Objective Function. Journal of the American Statistical Association, Volume 58..

renewables (season and weather conditions dependent); from this availability patterns and through the clustering procedure we obtain the corresponding supply load patterns for one representative day. By summing up the ENTSO-E data and (when needed) the contribution of intermittent renewables to the supply, we obtain a chronological load for the representative day. This chronological load reflects the annual pattern of daily load with the highest likelihood and therefore it describes the most probable picture of the dispatching conditions for a given year.

Electricity and steam demand chronological load curves, which need to be met through power plants generation, are calculated in POTEnCIA as the aggregate of the demand loads for the corresponding fuel of all individual end-uses (e.g. industrial ovens, cooking, motors, lighting etc.) in the final energy demand sectors. The end-use demand loads are obtained on an hourly basis using exogenously defined load patterns which reflect the corresponding operating modes.

The next step concerns the matching between the demand-driven chronological load curve (e.g. the blue curve in Figure 2) and the corresponding supply side representative day's chronological load curve for past years (currently up to 2012). This is done by explicitly calculating a correction factor on an hourly basis that makes the demand side load to match the supply load for the historical time series. This correction factor is then assumed to prevail over the projection period, given the exogenous character of the demand load patterns at the level of end-uses and the limited knowledge about their evolution.

The question that may arise is why POTEnCIA works with one representative day, instead of explicitly working with the typical days corresponding to each cluster (including those of extreme loads). One reason is obviously related to computational time, which is important given the large number of electricity generation technologies considered in the model. More importantly though, choosing a single representative day is justified by the fact that cluster-representing days do not exhibit any repetition pattern throughout the year, i.e. some of them respond to weekly patterns, others to seasonal patterns and finally there is a pure random component too. As it is not possible to project, with a reasonable degree of confidence, how this day-cluster categorisation will develop in the future, some (difficult) assumptions have to be made. The most straightforward assumption was finally made, i.e. assuming no change in the relative cluster shapes and weights, which implies adopting the single representative day option. However, within this single representative day approach, we enable some daily load profile changes arising from changes in prices, demand-side management options, etc.

The role of extreme day profiles is negligible when it comes to project generation on an annual basis because some of them are actually non-predictable data for power dispatchers. For example, a single day with an unforeseen low demand that may occur due to a general strike does not have any explicit implications on the way generators perform annual dispatching of e.g. nuclear and lignite power plants. Hence, such extreme load patterns are addressed by their contribution to the annual load only and not as stand-alone occurrences.

In result, POTEnCIA works with one representative day that provides the most likely load pattern for annual dispatching. However, in order to verify within a given scenario, whether the installed capacity (incl. the reserve capacity) can meet the demand of extreme loads and how the system will operate in such cases, snapshots of such extreme daily load profiles can be analysed.

### *5.1.2 From the chronological load curve to load regimes*

For the purposes of power plants dispatching in POTEnCIA, the hourly time segments of the chronological load curve of the representative day are transformed into load regimes of certain duration. Practically, this only means that the chronological load curve is sorted and ranked by (decreasing) power demand level (see Figure 3). Changes in the load profile of the representative day (as suggested in the previous section) can be accommodated with this load structure. For instance, potential shift in the peak hour to another hour, which may occur as a result of the evolution of different end-uses in the future, can be (dynamically) captured.

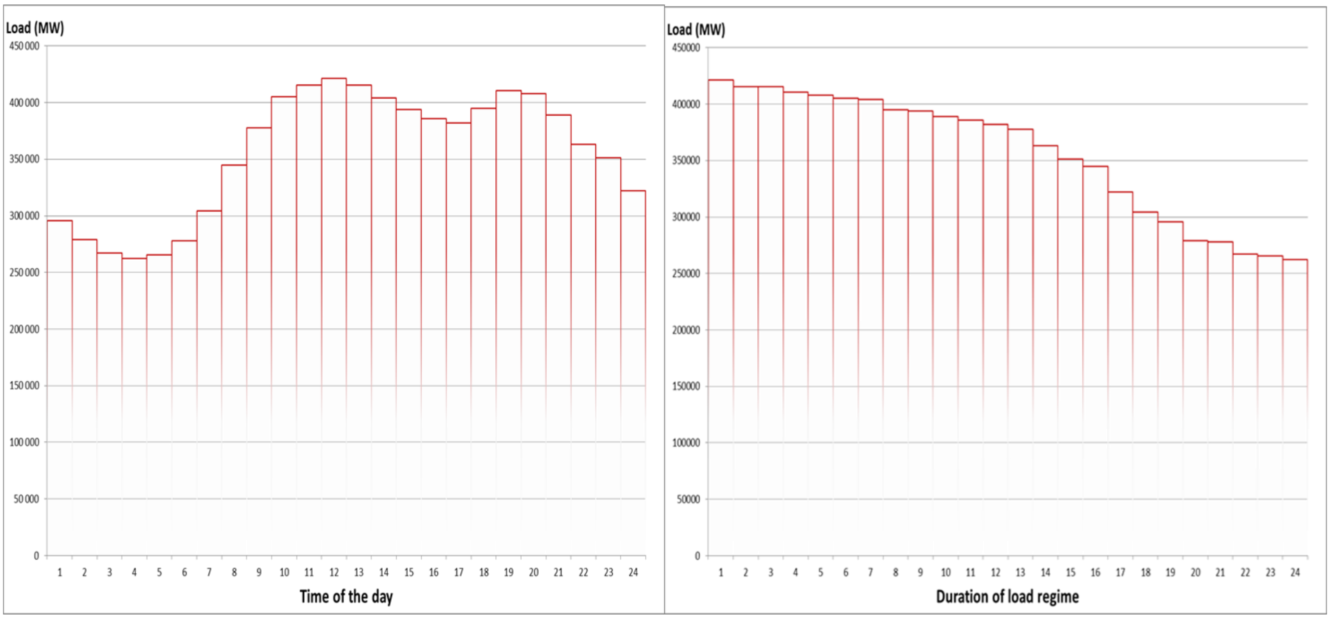


**Figure 3 Hourly chronological load curve to 24 load regimes**

The next step consists of the reduction of the number of load regimes from 24 (i.e. duration from 1 to 24 hours) to 7 with a fixed, non-uniform duration of 1 hour for the peak-load regime, 4 hours for each of the load regimes 2-6, and 3 hours for load regime 7 that corresponds to base-load (see Figure 4). For that purpose, a further step-wise discretisation process is followed that ensures that no information from the chronological load curve is lost and total energy demand is maintained.

The reduction from 24 to 7 load regimes is essentially driven by the computing time needed for solving the model. Tests indicated that the time required to solve the power dispatching phase for one year with a 24 load regime structure is around 35 times higher than the time required when selecting the 7 load regimes approach.

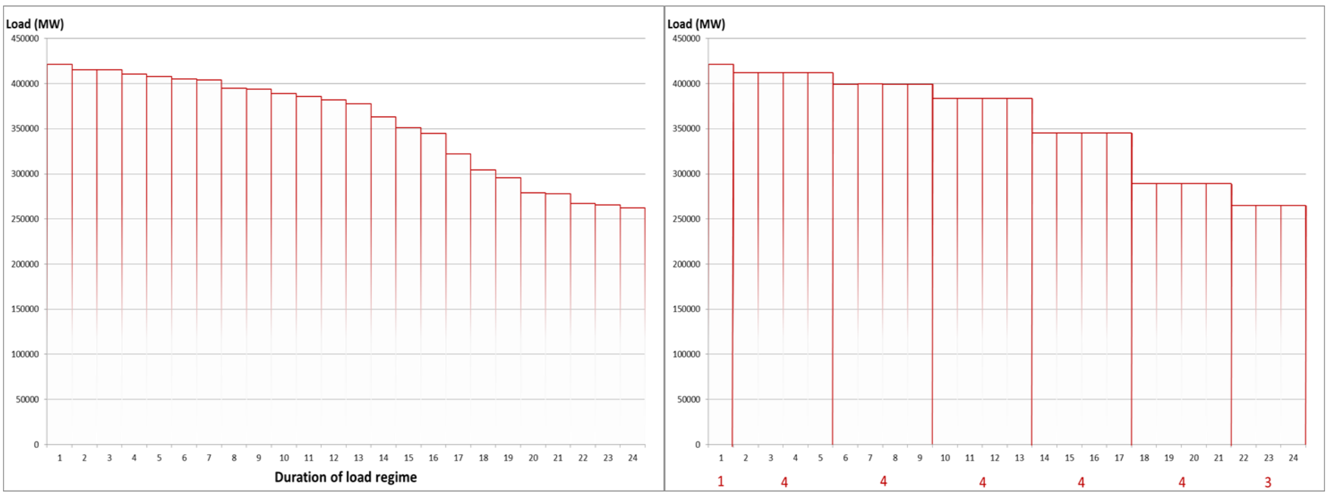


**Figure 4 From 24 to 7 load regimes**

As illustrated in the figure below the loss of information associated to this further discretisation process remains limited.

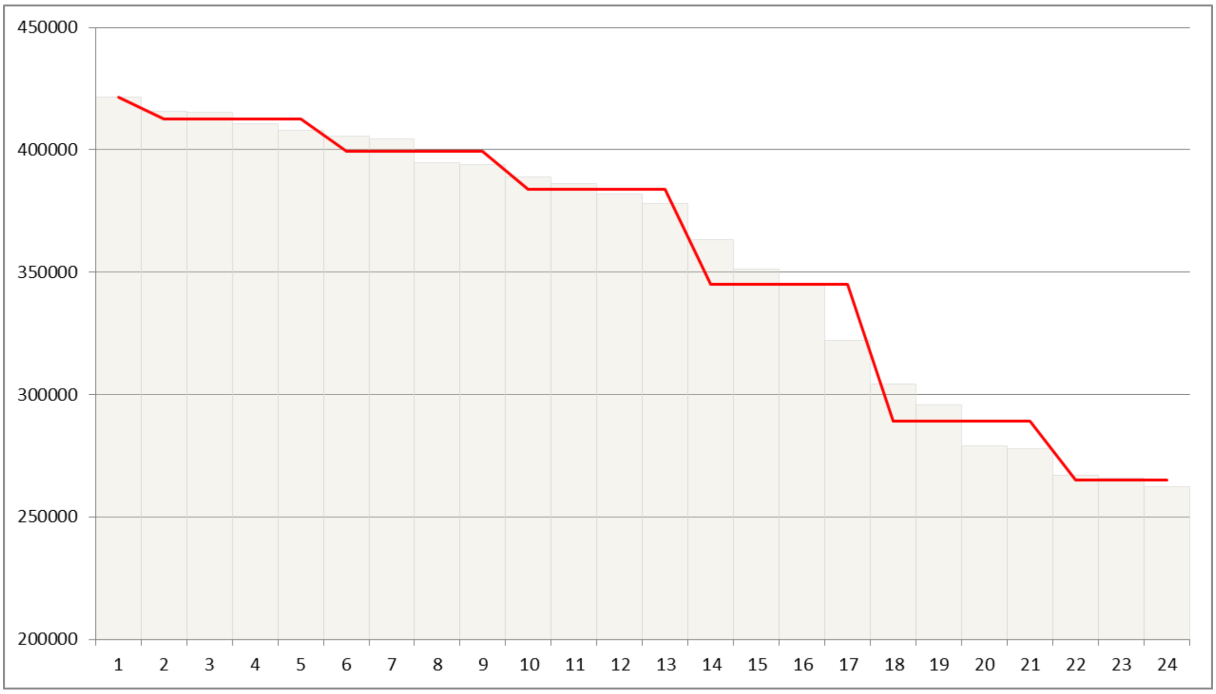


**Figure 5 Comparison between 24 and 7 load regimes patterns**

The overall discrete energy demand curve is then split into horizontal load regimes defined by the successive power demand levels and the corresponding time load duration hours which form the basis for power plants dispatching.

### *5.1.3 Integrating intermittent renewable energies in the different load regimes*

In POTEnCIA the information about the potential contribution of intermittent renewable energies within each load regime is retained when moving from the chronological load curve to the discretised load regimes. This is achieved by identifying at which load regime and for which power demand level the renewable energy can be generated.

Firstly, given the chronological load duration curve of the representative day that needs to be satisfied, the potential contribution of intermittent renewable energies within each time segment (hour) is determined, taking into account the availability pattern of the intermittent renewable in question. For instance, the graph below (Figure 6) illustrates the availability profile of solar power (on the right) that is determined by its natural potential versus the chronological load duration curve (on the left). Other priority dispatch renewable technologies (wind, hydro) would have similar availability profiles (statistically averaged). Hence, for each hour of the representative day, the potential contribution of the various intermittent renewable energies can be quantified.

In the hypothetical case of perfectly flexible generation technologies, the available technology options would fill up each discrete power demand level following a strict merit order approach on the basis of marginal operating costs. As a result, one would expect the renewable energy accumulating at the lower levels, i.e. to contribute mainly to base load regimes (see Figure 7 below left). As intermittent renewable energies are given priority dispatch due to their non-manageable character, it could also be argued that the chronological load duration curve faced by electricity generators would be the one obtained after subtracting their contribution. As shown on the right of Figure 7, the chronological load duration curve that needs to be met by electricity generators would obtain a totally different shape and characteristics.

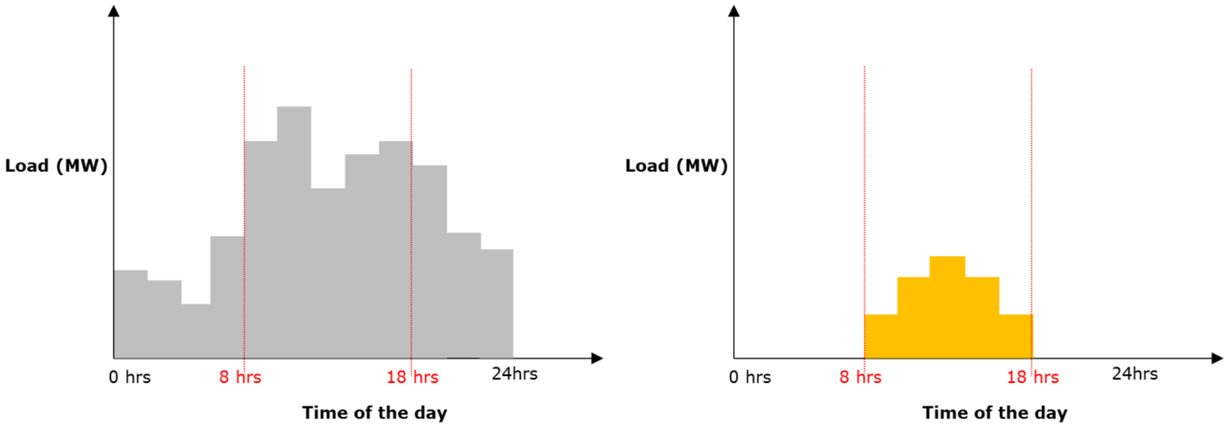


**Figure 6 Demand side and PV chronological load duration curves for a representative day**

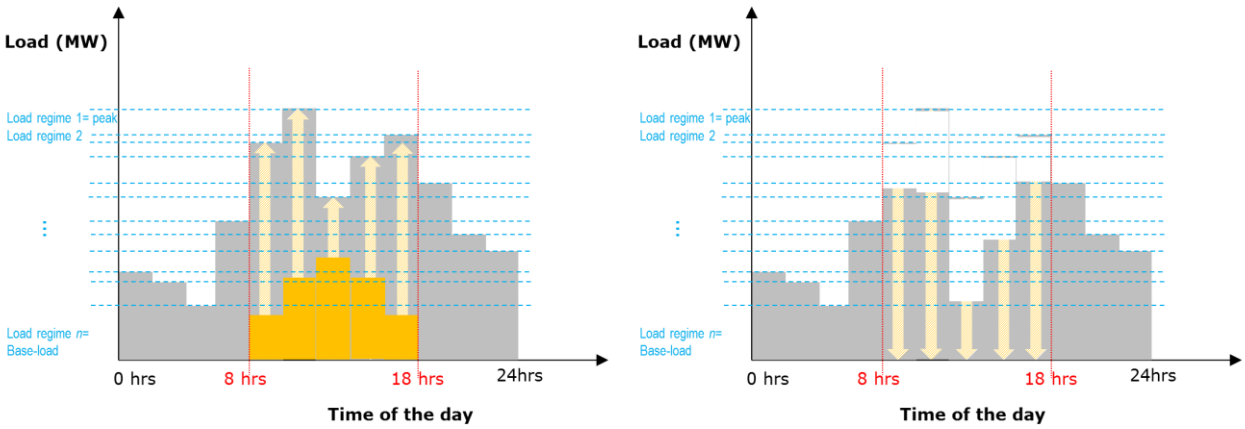


**Figure 7 Deterministic allocation of PV power generation in the chronological load duration curve of a representative day**

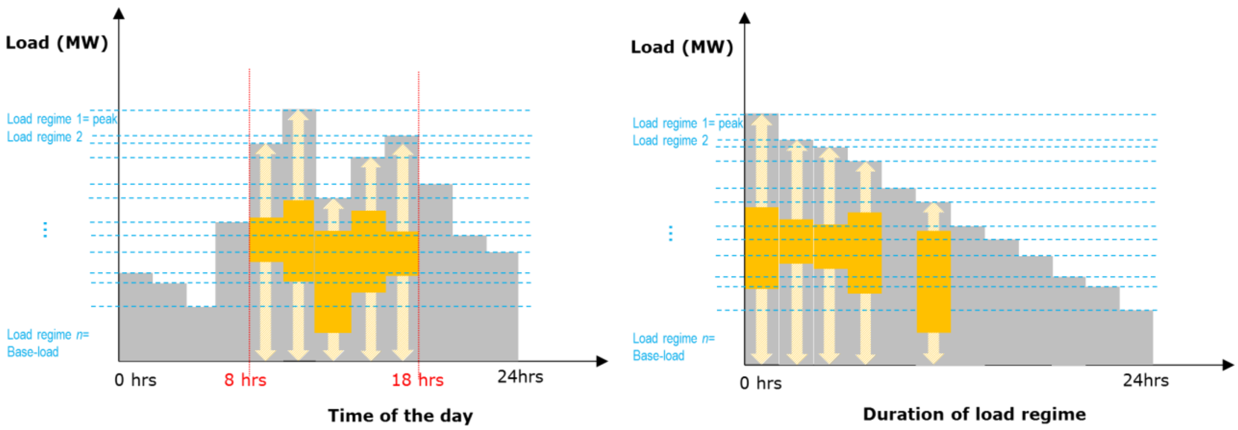


**Figure 8 Flexible allocation of PV power generation in the chronological load duration curve of a representative day**

Such a simplified approach would imply a, sometimes quite unrealistic, allocation of the contribution of intermittent renewables to the different (horizontal) load regimes. In real life, however, it is *a priori* unknown to which load regime within each time segment intermittent renewable energies will eventually contribute. The heterogeneity of ramping up and down costs of other power generation options results in not ranking the (quasi-zero cost) renewable energy at the very bottom, thus, allowing technologies with high load tracking costs to be maintained in the system in a cost effective manner. For instance, the costs of accepting solar PV power at the expense of turning off a nuclear power plant are huge, whereas if it is to replace a gas turbine power plant these costs would be negligible. The definitive ranking of priority dispatch technologies will therefore depend also on the costs of the competing technologies that may be replaced.

In order to capture this, POTEnCIA determines the extent to which intermittent renewables contribute to the different load regimes *based on economic criteria* under constraints of availability while taking into consideration the types of power plants that are replaced by them. In that context a flexible allocation of intermittent renewable energies takes place in the model accounting for the opportunity costs induced in the competing, traditional technologies. Of course as described earlier, the constraints concerning the potential contribution of intermittent renewable energies, which has been determined as a result of their load pattern and the chronological load curve of the representative day, are respected (see Figure 8).

Therefore, in POTEnCIA the power demand load curve is not by default altered due to renewable energies. Instead, intermittent renewable energies are being considered within the dispatching problem as a whole, alongside other power generators.

## 5.2 Methodological approach for the simulation of power plants operation

In POTEnCIA the operation of the power plant fleet is simulated as to meet the electricity demand at the minimum system operating cost under the following conditions:

- Capacity constraints related to the number and size of units installed, and the optimum operating mode[22] of a typical unit;
- Portfolio management constraints that preclude a strict merit order based on marginal operating costs;[23]
- Imports and exports of electricity;
- Uncertainty with regard to the continuous availability of intermittent power generation options (see below).

The dispatching process involves four distinct steps:

1. Calculation of the operating cost per unit of output for the different power plant types and for all the different (horizontal) load regimes of the load curve. This is carried out taking into account the power plant types techno-economic characteristics and the fuel and other cost elements related to the prevailing policy regime (e.g. ETS price or renewable value). When calculating the operating costs of the different plant types, the impact of the operating mode and the hours of operation in the different load regimes in relation to the optimum operating mode of each plant type are explicitly taken into consideration, reflecting the cycling operation costs of conventional thermal power plants.
2. Determination of the "attractiveness" of the different power plant options within the different load regimes versus the competing technology options in the same load regimes.
3. Generation of an explicit ranking order for power plant units' dispatching based on their attractiveness within each load regime. This ordering is performed simultaneously across all power plant types and load regimes.
4. Simulation of the power plant units operation as to satisfy the chronological demand load curve of a representative day. This is carried out in two steps:
    a. First, in order to meet minimum production requirements. This concerns the priority dispatching of intermittent renewable energies, ensuring that the energy generated by them (forced production) is dispatched. It may also be used as to reflect specific policies or technical constraints of the system (e.g. minimum production requirements and/or minimum rate of use of the installed capacities for a certain fuel type)
    b. The remaining part of the chronological demand load curve is then met on the basis of an economically driven dispatching across load regimes.

   For this purpose a multinomial logit formulation[24] is applied as to reflect portfolio management constraints. Dispatching is performed in repetitive steps under constraints related to portfolio management and to minimum accepted rates of use for the dispatched units.

These four steps followed as to simulate the power plants operation are described in detail in the next sections.

### *5.2.1 Operating costs calculation*

In POTEnCIA, power plants are differentiated according to the fuel type, the technology and the size. A further break-down refers to the equipment type; power plants are

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[22] The optimum operation mode is defined as that in which a power plant operates in line with its technical specification.

[23] If desired, POTEnCIA can also analyse dispatching under a pure merit order-approach.

[24] For a thoroughly review of these methods see for instance: Train, K., *Discrete Choice Methods with Simulation*, Cambridge University Press, 2003

distinguished between those that are equipped with CCS-technology and those that are not and between co-generation and "electricity-only" ones. In total, around 270 different power plant types are considered in the model.

Each power plant type is characterised by a set of techno-economic parameters, i.e.:

- the capital costs,
- the fixed costs,
- the variable O&M costs,
- the own consumption ratio (net to gross capacity ratio),
- the thermal conversion efficiency,
- the technical lifetime,
- the construction time,
- the technical availability (expressing the period of planned maintenance),
- the steam-to-electricity ratio in the case of co-generation plants,
- the $CO_2$ emissions capturing rate (applicable for CCS power plants), and
- the typical size of a power plant unit[25]

### *The notion of operating mode*

POTEnCIA allows considering the impact of cycling on thermal power plants' operation, within the different load regimes. In most of the energy models, power generation is modelled based on the assumption of stationary operation of the plants at their nominal or rated power output. However, the rising share of generation from intermittent renewable energies increasingly leads to operating modes that are far from stationary and imply partial loads (ramping and cycling). Hence, it is important to capture the effects caused by such operating modes.

Even in a stationary operating mode, the efficiency of a power plant depends on the output. If a unit is operated in part-load regime, its efficiency decreases due to e.g. less optimal fuel combustion and/or steam conditions and an own consumption that does not decrease proportionally with the output. Furthermore, a unit can be operated in part load up to a minimum level below which no stable operation could be guaranteed. [26]

Additional costs occur, if power plants are not operated in stationary mode, but rather start-ups (and shut-downs) occur. Start-up costs stem mainly from the additional wear of the plants and also from the fuel consumption when operating below the minimum output power. The costs for maintenance can vary significantly if either the yearly hours of operation exceed considerably the value the plant was designed for, or many start-ups have to be carried out.

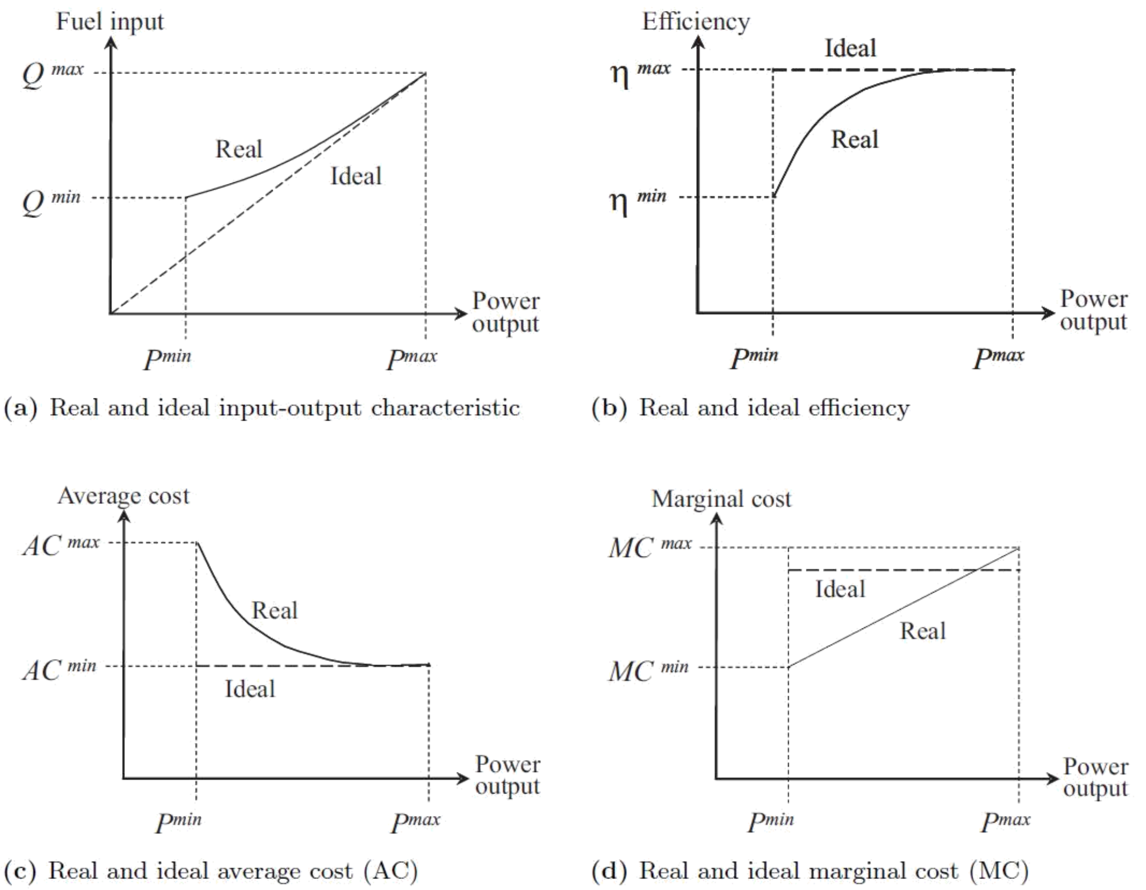
In POTEnCIA, this impact of the operating mode on costs is quantified. It is implemented through the introduction of:

- an efficiency correction factor that on the one side depends on the duration of each load regime (which in the model is assumed to link to a different number of power plant type specific start-ups) and on the other side on the actual rate of use[27] of the nominal capacity of a unit within a load regime (reflecting part load operation), and
- a variable O&M cost correction factor that can vary as a function of the hours of operation and the number of ramp-ups

[25] Concerning installed capacities detailed information is available for the period 2000-2015, based on the EPIC database, including the number of units installed and their average size (capacity), as well as both the year of commissioning and decommissioning of these capacities.

[26] This minimum load at which a unit can operate in a stable manner, reflects considerations on fuel combustion stability and other design constraints

[27] The actual rate of use within each load regime is an output of the model and largely links to the level of penetration of intermittent renewable energies. See Section 5.1.3.




(a) Real and ideal input-output characteristic (b) Real and ideal efficiency

(c) Real and ideal average cost (AC) (d) Real and ideal marginal cost (MC)

*Source: David Jose Martinez Diaz (2008): Production cost models with regard to liberalised electricity markets*

**Figure 9 Impact of operating mode on selected power plant properties**

Thus, for each thermal power plant type, and based on technical and operating considerations, the notion of the "desired domain of operation" is introduced in the model. To this end the "optimal" hours of operation are defined as the hours for which a unit yields the nominal efficiency. It is obvious that these hours of operation involve a certain cycling pattern which however is assumed not to have an impact on the efficiency of the unit. This hypothesis needs to be made as the number of ramp-ups of power plants cannot be explicitly dealt with in a model that addresses dispatching on an annual basis.[28]

The operating mode dependent efficiency correction factor $\eta_{cor}$ is given by:

$$\eta_{cor}(h_{ope}) = \left(\frac{h_{ope}}{h_{opt}}\right)^{-e_{dis}(h_{ope})}$$

where

| | | |
|---|---|---|
| $h_{ope}$ | = | operating hours |
| $h_{opt}$ | = | "optimal" hours of operation |
| $e_{dis}(h_{ope})$ | = | elasticity linking the operating efficiency to the hours of |

[28] For example the fact that a unit operates at 6000 hours does not provide us with any concrete evidence on the number of ramp-ups performed within a year (which could range from one to hundreds).

operation

and

$$e_{dis}(h_{ope}) = \begin{cases} e_{bmi} * \frac{(h_{min}-h_{ope})}{h_{opt}}, & h_{ope} < h_{min} \\ -e_{ama} * \frac{(h_{ope}-h_{max})}{h_{opt}}, & h_{ope} > h_{max} \\ 0, & h_{min} \leq h_{ope} \leq h_{max} \end{cases},$$

with,

| | | |
|---|---|---|
| $e_{bmi}$ | = | elasticity applicable for operating hours less than the desired range of operation |
| $e_{ama}$ | = | elasticity applicable for operating hours higher than the desired range of operation |
| $h_{min}$ | = | minimum operating hours within the desired range of operation |
| $h_{max}$ | = | maximum operating hours within the desired range of operation |

According to the above formulation, within the desired range of operation the efficiency of a power plant unit is only affected as a result of its operation in part load mode (Figure 9). For operating hours below the desired range of operation though, the unit is assumed to face an increasing number of ramp-up events over a year compared to the ones considered within the desired range of operation. This is reflected in the model through the introduction of an incremental factor on the elasticity that links the operating efficiency with the hours of operation and leads to a drastic deterioration of it as they further decline. In the case that the unit operates above the desired range of hours one could argue that a lower number of ramp-ups would take place on an annual basis. However, in the default setting of the model this number of ramp-ups is assumed to remain unchanged (i.e. elasticity $e_{ama}$ is set to 0) and thus the efficiency of the unit cannot further improve compared to the nominal one.[29]

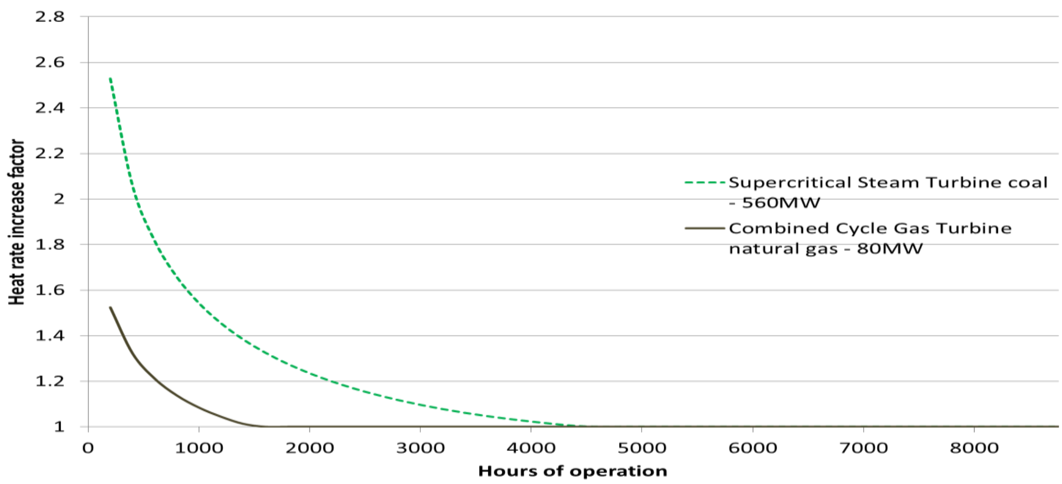



**Figure 10 Relationship between heat rate and hours of operation of a thermal power plant**

[29] In POTEnCIA this option can be activated if required in order to perform specific policy analysis.

The extent of the impact of the actual hours of operation on the power plants efficiency $\eta$ strongly depends on the type and size of the plant. Figure 10 illustrates this relationship between the heat rate (i.e. $1/\eta$) and the hours of operation for a large supercritical coal power plant and a more flexible small-sized natural gas fired combined cycle gas turbine.

The introduction of the above mentioned correction factor implies that the efficiency of a power plant becomes time dependent, thus it differs across the different load regimes. The efficiency $\eta$ is given by:

$$\eta(h_{ope}) = \eta_{tec} * \eta_{cor}(h_{ope})$$

where,

$\eta_{tec}$ = the technical nominal efficiency of a power plant

In the same manner the variable O&M costs of a power plant are assumed to vary as a function of the hours of operation:

$$C_{var}(h_{ope}) = c_{var\_tec} * c_{var\_cor}(h_{ope})$$

where,

$$c_{var\_cor}(h_{ope}) = \begin{cases} \left(\dfrac{\min(h_{ope}, h_{opt})}{\max(h_{ope}, h_{opt})}\right)^{-e\_ope}, & h_{min} \leq h_{ope} \leq h_{max} \\ \left(\dfrac{\min(h_{ope}, h_{opt})}{\max(h_{ope}, h_{opt})}\right)^{-e\_ext}, & \begin{matrix} h_{ope} < h_{min} \\ h_{ope} > h_{max} \end{matrix} \end{cases}$$

and

$c_{var\_cor}(h_{ope})$ = variable O&M cost correction factor

$e\_ope$ = elasticity for O&M cost applicable within the desired range of operation

$e\_ext$ = elasticity applicable for operating hours outside the desired range of operation

This equation mimics in a simplified manner the (observed)[30] impact of cycling operation on a power plant's O&M cost. An increased number of ramp-ups causes thermal and pressure-related material stresses to the power plant components, which reduce their life expectancy. This results in a rising need for maintenance (and eventually a reduced lifetime of the entire plant). In a similar way the over-utilisation of a power plant leads to a reduction of its technical lifetime as the equipment wears off faster than foreseen in its technical specifications. In the model this can only be captured by means of additional variable O&M costs.

The extent to which the operating mode affects the variable O&M costs largely depends on the type of the power plant in terms of the main technology involved (e.g. steam or gas turbine), its size, its preparedness for cycling operation in the initial design etc. For example, the operating mode more drastically impacts the O&M costs of a large scale super-critical lignite power plant than those of a gas turbine.

### *Power plant units operating cost*

For every power plant type the operating costs per kWh of output are calculated, based on the techno-economic characteristics of each unit, on the fuel costs and on other cost elements influenced by policies in place (energy efficiency premiums, renewable support

[30] See e.g. Kumar, N. et al. (2012): Power Plant Cycling Cost. Intertek APTECH, prepared for NREL.

etc.). As argued above, the increasingly frequent cycling operation of power plants makes it appropriate to explicitly consider their operating mode in the calculation of their operating costs. In POTEnCIA, this is implemented through the features described above. The resulting operating costs of producing one unit of output from a given power plant type $C_{ope}(h_{ope})$ is given as follows:

$$C_{ope}(h_{ope}) = \left[C_{var}(h_{ope}) + (C_{fuel} + C_{ETS} * em_{fuel}) * \frac{1}{\eta(h_{ope})}\right] * \frac{1}{rnc} + pol_{sup}$$

where,

| | | |
|---|---|---|
| $C_{fuel}$ | = | fuel cost |
| $C_{ETS}$ | = | $CO_2$ permit price arising from the Emission Trading System (ETS) |
| $em_{fuel}$ | = | $CO_2$ emission factor |
| $rnc$ | = | ratio of net over gross capacity (own consumption ratio) |
| $pol_{sup}$ | = | policy support parameter (e.g. renewable value) |

The above equation can be split into two parts; one that describes the nominal operating costs, $C_{nom}$, which is irrelevant to the operating hours and another that reflects the incremental operating costs induced by the operating mode, $C_{mod}(h_{ope})$:

$$C_{nom} = \left[C_{var\_tec} + (C_{fuel} + C_{ETS} * em_{fuel}) * \frac{1}{\eta_{tec}}\right] * \frac{1}{rnc} + pol_{sup}$$

$$C_{mod}(h_{ope}) = C_{ope}(h_{ope}) - C_{nom}$$

The importance of accounting for the operating mode when calculating the operating cost per unit of output of a power plant is clearly illustrated in Figure 11.

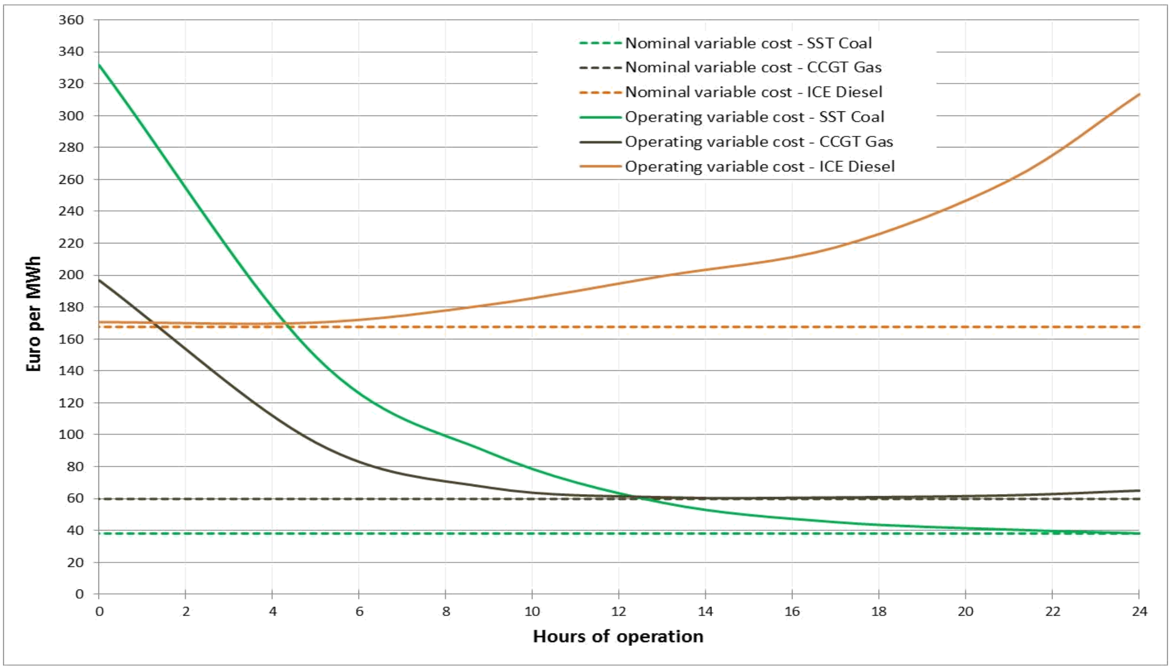



**Figure 11 Relationship between operating cost and operating mode**

In POTEnCIA the operating costs ($C_{ope}(l)$) in the different load regimes $l$ could be calculated assuming that the operating hours correspond to the duration $h(l)$ of each load regime. This approach would presume that operators are fully aware of the duration of the load regimes as derived from the discrete energy demand load curve (see Section 5.1.2). In real life, however, generators are faced with uncertainties regarding the exact hours that a power plant unit will operate on an annual basis. Such uncertainties are related to possible unplanned outages, changes in the demand patterns within the year or fluctuations in the contribution of intermittent renewable energies, creating a suboptimality as regards producers' decisions. In order to mimic this behaviour in POTEnCIA, the operating costs of a power plant type within a certain (horizontal) load regime are calculated using a revised number of operating hours $h^*(l)$ (which obviously depend on the discretization of the load duration curve) This revised number of operating hours better reflects the load of extreme clusters in the producers' decision making whilst it takes into account the continuous nature of the load curve. [31]

### 5.2.2 Determination of 'attractiveness' and ranking of power plant units

The operating cost of each plant type in the different load regimes in combination with a market acceptance factor are then used in order to identify the 'attractiveness' of a certain power generation technology option compared to all other competing options.

This market acceptance factor reflects non-economic, exogenously defined and specific to the power plant types, drivers that influence producers' decision ($maf_{exog}$). Furthermore, possible changes in producers' behaviour as a response to prevailing policy assumptions are also taken into account:

$$maf = maf_{exog} * \left[\frac{\left[C_{var\_tec} + \left(C_{fuel} + C_{ETS} * em_{fuel}\right) * \frac{1}{\eta_{tec}}\right] * \frac{1}{rnc} + pol_{sup}}{\left(C_{var\_tec} + C_{fuel} * \frac{1}{\eta_{tec}}\right) * \frac{1}{rnc}}\right]^{-e_{pol}}$$

where,

| | | |
|---|---|---|
| $maf$ | = | endogenous market acceptance factor as a function of policy |
| $maf_{exog}$ | = | exogenously defined market acceptance factor by power plant type |
| $e_{pol}$ | = | elasticity for the reaction of the market acceptance factor to policy-induced costs |

The "attractiveness" of generating one unit of output from a certain power plant type and within a specific load regime is then determined on the basis of its operating cost, the market acceptance factor and the optimum hours of operation of the power plant type:

$$attr\,(l) = maf * C_{ope}(h^*(l))^{-e_W(l)} * \begin{cases} 1 \quad , & h_{opt} > h(l) \\ \left(\frac{h_{opt}}{h(l)}\right)^{e_{soh}} , & h_{opt} \leq h(l) \end{cases}$$

where,

| | | |
|---|---|---|
| $attr\,(l)$ | = | measure of attractiveness of a power plant type within load regime l |
| $e_W(l)$ | = | cost elasticity, dependent on the load regime |

[31] In doing so neighbouring load regimes are combined and averaged by means of energy and capacity, resulting in the revised number of operating hours $h^*(l)$ for each one of them.

$e_{soh}$ = elasticity reflecting the operating constraints of the unit

Through the inclusion of the optimum operating hours in the above formulation, it is possible to take into account limitations related to the potential hours of use of the plant types within the different load regimes due to both technical and availability constraints. This is of particular relevance for intermittent renewable energies, whose operating hours are dependent on natural conditions. On this basis the attractiveness of the different power plant types incorporates the effect of limitations related to the hours of operation and the discontinuous character of energy output generated from intermittent renewable energies.[32]

As it can be seen in the equation above, the attractiveness $attr(l)$ of the generated output per power plant type is not linearly linked to the inverse of the corresponding operating costs. Instead a load regime-dependent elasticity $e_W(l)$ is introduced. This makes it possible to capture the different perception by producers of the alternative options' attractiveness in each load regime. It is reasonable to assume that in the base-load regime the behaviour tends to converge towards a pure merit-order approach (comparatively large $e_W(l)$) whereas in the medium and peak load regimes portfolio management considerations (implying a diversification of production options) play a more important role (comparatively low $e_W(l)$).

This attractiveness indicator can directly act as a driver in the ordering and allocation of the different power plant types *within* a given load regime. However, in order to enable the comparison of the attractiveness of the output of a given power plant type *across* the different load regimes with the available options within each one of them, a normalisation by load regime is required:[33]

$$dms(l) = \frac{attr\ (l)}{\sum_{options\ (l)} attr\ (l)}$$

According to discrete choice theory, the output of this normalisation $dms(l)$ could be seen as the probability of choosing a certain power generation option compared to the available alternatives following the principles of a multinomial logit formulation for market shares calculation. In deterministic terms it equals to the "desired" contribution of a certain option by means of energy generation and can therefore be interpreted as the "desired market share" of that option within each load regime.

On the basis of the desired market shares the "potential" generation (i.e. unconstrained by means of capacity, rate of use, fuel availability etc.) by power plant type and load regime is then calculated. This potential generation is then used as to order the power plant types across all load regimes.

### 5.2.3 Simulation of power plant units operation

#### General approach: unit commitment

POTEnCIA simulates the annual operation of power plant types so as to satisfy the chronological demand load curve, mimicking a unit commitment approach. This allows for a more realistic representation of the power plants operation compared to an approach that considers the capacity related to a certain power plant type as a whole. At the same time this approach largely enhances the level of detail of the model output.

[32] For example, electricity generated from wind energy is produced at very low operating costs; therefore, it would be attributed a very high attractiveness throughout all load regimes. However, in real life both its operating hours are limited and the energy generated is discontinuous. This reduces its attractiveness compared to a unit that provides continuous energy without such operating constraints, e.g. in the base load regime.

[33] This is not the same as normalising over all load regimes, which would result in a loss of load specific information.

In order to simulate the operation of (representative) units rather than looking at the total installed capacity of a certain power plant type, the number of units available and their corresponding operating constraints need to be accounted for. The possible range of operation of a unit within a given load regime is defined through:

- the unit size (and its technical availability),
- the unit's efficiency that depends on the operating hours,
- the hours of availability of the resource as such (for intermittent renewable energy sources),
- the optimum hours of operation (if applicable)[34] , and
- the minimum stable load[35] at which the unit can operate

The consideration of unit-specific operating constraints makes it possible to distinguish within a given load regime between a unit's contribution to satisfy the electricity demand in terms of kWh and its contribution to meet the load in terms of power (kW). Whereas a thermal unit's contribution to electricity generation also implies a corresponding contribution to the load of the regime it is allocated in, this may not be the case throughout all load regimes for intermittent renewable energies since these are also constrained by their naturally limited hours of availability. Hence, a unit that is dispatched in a load regime with duration larger than its hours of availability cannot contribute on its own to the power load, even though it contributes in terms of electricity generation. However, if the hours of availability of the resource are higher than the duration of a load regime (whilst the optimum hours of operation of one unit are lower) then multiple units could be "bundled" so as to contribute to the load of the regime.

This bundling can be assumed for instance for wind power. For example, a 1kW wind energy unit with normal hours of operation of 1752 hours cannot replace one kW of base load power. However, under the assumption that no limits exist in the maximum natural hours of wind availability, justifiable when considering an extensive geographical spread regarding the wind parks location, multiple units (in this example five) could be considered to operate in series as to generate energy throughout the entire duration of the load. Hence, these multiple units together could contribute not only to the electricity generation but also to the power of the base load regime, under the assumption of permanent wind availability in some spots all over the country/zone considered. On the contrary for PV the naturally possible maximum hours of operation are restricted by the sunlight hours; hence, PV units cannot contribute to the power load in this regime though they can satisfy part of the electricity generation within it. This implies that other units will need to be dispatched so as to meet the regime's load. However these last units will face a reduction in their rate of use during the period of time in which PV units contribute in electricity generation.

The distinction between a unit's contribution in terms of electricity and in terms of power (load) to a certain load regime provides important additional information on the operation of the power sector:

- The units in operation and the unused ones can be identified instead of considering that the entire capacity of the installed stock is run at partial load.
- For the units in operation, the actual rate of use of the capacity (reflecting their operation in part load conditions) can be determined within each load regime. Thus, it becomes possible to assess the impact of intermittent renewable energies on the utilisation rate of thermal power plants.

[34] Whereas the hours of availability of solar energy would correspond to the sunshine hours, the observed hours of operation are only a fraction of this, due to days without sunshine, limits in the unit's availability etc. These observed hours of operation (calculated on the basis of historic data by dividing the electricity generation to the total installed capacity) are considered as the optimum hours of operation for intermittent renewable energies in the model.

[35] Such a restriction, with regard to the minimum load at which a unit can operate in a stable manner, is mainly influenced by the considerations on fuel combustion stability and other design constraints. Hence, it varies significantly across technologies.

- If a unit is under-utilised within a certain regime, i.e. used in part load, its unused capacity is treated as spinning reserve for the system.

As anticipated above, POTEnCIA treats power plants operation in two consecutive steps:

1. Firstly, mandatory production requirements from certain fuel or technology types are met by operating the associated units across all load regimes following their ranking order;
2. Secondly, different power plant types units are allocated, on the basis of economic criteria, as to satisfy the unmet load within each load regime.

In both cases the desired market shares of the different options available are taken into account as to identify the amount of electricity generated and the number of units dispatched.

### *Applying the portfolio management approach in power plants operation*

Power plant units are operated seeking to achieve their desired market share levels as obtained from the multinomial logit formulation described in Section 5.2.2, while respecting the relevant operating constraints. In other words a portfolio management approach is adopted in the model with regards to the allocation of power plant units in the load regimes instead of seeking a least cost solution for electricity generation.

The adoption of such an approach is justified by the fact that, as explained earlier, in POTEnCIA a unit commitment approach is mimicked. However, as it is not possible to address individual units (whose number comes close to 500 000 in the EU), the dispatching process is narrowed down to some 270 representative unit types. For each of the latter a number of identical units can be considered (summing up to the real number of existing units). The properties of each representative unit type represent the average characteristics of the numerous similar (by means of equipment characterisation) units installed. The underlying real units may nevertheless have minor or larger deviations in their operating costs reflecting different technological characteristics that are strongly linked to their year of commissioning. [36]

This variety of units means that in real life their dispatching in the different load regimes would most likely be quite fragmented. For example, assuming a simplified case in which two different power plant types, A and B, are available with n number of units of the same size (for simplicity) each, that the aggregate power plant type A is marginally cheaper than power plant type B and that we need to satisfy a load equivalent to n units then the following options can be envisaged:

- In a least cost solution approach all units of power plant type A would be dispatched and none of type B
- In real life conditions, in which the explicit characteristics of each unit available are known, a fragmentation of units dispatching would occur, as most likely some units of type B would be more cost effective than some others of type A. Therefore, the dispatching order (the index referring to the number of the unit dispatched) would look like A1-A20, B21, A22-A50, B51, A52-A60, B61-Bn

This fragmentation observed in real life conditions is what is captured through the use of the desired market shares when simulating the operation of power plant units. The

[36] For example it is obvious that the efficiency of a natural gas fired gas turbine combined cycle unit that has been commissioned in 2000 is different to that of an identical unit commissioned in 2010 due to the technological evolution in that period.

allocation of the units in each load regime is performed through an iterative process, in which the ranking, the desired market share and the number of available units of each power plant type, alongside the remaining capacity within a load regime that needs to be satisfied are considered.[37] In the case that either the designated market share is reached or the number of available units is exhausted the subsequent power plant type (by means of ranking) is dispatched until meeting the remaining load within each load regime.[38] In avoiding unrealistically small contributions from power plant units[39] a constraint that reflects the minimum stable load at which a unit can operate is also introduced.[40]

This iterative process continues until the entire load (of all load regimes) as well as the total electricity demand is met. Since in the case of intermittent renewable energies their contribution in terms of electricity generation does not by default translate into a corresponding contribution in terms of load, the utilisation rate of the thermal power plant units is affected. Their actual rate of use compared to their theoretical contribution within a given load regime provides an indication of the spinning reserve.

### *Mandatory production requirements*

Policy-related and/or strategic considerations can result in minimum levels of electricity generation from certain fuel types. Such considerations link to:

- Quotas set by policies (e.g. electricity generation from biomass)
- Electricity generated from cogeneration power plants[41]
- Intermittent renewable energy forms for which priority dispatching is assumed
- Possible limitations related to installed capacities (e.g. nuclear power plants) or the existence of indigenous energy sources (for example lignite, coal etc.)

#### *Minimum production requirements*

POTEnCIA meets these "minimum production requirements" through allocating the power plant units for which such requirements apply, while taking into account the attractiveness of all alternative options within each load regime. In addition, the allocation of units respects their operating constraints and the potential electricity that can be allocated within each load regime. This means that even though the imposed minimum production requirements are fuel- or technology-specific, the properties of the entire installed stock are fully considered.

The allocation starts from the most attractive option across all load regimes, i.e. from the load regime in which a certain power plant type that needs to satisfy a minimum production is ranked first, and takes into account the attributes of the specific regime (duration, electricity demand etc.) and the number of available units. This process is

[37] A further constraint can be introduced in POTEnCIA so as to limit the maximum contribution within a load that can be attained by one technology. Such constraint may reflect considerations on supply security.

[38] In the case that after exploiting all options available the remaining capacity of a load regime is not met, the process is repeated.

[39] Applying the multinomial logit approach implies that all available power plant types obtain a certain, non-zero market share in each load regime. This may result in operating (in accordance to the market shares) only a small fraction of one individual unit as the allocated capacity can be disproportional to the unit's size.

[40] POTEnCIA also offers the option to consider in each iteration only units of those power plant types with a significant market share, i.e. which are of dominant nature within a given load regime.

[41] For cogeneration power plants it is considered that they are primarily dispatched in satisfying a distributed steam demand curve. The electricity output (initially based on a reference steam to electricity ratio for the dispatched power plant units) is then allocated to the appropriate load regimes of the electricity demand curve and is treated as a minimum production requirement with, however, a flexibility in terms of adapting the steam to electricity ratio as to better reflect the characteristics and constraints of electricity demand. It needs to be stressed that the distributed steam and electricity load curves do not have by definition the same load pattern.

repeated (spanning all load regimes and power plant types following their ranking) until either meeting the minimum production requirements or allocating all the available units of the corresponding fuel type.[42]

### *Priority dispatching of intermittent renewable energies*

When dealing with the allocation of intermittent renewable energies in the context of priority dispatching two additional constraints of high importance apply. The first one concerns their availability (expressed by means of a representative day's natural availability pattern) and the second reflects uncertainties with regards to this availability on an annual basis.

In POTEnCIA these natural load patterns of intermittent renewable energies availability are explicitly taken into account when moving from the chronological demand load curve to the discretised load regimes. As described in Section 5.1.3, the potential contribution of an intermittent renewable energy source within each load regime is calculated while ensuring the synchronicity of the chronological load demand curve and the natural availability pattern of the intermittent renewable energy.

In addition, the model offers the possibility to take into account uncertainties with regards to the continuity of the availability of the renewable energy resource over a year. The natural load pattern applied reflects the characteristics of a representative day; however, there exists a high likelihood that renewable energy resources will not be available for a number of specific days in a year due to weather conditions (e.g. no wind, no sun etc.).

In order to capture these discrepancies that may occur on an annual basis the option of introducing a constraint is available in POTEnCIA. This constraint would limit the potential contribution of intermittent renewable energies in the electricity generation of a load regime.[43] In this case part of the electricity generation in the load regime needs to be satisfied by other (thermal) power plant type units.

POTEnCIA identifies the contribution of intermittent renewable energies across the load regimes. It follows the minimum production requirements' approach, while respecting in addition the constraints mentioned above. The optimum hours of operation of one unit on an annual basis are, also, explicitly taken into account. This way the competitiveness of intermittent renewables within each load regime compared to the (possibly thermal) power plants that are replaced by them is accounted for.

Furthermore, the approach retained allows assessing the impact of different policy related assumptions on the allocation of intermittent renewables in the load regimes. As the competitiveness of an intermittent renewable energy source depends on the operating costs of the power plants it replaces, the load regime in which the renewable source will operate varies in dependence to the policy assumptions introduced.

Finally, the model allows identifying the possible curtailment of intermittent renewable energy units and/or quantifying the need for spinning reserve in the different load regimes through the explicit consideration of the unit's contribution to the load by means of capacity dispatching:

- For example, if allocating an intermittent renewable energy unit in a load regime with duration below the unit's optimum operating hours is found to be a cost-effective option, then part of the electricity generated from that unit[44] cannot be allocated in the load regime; thus, curtailment of the unit's electricity output takes place.

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[42] This, of course, implies that minimum production requirements do not, by default, form a binding constraint in the model

[43] In other words the electricity generation of a load regime cannot be solely met through units of an intermittent renewable energy type.

[44] This part corresponds to generation occurring for the number of the unit's standard operating hours that exceed the duration of the load regime.

- On the other hand, if a unit is operated in a load regime whose duration is longer than the hours the renewable energy resource is available (for example, when allocating solar PV units in base load), its capacity by default cannot be considered to contribute to the load of the regime. Hence, the load needs to be met by other power plants dispatched in the same load regime, which nevertheless would not be operated in full load. Their underutilisation provides a notion of the spinning reserve.

When a renewable energy unit is operated in a load regime that falls within the hours of availability of the resource, POTEnCIA allows for different interpretations as concerns the unit's contribution in satisfying the load. On the one extreme, it may be argued that the inherent uncertainty related to the unit's availability over the entire year means that it does not account for any secured capacity in satisfying the load. In this case, the whole load needs to be met by capacities of other power plants. On the other extreme, one may assume that the unit's contribution in terms of energy fully translates into its contribution to the load of the regime, i.e. assuming, as discussed above, that several units are dispatched in series (bundled).

#### *Dispatching within a load regime using economic criteria*

The implementation of the above mentioned dispatching procedure in meeting minimum production requirements constraints leads in partially satisfying the electricity generation and load of the different load regimes. The allocation of the remaining available units in the updated (both by means of load and electricity generation) load regimes is then performed following the above described methodology.

However, this second phase of simulating the power plant operation addresses the allocation of capacity in the different load regimes. In this sense it differs to the case of simulating the operation of power plants to meet the minimum production requirements, in which both capacity and electricity generation options were simultaneously treated. The electricity generation of the different power plant units operated is then calculated as a function of the dispatched capacity, the duration and the, explicitly calculated,[45] actual rate of use of this capacity within each load regime.

[45] This actual rate of use, which is assumed to be uniform for all thermal power plants dispatched in the second phase within a specific load regime, is calculated as the ratio of the remaining electricity in that load regime after the dispatching for meeting minimum production requirements over the unmet capacity multiplied by the duration of the regime.

## 5.3 Capacity planning

### 5.3.1 Types of agents and capacity planning under uncertainty

In POTEnCIA the capacity planning in power generation is performed by means of considering distinct types of agents' behaviour for investing in the power market under imperfect information as regards the future policy:

- Dedicated producers are considered to be those who invest only in a specific segment of the market, corresponding to a well-defined part of the load duration curve, while ignoring the overall power system characteristics. An example for this may be an investor in renewable energies in a system that combines fix remuneration with guaranteed dispatch.
- Multiple market agents. Each market agent has a different perception of the stringency of future policies and makes a specific individual investment choice (e.g. one market agent evaluates its investment decision applying a carbon price of 100€/t $CO_2$, another considering a price of 50€/t $CO_2$ and another applying a price of 1 €/t $CO_2$). In order to obtain the "average" investment decision of these various agents a weighted average of the individual decisions of each one of them and of their importance in the sector applies. In POTEnCIA the share of the different agents with regards to the overall decision making links to the prevailing policy conditions versus their specific views.
- A central decision planner, reflecting for example a large dominant utility. Here, the central planner foresees different possibilities for the future of policies and weights them in order to obtain the specific, economically driven, final investment choice. This agent incorporates the behaviour of dedicated producers and market agents, but simultaneously examines different possible evolutions of the system characteristics by identifying the likelihood of the costs of the different investment options; based on this he identifies the most likely cost characteristics of each investment option. On this basis, the market shares of the final investment choice are derived.

The default setting that POTEnCIA applies in performing the investment decision is the one of the central planner. However, the possibility to activate the other two types of agents' behaviour is available (including a possible combination of the three types of planners using exogenous weights).

The model moves away from the perfect foresight framework, in other words optimisation with perfect information, and tries to mimic real world decision making in the capacity planning by not considering with certainty fixed, predetermined values for the future key policy parameters. In doing so, a dynamic recursive perfect foresight with imperfect information approach is followed.

To this end, uncertainties concerning the evolution of policy parameters are introduced by default in the investment decision making, which reflect different expectations concerning the likelihood and/or the stringency of implementation of future policies such as the ETS, renewable support schemes, efficiency policies, or any possible combination of these. At the same time, these expectations take into account the reality of the prevailing policy.

In order to achieve this, the operating costs of alternative investment options are simultaneously calculated for a number of points within the (multidimensional) policy space, spun by the values that the respective policy parameters could take. The significance of each of these points – which reflects a unique combination of the policy values considered – is calculated as a function of the distance to the prevailing policy, forming an asymmetric distribution that evolves dynamically over time.

The incorporation of uncertainty in the investment decision allows also for a quantification of the "searching costs", or the costs caused through the lack of a clear and binding signal. This may be interpreted as the difference of the costs of a solution under imperfect policy information with those of a solution with a predetermined evolution of the policy parameters.

### 5.3.2 Identification of investment needs

The domain for new investments in power generation is determined by the gap between:

- the net installed capacities available for operation – i.e. capacities not available for operation due to maintenance and overhauls, outages etc. are by default not considered,
- the peak load plus a reserve margin – i.e. the available capacity needs to exceed the peak load demand by a certain fraction (the 'reserve margin') in order to be able to satisfy unanticipated power demand or counterbalance a loss in generation

Further considerations of the system stability, through the introduction of a boundary condition for the capacity in use versus the total capacity installed are reflected.

The load profile to be met by new investments is the weighted average of the load profile of the capacities that are decommissioned and the load pattern of the evolving demand load curve.

### 5.3.3 Calculation of investment options' attractiveness

Similar to the simulation of power plant units' operation (Section 5.2.3), the model applies a portfolio management approach also in capacity planning rather than seeking a strict least-cost solution. To this end, the attractiveness of different investment options, which is further employed to obtain their market shares, are determined, following the formulation of a nested multinomial logit approach. The attractiveness of a power plant type builds on:

- its techno-economic characteristics including the unit size,
- its availability (in terms of primary resource)
- the prevailing policy conditions,
- the unit's operating conditions,
- the load curve to be satisfied and the hours of operation,
- the realisable and technical potentials, and
- system stability considerations,

while also accounting for non-economic factors. Unit sizes are fully respected, mimicking a mixed integer programming approach.

The cost characteristics of alternative investment options are calculated by load regime on the basis of the annuities of their capital costs, and their fixed and variable operating costs, taking into account fuel prices and policy incentives and costs. A myopic perfect foresight is applied over the construction time period, i.e. characteristics and prices are perfectly known for the time at which the capacity becomes operational.

As described in Section 5.2.1, the unit investment costs explicitly consider the operating mode of a power plant, i.e. the costs that occur depend on the hours of a load regime linked to the increased number of ramp-ups and operation in spinning mode. For investment options with limited hours of availability, the need for 'bundling' various units in order to contribute to the load regime with larger duration is taken into consideration.

The unit investment costs of alternative investment options as regards power plant technologies by load regime are then combined with the market acceptance factor, considerations on related potentials and the system stability indicator, in order to further determine the desired market share of the considered investment options.

- The market acceptance factor reflects deviations from economic optimality, which occur as a result of the availability of domestic resources and existing infrastructures. In addition, a scenario specific element is introduced to capture possible changes in investors' behaviour as a response to the policies assumed.
- The realisable and the technical potentials are taken into account for both renewable energy sources and depletable fuels. Whereas the technical potential represents a theoretical constraint that by default cannot be exceeded, the realisable exploitable potential can be surpassed. If the realisable potential is already exploited at a large extent, the related investment option becomes less attractive due to additional costs that occur. However, this does not imply that because the economically exploitable potential is reached no further investment will materialize for the specific option. In other words, certain policy regimes may lead to an endogenous revision of the economically exploitable potential towards the absolute limit that is expressed by the technical potential.
- The attractiveness of the competing investment options further considers the system stability indicator, which is defined as the ratio between the capacity in operation and the peak load. Through this indicator a signal is sent from the dispatching to the investment decision. In cases of high shares of technologies that contribute mainly to the energy generation while delivering limited contributions to the power, the system stability indicator supports investment options that contribute to a reliable available capacity.

For all three types of agents considered and appropriately accounting for the particularities of each one of them, the model follows the formulation of the nested multinomial logit in order to obtain the attractiveness of different investment options and finally the investment choice.

### *5.3.4 Implementation of investments*

In the implementation of the investment decision, co-generation plants are installed driven primarily so as to satisfy the demand for distributed steam (net of the parts generated in district heating plants). The corresponding electric capacities of the cogeneration plants that are installed to match the steam investment gap are taken into consideration when determining the investment gap for electric capacities.

The newly installed capacities are then determined on the basis of the market shares as described above, yet taking into account their unit plant sizes. This means that investment in new capacities takes place in quanta that are multiples of the minimum plant unit sizes (which differ by technology; moreover, POTEnCIA explicitly introduces up to four unit sizes for each technology). In the absence of explicit unit size representation for power plants in POTEnCIA it is very likely that projected investment capacities are not a multiple (m) of the minimum unit size (u) of a plant. The power generator then undertakes an investment equal to m times u. m is the upper rounded number of the projected capacity divided by u in the case that the residual of that division is larger than a certain threshold (percentage P). In case that threshold is not reached the capacity invested is equal to m-1 times u. The preferences for delaying or advancing investments are influenced by the policy regime assumed, expressed amongst others through the value taken by the threshold P.

Following the investment performed in each specific year and the scrapping of equipment decommissioned in that year, the characteristics of the installed equipment are updated on an annual basis. These explicit vintage characteristics of the installed equipment enable a much more realistic assessment of the energy savings and $CO_2$ emission reduction potentials in the power sector. Since the techno-economic characteristics of the capacities that leave the stock in a given year due to replacement are known, they can be compared to the characteristics of the new power plants replacing them, thereby directly providing the related savings as regards energy and $CO_2$ emission.

## 5.4 Consideration of system stability, storage and grid

POTEnCIA introduces a number of novel concepts going beyond the notion of the 'reserve margin' in order to carefully address the system stability in the power sector. To this end, endogenously derived signals are sent from the dispatching of the power plants to the capacity planning, affecting both the level of investment needs and the attractiveness of competing investment options.

- Boundary conditions for the capacity in use versus the total capacity installed are introduced, which ensure that sufficient capacity is available to meet the load in all circumstances, and have an impact on the level of investment.
- A system stability indicator is computed at the same time, as the ratio between the capacity in operation and the peak load. Through this the bundling of power plant units and the exploitation of capacities that contribute mainly in satisfying the energy but do contribute to the load only to a very limited extent due to e.g. constraints in the availability of their primary resource (wind, PV), are reflected. When this indicator reaches high levels the investment options that contribute to the reliable available capacity become more attractive compared to options that further contribute to the satisfaction of energy and not load.

System stability can be further enhanced by the inclusion of storage options. Besides the option of hydropower, hydrogen production through electrolysis is considered as another option to use excess electricity. Hydrogen production capacities are installed on the basis of economic grounds. The hydrogen produced is fed into the natural gas grid. According to the FP6 co-funded project NaturalHy,[46] an addition of up to 20% hydrogen does not significantly compromise the safety related to transmission, distribution and use of natural gas. Alternatively hydrogen can be stored locally and used on-site (i.e. without the need for constructing a hydrogen pipelines network) in fuel-cells power generation units.

Whereas the above options relate to storage at the system level, in some cases this can also be addressed at the level of individual technologies. For the time being this is implemented in POTEnCIA for Concentrated Solar Power Plants, for which the investor can choose between an option without storage (and thus lower full-load hours) at lower capital costs, and another option with storage.

Grid stability is also addressed in POTEnCIA through the implicit representation of the high, medium and low voltage power grid of each country. If, for example, a significant rise in the power production at the low-voltage level (as a result for example of large investment at the level of independent power producers – IPPs) endangers the grid stability, the necessary grid extension is implicitly captured by the model through an increase (non-linear) in the corresponding grid costs. At the same time additional electricity losses are captured.

Finally, cross-checks can be undertaken to evaluate whether the reliable available capacities match the demand also in extreme situations. To this end, for a given year and a specific scenario, the production and/or the demand profile of an extreme day can be introduced in POTEnCIA, assuming e.g. very high and/or very low wind energy production levels in combination with limited availability of PV and high demand loads.

[46] http://www.naturalhy.net/

## 5.5 Electricity pricing

POTEnCIA uses a combination of marginal and average cost pricing, while ensuring a full recovery of costs. In the calculation of the electricity tariff, the model considers the operational costs, the payback of fixed costs, and the specific load profiles of the demand sectors for each energy use. Moreover, the annuities of the capital of capacities that are not in operation are identified and added to the total generation costs.

In addition, mark-ups are introduced to reflect market power. Policy relevant costs to the system caused by e.g. support schemes introduced for renewable energies or cogeneration plants or through the ETS certificate prices[47] are assumed to be passed on fully to the consumers.[48]

The pricing further takes into account the transmission grid costs through a non-linear cost function. A simplified representation of the electricity network is implemented in POTEnCIA. Once the capacity of the existing national grid is exploited, a further capacity increase will create a need for additional investment in transmission capacities.

A key feature of POTEnCIA is that the implementation of the dispatching regarding both the hourly load profile and the load regimes (see above) results in the calculation of the electricity generation costs on an hourly basis. In other words, POTEnCIA identifies for each hour of the representative day the cost of generating electricity, differentiating between variable costs, the generation costs when considering only the capacities in operation (including the annuities of the capital allocated to different time segments), and the total costs including the capacities not in operation.

The information of the hourly costs of electricity makes it possible to endogenously calculate different pricing regimes for distinct users, taking as a basis their hourly demand load patterns (which are defined at the level of energy uses). Moreover, the hourly variable electricity generation costs provide a clear signal to the different consumers, and allows for implicitly addressing, through reflecting the value of load shifting, Demand Side Management policies through changes in the load pattern of the consumption, by energy use.

[47] By default, auctioning of certificates is assumed in the power sector, and subsequently costs are passed on to the consumers. However, alternative allocation schemes can be introduced (e.g. grandfathering).

[48] In the set-up that decentralised Independent Power Producers are allocated to the demand side, for the power fed into the grid from independent power producers the remuneration paid and potential additional grid costs are taken into consideration in the determination of the overall tariff.

# 6. ENERGY NETWORKS IN POTEnCIA[49]

One additional feature of POTEnCIA concerns the simulation of the interconnections and exchanges of electricity across countries in the European electricity market. For this purpose a simplified network which comprises nodes (one for each country) and links (one per pair of neighbouring countries for which a physical interconnection exists – one or more lines) is modelled with the scope to minimise the cost / maximise the profit for the electricity market at the European level. The optimisation is performed under constraints for line flows (in terms of energy flows) for each link and potential production at the level of each node with given electricity generation costs (as a result of the planning and dispatching model for power generation) for each time segment. The output of the model comprises the exchanges of electricity across European countries per time segment on an annual basis. The potential extension of the power trade approach to other important interconnected markets is also foreseen to be explored.

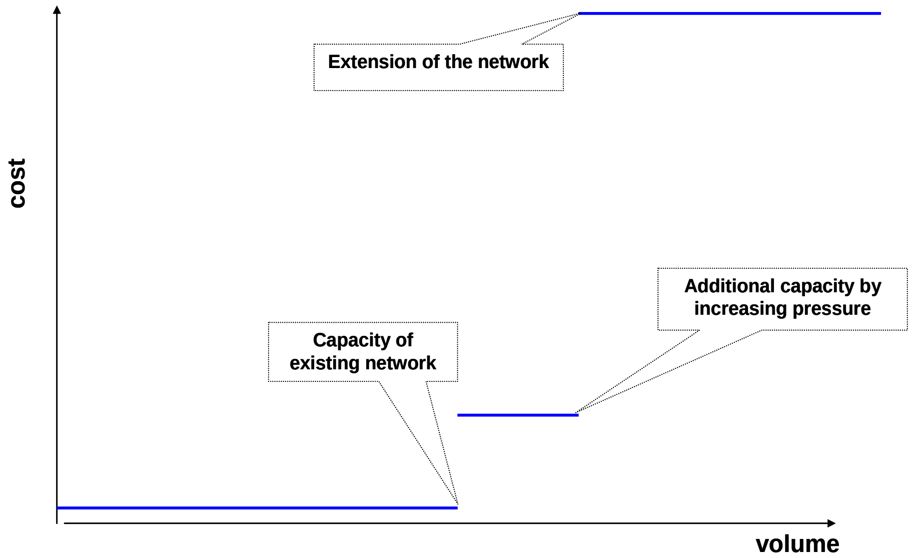


**Figure 12 Natural gas transmission cost curve**

In the same context natural gas pipelines networks are implicitly simulated through the introduction of natural gas supply cost curves that link the price of natural gas to the level of exploitation of existing infrastructure and the need for additional investment in case demand exceeds supply potentials. Hence, when quantity demanded through a network exceeds the one that can be supplied with the existing infrastructure, the consumer is faced with an increased cost in his investment decision (and only there), reflecting the need for an infrastructure extension. In case that his decision remains unchanged, then an investment in infrastructure is assumed to take place. Also an intermediate step is considered, referring to an increase in the volumes transported by the existing infrastructure through an increase in the pressure in the pipe. This is described through a stepwise approximation of a non-linear cost function.

[49] The modelling of the energy networks is still under development. It is envisaged to be operational by September 2016.

# 7. REFINERIES AND OTHER TRANSFORMATION PROCESSES

As regards liquid fuels supply the operation of a simplified refinery module is incorporated in the overall modelling tool. The output of the refineries sector is driven by the demand of the different refined fuels, taking into consideration the limited flexibility in adapting the refining processes.

No representation of processes involving transformation of raw material into different biomass and biofuels types is envisaged in the model at this stage. Exogenously prescribed supply curves for the different biomass types and refined biofuels are used instead.

For hydrogen production the current version of the model considers only the option of electrolysis. The hydrogen produced can be distributed through the existing natural gas infrastructure (i.e. blended with natural gas) or used on-site for power generation.

Other transformation processes (cokeries, blast-furnaces etc.) are represented in the model in a simplified manner.

# 8. PRIMARY FUEL SUPPLY

POTEnCIA will link to the existing POLES model as regards the exploitation of indigenous fossil fuel resources and the development of international fuel prices. As regards renewable energy forms, potentials and costs will be treated as exogenous input to the model coming from various sources (land-use and agricultural models, intermittent renewables potential estimation models etc). No representation of processes involving transformation of raw material into different biomass and biofuels types is envisaged in the model at this stage. Exogenously prescribed supply curves for the different biomass types and refined biofuels are used instead.

## 8.1 Composition of fuels

By default, energy carriers in POTEnCIA are not considered as pure fuels but as an aggregation of the main energy carrier and several less significant energy carriers with comparable characteristics. The composition of the representative fuel is specific for each sector. For example, in some industries coke is considered as a separate fuel, whereas in other sectors this is aggregated to a coal blend. Similarly, in most sectors 'fuel oil' contains a variety of other liquid fuels, whereas those are treated separately in industry.

For all fuel blends, and specific for each sector (Eurostat level), the dynamically evolving emission factor has been determined for the years 2000-2010, using the UNFCCC emission factors as a basis. The outcome of the data calibration process for the years 2000-2010 at high level of disaggregation in line with the decomposition of energy consumption are part of the decomposition results.

## 8.2 Blending of fuels

For a number of fuels, a blending of main fuels with substitutes (that often are of renewable nature) is explicitly calculated based on the competitiveness of the respective fuels, taking into account support policies. Minimum and/or maximum blending levels are introduced – where appropriate - to reflect limits established by existing legislation, and/or by technical considerations.

For example, diesel fuel in POTEnCIA contains a certain share of first generation biodiesel (FAME – Fatty Acid Methyl Ester), whose blending level is determined on economic grounds and can reach up to a certain limit that is prescribed by the fuel standard.[50] Diesel fuel can further be blended without limits with synthetic diesel, which can be produced from biomass (BtL – Biomass to Liquids), coal (CtL – Coal to Liquids) or natural gas (GtL – Gas to Liquids). Gasoline can be blended with bioethanol[51]; the distinction between first and second generation bioethanol is made based on technical constraints and cost elements that are derived from exogenous cost curves. Kerosene

[50] The fuel quality directive and the fuel standard allows for the use of 7% (first generation) biodiesel (B7). It is assumed that the blending remains on this level for passenger cars for technical reasons. However, trucks can use biodiesel with a higher blending reaching 20% (B20).

[51] The present fuel quality directive allows for the use of blends of 10 % bioethanol in gasoline (E10; 6.7% in energy terms). In addition, ETBE (Ethyl Tert-Butyl Ether) can replace MTBE (Methyl Tert-Butyl Ether) in the fuel production which can add up to an additional 4.6% in energy terms. For ligno-cellulosic (or: 2nd generation) bioethanol the same limitations apply as differences lie in the production process and not the final product as such.

used in aviation jet engines can be a blend of fossil-based kerosene and synthetic fuels.[52]

Gas distributed through the natural gas grid is in POTEnCIA considered to be a blend consisting of natural gas (methane), (processed) biogas, and up to 20% hydrogen (which can be blended without any technical problems according to research done by the FP6 co-funded project NaturalHy). For hydrogen production the current version of the model considers only the option of electrolysis. The hydrogen produced can be distributed through the existing natural gas infrastructure (i.e. blended with natural gas) or used on-site for power generation.

[52] Synthetic Paraffinic Kerosene fuels produced with the Fischer-Tropsch process have already achieved certification for commercial use at 50% blend under the International specification ASTM D7566 (American Society for Testing and Materials).

# 9. MODELLING OF SPECIFIC POLICIES

## 9.1 Capturing of alternative policy implementation schemes in POTEnCIA

POTEnCIA can address both explicitly defined policies and those that are implicit, including not yet defined future policies. Explicit policies are directly assessed in POTEnCIA resulting in changes of consumers' investment decisions and in the operation of the energy related equipment. Such types of policies may result in additional costs. Consequently, consumers' investment decisions as well as their behaviour are affected. Such policies include:

- Policies related to energy taxation
- Policies related to support schemes for the replacement of installed inefficient equipment (e.g. subsidies on capital costs of cars)
- Minimum efficiency standards for technology options
- Feed in tariffs etc.

Undefined future policies that link to meeting a certain policy target are addressed through the *dual value* ("shadow price") of the corresponding constraint. The dual values, which can be differentiated across sectors, act as an incentive on the decision-making concerning the investment in new energy equipment and/or the operation of the installed equipment. They do not create a direct policy cost by default. Instead, they reflect – and quantify – the effort required in order to achieve a given target without assuming a certain set of explicitly defined future policies.

As concerns the modelling of measures by means of a constraint (i.e. involving the introduction of an efficiency value as for consumers to react towards the purchasing of more efficient equipment) in an ideal world measures involving a positive effect on NPV would be directly adopted by consumers even in absence of any constraint. However, in real life consumers are not behaving in an economically optimal manner:

- First of all they are faced with budgetary restrictions (investing in a high capital cost option even if delivering a positive NPV effect would mean that their budget directed to other needs will be reduced, and in some cases this may be affordable, in others not).
- In addition - and depending on their profile - consumers lack information and/or not perform a complete economic assessment on the alternative investment options before deciding. In that context one would expect big industrial consumers to make much more rational decisions in comparison to individual households.
- Different consumers also perceive the risk of moving towards novel and rather immature technology options in a different way. Furthermore the issue of non-economic preferences (reflecting consumers' behaviour and habits) lead to a further deviation from the economically optimal decisions.

It is in that framework (and mainly for the three above-mentioned reasons) that even for economically optimal options a constraint (and thus an efficiency value) may need to be introduced as for consumers to react. However, the introduction of the efficiency value does not by definition imply an additional system cost as it only acts by means of making consumers improve their investment decisions vis-à-vis energy efficiency.

Capturing the non-optimal behaviour of some consumers' categories is one of the reasons that justify a hybrid modelling approach, departing from the traditional linear optimisation framework. This hybrid approach is more justified when focus shifts from the supply side to the demand side, on which more cases of myopic, non-optimal choices are observed. Within this scheme, an additional constraint may turn out in lower total system costs, something essentially impossible with a pure optimisation modelling approach, discarded by the reasons hinted.

The introduction of policies generates a response in the decision-making of the representative agent as regards the investment in new equipment and/or the use of the installed equipment. This response is multifaceted and can be captured in POTEnCIA by the introduction of specific mechanisms. To this end, the parameters of the discrete choice market sharing function react to the introduction of policies.

Policies affect the costs of the competing options, and thereby change their attractiveness. Beyond this, however, changing policy regimes also affect the representative agent's behaviour. For example, the presence of a policy framework that strongly favours a certain type of technology, changes not only the related costs, but also affects the perception of the technology (gaining the understanding that a certain type of technology is societally favourable). This is captured through a policy-dependent element of the market acceptance factor.

At the same time, the introduction of a strict policy framework may result in a better understanding of the costs of different option. In consequence, the choice made by the representative agent would become more economically optimal rather than being influenced by non-economic considerations. To this end, POTEnCIA introduces the possibility of a policy driven (endogenously derived) change in the elasticity of substitution of the market sharing function.

## 9.2 Energy efficiency policies

### *9.2.1 Technology-oriented policies*

Technology-oriented policies that set minimum efficiency standards for a certain production, such as the eco-design of energy-using products legislation, are addressed at the level of the technology. Minimum efficiency standards can be explicitly modelled when the technologies targeted correspond to the technologies as defined in POTEnCIA. They directly influence the techno-economic characteristics of the 'worst-performing' option T1; since this will then lead to a change in the definition of the stock, also the techno-economic characteristics of the technologies T2 and T3 are affected. Hence, both the primary and the secondary impact of such legislation can be modelled. For policies that address technologies at a level of detail that goes beyond the one of the technology groups, an ex-ante analysis is necessary.

Technology-oriented policies that do not prescribe minimum technical standards but rather impose the phase-out of a certain technology group (e.g. the phase out of incandescent lamps), can be explicitly represented through a modification of the corresponding market acceptance factor.

### *9.2.2 Policies on non-energy equipment options*

Some policies aim at improving the energy efficiency of an entire system (e.g. lighting system; production process) rather than targeting individual energy-using equipment (a light bulb). In POTEnCIA, these would be described through changes (coming at a cost, though) in the infrastructure efficiency parameter (IEP; Section 3.2.4), which describes the optimality of use of the energy-equipment.

The energy performance of buildings directive aims at a lowering of the specific heating energy consumption through both, an improvement in the thermal envelope and more efficient boilers. POTEnCIA can deal directly with levels set for insulation through the explicit calculation of the space heating energy avoided, taking into account the u-value, the degree days and the shape and size of a representative building cell for each Member States.

### *9.2.3 Policies addressing consumers' behaviour*

A number of policies target consumer's behaviour. For example, labelling will primarily influence consumer's decision making when investing in new lighting equipment. Hence, it is not a technology-oriented policy, but one affecting the behaviour. In the medium term, however, it will also foster technological progress. Such policies will be addressed through the market acceptance/maturity factor. The market acceptance factor is initially exogenously defined over the projection period.

### *9.2.4 Complementary policies*

Complementary policies include those that aim at an accelerated turnover of the stock of the installed equipment in order to rapidly phase out older, energy-intense equipment. This can be directly represented in POTEnCIA due to the explicit vintage characteristics that have been introduced also in the demand side.

### 9.2.5 Summary: modelling of energy efficiency policies

Table 8 summarises the way in which different types of energy efficiency policies can be reflected in POTEnCIA, i.e. which feature will need to be modified in order to reflect a certain type of policy. It is important to note that the tables do not indicate which features of the model are affected by the policies. Since POTEnCIA follows the partial equilibrium paradigm for the overall energy system all features will respond to the introduction of a policy. Note that the direct assessment of a certain policy requires that the level of technology disaggregation in POTEnCIA matches that of the policy. For policies that address technologies at a level of detail that goes beyond the one of the technology groups, an ex-ante analysis is necessary. Policies that can be explicitly modelled in POTEnCIA are indicated with an X, whereas those that are dealt with in an implicit manner with an O. In the case that both approaches can be followed it is indicated with an X/O.

**Table 8 Schematic overview on how different types of energy efficiency policies are reflected in POTEnCIA**

| Type of policy / Reflection in POTENCIA through… | Technology dynamics | Cost factor[1] | Market accep-tance/ maturity factor | Dual value ('energy efficiency value') | Infra-structure efficiency parameter | Equipment vintages |
|---|---|---|---|---|---|---|
| **Technology policy (e.g. standards)** | | | | | | |
| … on energy equipment (e.g. Eco-design) | X[2] | | | | | |
| … phasing out technology groups | | | X/O[3] | | | |
| … on the system rather than the energy equipment[4] | | | | | O | |
| **Price-driven policies** | | X | | | | |
| **Financial support schemes** | | X/O | | | | |
| **Energy efficiency target** | | | | X/O | | |
| **Policies aiming at behavioural changes…** | | | | | | |
| … through labelling | | | O | | | |
| … through awareness & education | | | O | | O | |
| **Policies to accelerate the turnover of stock** | | | | | | X |

1. The cost factor is the annual cost of making a specific choice on a specific level. It reflects the engineering (technical) cost of delivering a specific utility (unit of energy service) to the consumers, taking into account the techno-economic characteristics of a technology option, such as the capital, fixed and variable costs, efficiency factors.

2. Minimum efficiency standards prescribed directly influence the techno-economic characteristics of the 'worst-performing' option T1.
3. Technology-oriented policies that do not prescribe minimum technical standards but rather impose the phase-out of a certain technology group (e.g. the phase out of incandescent lamps) can be explicitly represented through a modification of the corresponding market acceptance factor.
4. This means a technology-oriented legislation that does not address individual technologies but rather affects the entire systems. Intelligent lighting control systems (e.g. motion sensors) in offices would fall under this group.

## 9.3 Renewable energy policy measures

Renewable energy support policies in EU Member States are implemented in a many different manners. There are important differences in the type of support scheme applied, in particular between price-based and quantity-based mechanisms. Support policies further vary in their support levels (and their evolution over time), the technology disaggregation and in other design options.

In the following, we illustrate the approaches applied to represent economic support schemes of various types, quantity-based renewable energy policies and non-economic policies. Other major policies influencing the deployment of renewables are briefly mentioned at the end of this chapter.

### 9.3.1 Financial support schemes

A number of financial support schemes to renewables can be explicitly addressed in POTEnCIA. These include in particular the following ones:

a. **Feed-in tariff (FIT) systems or feed-in tariff premiums** that guarantee a predetermined price per unit of renewable electricity to the corresponding producers. This feed-in system may take form of either a fixed tariff instead of the market price, or a premium paid on top of the market price. Feed-in tariffs or premiums are in general designed in a technology-specific manner.
b. **Investment incentives** aim at covering a certain share of the initial investment of a renewable energy project. The original support is either introduced in relative terms as a percentage of the initial investment covered or in terms of the absolute investment grant per unit of installed electric capacity.
c. **Tax reductions**: an exemption (partial or full) of renewable energy technologies from different taxes.
d. **Low interest loans**: In the case of low interest loans, renewable energy projects have access to capital with lower interest rates than common on the market.

Whereas feed-in tariff systems address the renewable energy generation, investment incentives and low interest loans address the capacity. In addition, feed-in tariff schemes are often very technology-specific with support levels being oriented at the electricity generation costs of the technologies. Support levels are often broken down into the renewable energy source used, the specific conversion technology (e.g. in the case of biogas anaerobic digestion plants or gasification), plant size, local factors such as wind conditions, etc. The described distinguishing features used in the real world to determine the support level are aggregated in order to match the POTEnCIA renewable energy technology categories.

In capacity planning, the different support schemes are addressed by means of subsidies on the average generation costs. Whereas this is straight-forward for policies that address capital costs (such as investment incentives and low interest loans), for feed-in tariffs and/or premiums the corresponding support schemes are calculated taking into account the level of the support and its duration (and evolution), and capacity limits where relevant.

The costs of the support schemes can either be passed on to the electricity user or are considered as general subsidies from outside of the energy sector. The allocation method depends on the types of the schemes and the scenario settings.

### 9.3.2 Quota obligations

A quota obligation is a quantitative-based support policy, in which a renewable energy target set by law has to be fulfilled by suppliers and/or consumers of energy. It is usually combined with tradable green certificates (TGC), with the certificate price being established through the matching of supply and demand. If some of the obliged parties are not able to fulfil the quota, a penalty payment may be determined.

There are two options of meeting a given renewable energy quota in the model:

- A quota can be directly set as a constraint for the energy system. In that case, one may consider 'softening' the constraint somewhat in order not to force the model into extreme solutions (these fuzzy boundaries can be achieved through iterations).
- Equivalently, a quota can be modelled through the dual value of the corresponding constraint (which ideally should be equivalent to the value of the tradable green certificates). Such a dual value is introduced in the decision-making and acts in the same way as an economic support. However, it does not directly form part of the system cost even though it induces additional costs through the deployment of more costly technology options.

For the power generation sector and in its initial applications the quota obligation was generally a technology-uniform support scheme, but recently several types of technology-specific quotas have been introduced in some countries (e.g. in the United Kingdom, Italy). Thus, quotas may be implemented on technology level or certificates may be weighted depending on the respective technology. In the latter case each technology receives a multiple of one support scheme per unit of electricity, generally calculated to take into account the different electricity generation costs.

### 9.3.3 Complementary policies

Price- and quantity based renewable energy policies are usually embedded in a wider favourable policy environment. Complementary policies can take many different forms and are not mutually exclusive. They reach from priority grid access as a more tangible option to policies that influence consumers' perception or the expectations of investors.

- Priority dispatching of electricity generated from renewable energy sources as prescribed by existing legislation is considered in the short term. In the longer term, a continuation of priority dispatching can be included in the scenario assumptions if considered appropriate. In their absence, renewables like any other technology enter on the basis of the operating cost into the dispatching (see also Section 5.1.3).
- Accelerated authorisation procedures for renewables can be translated into shortened construction times. As a result the construction cost for these technology options is reduced. Furthermore, these technologies (mainly wind turbines) become a "fast-track" solution in situations of underinvestment.
- In POTEnCIA, investment decisions are typically driven by the cost factor, understood as the engineering cost, and the market acceptance/maturity factor that reflects distortions which lead to sub-optimal choices. The latter factor is usually determined endogenously, and is linked e.g. to the cost of energy. In principle, however, it may be modified to reflect scenarios of strong technology push and heightened consumer awareness. Hence, expectations of investors on the technical evolution of innovative options would change the maturity factor and therefore influence the capacity planning with regard to these options.
- The investor's perception of risk is expressed in the WACC index (alternatively the subjective financing capability rates on the demand side). Investors' expectations on favourable future economic framework conditions could be represented by a lower WACC. However, in the default setting POTEnCIA does not modify the WACC across scenarios. Instead, the influence of a changing policy framework on the investor's perception of competing technologies are captured through a scenario-specific element in the market acceptance factor; moreover, a more economically rational behaviour in the investment decision making can be introduced through a policy driven (endogenously derived) change in the elasticity of substitution of the market sharing function (see section 9.1).

- Some consumer groups decide to pay a premium for electricity produced from renewable energy sources. This can be approximated in POTEnCIA assuming that it acts as a kind of additional premium for producers.

### *9.3.4 Future (or additional) renewable energy policies*

Existing policies are included in POTEnCIA over the entire time of their agreed duration. Beyond that time horizon, the assumptions depend on the scenario settings.

For the future where no information exist on the type and design of the support policy in individual Member States, as default the model provides the least-cost option of meeting a certain share via its dual value. Another option may be to assume a reduction in the feed-in tariffs or premiums alongside the reduction in capital costs of the various RES technology options. Alternatively, an alignment of different RES-policies in EU Member States may be simulated through a kind of 'contraction and convergence' premium proxies. These proxies could pick up existing differences in the support levels between technologies and Member States in a certain year and gradually converge into one single value (the dual value of the target at the EU level) over a longer time horizon.

POTEnCIA further allows assessing scenarios that differ in the investors' perception regarding future renewable energy policies in power generation. As explained in Section 5.3.1, investments in new power generation capacities are made under uncertainty. This means that investors take a decision on the basis of their expectations about the future evolution of policy incentives and costs, and not on the basis of perfect knowledge. This feature can be used to quantify the impact of the investor's perception regarding the bindingness and the (favourable) conditions created by an assumed future renewable energy framework on the deployment of these technologies.

### 9.3.5 Summary: modelling of renewable energy policies

**Table 9 Schematic overview on how different types of renewable energy support policies are reflected in POTEnCIA**

| Type of policy / Reflection in POTENCIA through… | Cost factor[1] | | | | Market accep-tance/ maturity factor | Techno-logy dynamics | Dispat-ching rules |
|---|---|---|---|---|---|---|---|
| | Total costs | Capital cost (incl. financing) | Dual value ('renewables value') | Weighted Average Cost of Capital (WACC) | | | |
| **Financial support policies** | | | | | | | |
| … on generation output: feed-in tariffs / -premiums | X | | | | | | |
| … investment incentives | | X | | | | | |
| … low interest loans/market risks | | | | O | | | |
| … tax reductions | X | | | | | | |
| **Quota obligations** | | | X/O | | | | |
| **Technology policy** (e.g. min. efficiency biomass boiler) | | | | | | X | |
| **Removal of priority dispatch rules** | | | | | | | O |
| **Removing non-cost barriers** | | | | | O | | |
| **Sustainability criteria for biofuels** | O | | | | | | |
| **Promotion of self-consumption** | | | | | | | X |

1. The cost factor is the annual cost of making a specific choice on a specific level. It reflects the engineering (technical) cost of delivering a specific utility (unit of energy service) to the consumers, taking into account the techno-economic characteristics of a technology option, such as the capital, fixed and variable costs, efficiency factors.

## 9.4 Modelling of the carbon market and other climate policies

### *9.4.1 Emission trading system*

The EU emission trading system (ETS) is a key policy in reaching the EU's greenhouse gas emission mitigation targets. This section describes how it is approximated in POTEnCIA.

In a first place, the very detailed disaggregation of $CO_2$ emissions and energy use into sub-sectors and processes on the demand side allow for an improved match of the application scope of the ETS. In power generation, the explicit distinction of size groups makes it possible to define a group of small (XS) power plants with a capacity that remains below the threshold of plants covered by the ETS. As regards transport, domestic and international aviation as well as bunkers are defined as separate sub-sectors. Eventually, in POTEnCIA the fuel characteristics are defined individually for each sector and related emission factors are associated.

In POTEnCIA two different approaches can be followed in achieving the ETS cap:

1. The first approach starts with defining an exogenous trajectory on the quantities of ETS emissions in the horizon to 2050, which by construction meets the ETS $CO_2$ emissions cap. In this case the contribution of banking or borrowing (within the compliance period) of emission permits (including the use of CDM) is predefined (i.e. incorporated in the assumed trajectory) in a consistent way with assumed banking behaviour. The corresponding ETS prices are calculated endogenously in an iterative process (the dual value of the ETS emissions constraint). In doing so, the endogenous calculation of the carbon value uses an initial estimate of the price elasticity of the emissions to adapt the carbon price in the subsequent steps for every year so as to meet the targeted cumulative emission budget.
2. The second approach starts with an exogenous trajectory on the ETS price. Banking and (within the compliance period) borrowing are used to match the difference between the ETS $CO_2$ emissions cap and the projected $CO_2$ emissions. The result is checked for economic plausibility and compliance with the cumulative cap and if necessary the ETS price trajectory is modified. Furthermore in the case that this approach is combined to exogenous trajectory on the quantities of ETS allowances it is possible to quantify the banking and borrowing as it take place on an annual basis. If, for example, an economic crisis is introduced and the emission targets not revised accordingly, the model would foresee additional banking of $CO_2$ permits.

The allocation schemes introduced (auctioning and grandfathering) can be adapted to the various sub-sectors. From a pure economic modelling viewpoint, there is no difference in the decisions as regards investment and energy use between auctioning and grandfathering; their only difference occurs in the calculation of the cost of providing a service[53].

A key feature of POTEnCIA is that capacity planning in the power sector is implemented under uncertainty concerning the expected evolution of the future policy. To this end, competing investment options are assessed under a wide range of possible values that the policy parameter may assume in the future. The significance of each of the possible solutions is expressed through an asymmetric function around the prevailing policy in place in the corresponding year. In this case, the investment decision takes into account the prevailing policy (expressed either through the ETS prices or the ETS quantity constraint trajectories). Hence, because of the mechanism introduced the carbon value applied in investment decision-making is endogenously derived by the model, and is not

[53] In power generation, the different allocation schemes may create a second-order effect. Under the assumption that the $CO_2$ price was passed on to consumers through the electricity price in the case of auctioning, the demand for electricity may be affected.

by default equivalent to the prevailing policy parameter that is faced by producers when they dispatch the capacities.

In order to assess the impact of different expectations regarding the ambition level and/or the stringency of implementation of future policies on the investment decision making, the range of the policy values considered (i.e. the 'policy space') can be modified. In order to reflect a policy future in which the investor perceives stringent and very binding future emission reduction policies and is therefore proactive in his investment decision, the interval that is introduced for the carbon value does not start from zero and reaches up to very high levels. On the contrary, a policy future in which the representative agent does not believe in the bindingness of future ETS emission caps (or alternatively considers that they are easy to meet) can be reflected through the introduction of a range that includes only carbon values up to modest levels. Moreover, it is possible to exogenously identify different shapes of the distribution function that reflects the likelihood of each policy option.

POTEnCIA also offers the option to implement capacity planning under a traditional deterministic approach. Instead of introducing uncertainty in the decision-making, investments would then be carried out for a predetermined, explicitly identified carbon value. If this deterministic value assumes the same level as the central policy value of the distribution, the differences in the costs of the deterministic solution compared to that of the one under uncertainty could be interpreted as the "searching costs", or the costs caused through the lack of a clear and binding signal.

### 9.4.2 Other policies

Other $CO_2$ emission reduction targets and policies can be introduced through several mechanisms:

- Exogenous carbon values or $CO_2$ emission constraints achieved by endogenous carbon values can be introduced in the non-ETS sectors or for the economy overall in the case of cross-sectoral emission target scenarios; they reflect the dual value of a carbon constraint that can be set at all levels of the nested tree; usually, this constraint is defined as a dynamically evolving pathway over time.
- As average $CO_2$ emission standards for the new car fleet depend on the market shares between different types of cars and, within each type, the shares of the various technologies (T1-T3 that vary in their efficiency and costs) they cannot be modelled deterministically. Meeting the average standard for the new fleet will be controlled in an ex-post analysis. If necessary, the characteristics of the technology-options T1-T3 can be adapted for each technology group so as to meet the target (i.e. by setting a minimum standard for technology T1 – this is done exogenously); additionally, market factors between the various technology groups (diesel vs. gasoline vs. plug-in hybrid vs. electric vs. fuel cell vehicles) can be modified – linked to policy assumptions such as carbon values, efficiency values and/or a policy specific "economic value", exploring different degrees of uptake of, for example, hydrogen or electric vehicles. The fact that in POTEnCIA, the number of new agents is explicitly calculated, adds significantly to the accuracy of the analysis.
- Proposals that address the deployment of an infrastructure for alternative fuels can be directly assessed through the modification in the market acceptance factor of the related vehicle technology.

### 9.4.3 Summary: modelling of $CO_2$ emission reduction policies

**Table 10 Schematic overview on how different types of $CO_2$ emission reduction policies are reflected in POTEnCIA**

| Reflection in POTENCIA through… / Type of policy | Cost factor | Dual value ('carbon value') | Market acceptance/ maturity factor | Technology dynamics | Model specific feature |
|---|---|---|---|---|---|
| **Emission Trading Scheme** | | | | | |
| … ETS $CO_2$ emissions cap[1] | | X/O | | | |
| … exogenous trajectory of the $CO_2$ price[2] | X | | | | |
| … investment uncertainty | | | | | O |
| **Non-ETS sectors** | | | | | |
| … (sectoral) $CO_2$ emissions caps[3] | | X/O | | | |
| **Policies aiming at behavioural changes** | | | O | | |
| **Technology policy** | | | | X | |
| **Average $CO_2$ emission standards new vehicle fleet *(heuristically)*** [4] | | O | | O | |
| **Policies supporting infrastructure** | X/O | | | | |

1. In POTEnCIA two different approaches can be followed in achieving the ETS cap: The first approach starts with defining an exogenous trajectory on the quantities of ETS emissions in the horizon to 2050, which by construction meets the ETS $CO_2$ emissions cap. In this case the contribution of banking or borrowing (within the compliance period) of emission permits (including the use of CDM) is predefined (i.e. incorporated in the assumed trajectory) in a consistent way with assumed banking behaviour. The corresponding ETS prices are calculated endogenously in an iterative process (the dual value of the ETS emissions constraint). In doing so, the endogenous calculation of the carbon value uses an initial estimate of the price elasticity of the emissions to adapt the carbon price in the subsequent steps for every year so as to meet the targeted cumulative emission budget.
2. The second approach starts with an exogenous trajectory on the ETS price. Banking and (within the compliance period) borrowing are used to match the difference between the ETS $CO_2$ emissions cap and the projected $CO_2$ emissions. The result is checked for economic plausibility and compliance with the cumulative cap and if necessary the ETS price trajectory is modified. Furthermore in the case that this approach is combined to exogenous trajectory on the quantities of ETS allowances it is possible to quantify the banking and borrowing as it take place on an annual basis. If, for example, an economic crisis is introduced and the emission targets not revised accordingly, the model would foresee additional banking of CO2 permits.
3. Exogenous carbon values or $CO_2$ emission constraints achieved by endogenous carbon values can be introduced in the non-ETS sectors or for the economy overall in the case of cross-sectoral emission target scenarios; they reflect the dual value of a carbon constraint that can be set at all levels of the nested tree; usually, this constraint is defined as a dynamically evolving pathway over time.

4. As average $CO_2$ emission standards for the new car fleet are manufacturer specific and depend on the market shares between different types of cars and, within each type, the shares of the various technologies they cannot be modelled deterministically. Meeting the average standard for the new fleet is controlled in an ex-post analysis following which, if necessary, the characteristics of the technology-options can be adapted for each technology group so as to meet the target. Alternatively, the achievement of the target can be dealt with in an implicit manner by means of introducing a carbon value (specific to the vehicle fleet in question) which acts on both the market shares between different types of vehicles (allowing for changes in the fuel mix), and, within each type, on the shares of the different technologies (boosting the penetration of more efficient – and consequently less emitting – vehicles in the market).

# ANNEX I Model structure per sector

## Annex I.1 Industrial sectors

### *Iron and Steel*

Integrated Steelworks

Electric Arc

Direct Reduced Iron (DRI) and EAF (iron ore)

Alkaline electrolysis

## *Integrated Steelworks*

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Iron and Steel - Integrated steelworks | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Steel: Sinter/Pellet making | Steel: Sinter/Pellet making | Industry: Solids |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | Steel: Blast/Basic oxygen furnace | Steel: Blast /Basic oxygen furnace | Industry: Solids |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | Steel: Furnaces, Refining and Rolling | Steel: Furnaces, Refining and Rolling - Thermal | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Steel: Furnaces, Refining and Rolling - Electric | Industry: Electric |
| | Steel: Products finishing | Steel: Products finishing - Thermal | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Natural gas |
| | | Steel: Products finishing - Steam | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Steel: Products finishing - Electric | Industry: Electric |

## *Electric Arc*

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Iron and Steel - Electric arc | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Steel: Smelters | Steel: Smelters | Industry: Solids |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | Steel: Electric arc | Steel: Electric arc | Industry: Electric |
| | Steel: Furnaces, Refining and Rolling | Steel: Furnaces, Refining and Rolling - Thermal | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Steel: Furnaces, Refining and Rolling - Electric | Industry: Electric |
| | Steel: Products finishing | Steel: Products finishing - Thermal | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Natural gas |
| | | Steel: Products finishing - Steam | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Steel: Products finishing - Electric | Industry: Electric |

## *Direct Reduced Iron (DRI) and EAF (iron ore)*

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Iron and Steel - Direct Reduced Iron (DRI) and EAF (iron ore) | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Steel: Direct reduction of Iron Ore | Steel: Direct reduction with reducing agent | Industry: Solids |
| | | | Industry: Natural gas |
| | Steel: Electric arc | Steel: Electric arc | Industry: Electric |
| | Steel: Furnaces, Refining and Rolling | Steel: Furnaces, Refining and Rolling - Thermal | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Steel: Furnaces, Refining and Rolling - Electric | Industry: Electric |
| | Steel: Products finishing | Steel: Products finishing - Thermal | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Natural gas |
| | | Steel: Products finishing - Steam | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Steel: Products finishing - Electric | Industry: Electric |

## Alkaline electrolysis

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Iron and Steel - Alkaline electrolysis | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Steel: Alkaline Electrolysis | Steel: Alkaline Electrolysis | Industry: Electric |
| | Steel: Furnaces, Refining and Rolling | Steel: Furnaces, Refining and Rolling - Thermal | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Steel: Furnaces, Refining and Rolling - Electric | Industry: Electric |
| | Steel: Products finishing | Steel: Products finishing - Thermal | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Natural gas |
| | | Steel: Products finishing - Steam | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Steel: Products finishing - Electric | Industry: Electric |

### *Non-ferrous metals*

Alumina production

Aluminium production –Primary

Aluminium production –Secondary

Other non-ferrous metals

## *Alumina production*

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Alumina production | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Alumina: High enthalpy heat processing | Alumina: High enthalpy heat (steam) | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | Alumina: Refining | Alumina: Drying and calcination | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |

## *Aluminium production –Primary*

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Aluminium production -Primary | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Aluminium: Electrolysis (smelting) | Aluminium: Electrolysis | Industry: Electric |
| | Aluminium: Processing (metallurgy e.g. cast house, reheating) | Aluminium: Processing - Thermal | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Aluminium: Processing - Electric | Industry: Electric |
| | Aluminium: Products finishing | Aluminium: Finishing - Thermal | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Natural gas |
| | | Aluminium: Finishing - Steam | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Aluminium: Finishing - Electric | Industry: Electric |

## *Aluminium production –Secondary*

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Aluminium production -Secondary | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Aluminium: Secondary aluminium (incl. pre-treatment, remelting) | Aluminium: Secondary aluminium - Thermal production | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Aluminium: Secondary aluminium - Electric produ | Industry: Electric |
| | Aluminium: Processing (metallurgy e.g. cast house, reheating) | Aluminium: Processing - Thermal | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Aluminium: Processing - Electric | Industry: Electric |
| | Aluminium: Products finishing | Aluminium: Finishing - Thermal | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Natural gas |
| | | Aluminium: Finishing - Steam | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Aluminium: Finishing - Electric | Industry: Electric |

## *Other non-ferrous metals*

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Other non-ferrous metals | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Other metals: Production | Other metals: Production - Thermal | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Other metals: Production - Electric | Industry: Electric |
| | Other metals: Processing (metallurgy e.g. cast house, reheating) | Other metals: Processing - Thermal | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Other metals: Processing - Electric | Industry: Electric |
| | Other metals: Products finishing | Other metals: Finishing - Thermal | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Natural gas |
| | | Other metals: Finishing - Steam | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Other metals: Finishing - Electric | Industry: Electric |

### *Chemical Industry*

Basic chemicals

Other chemicals

Basic pharmaceutical products

## Basic chemicals

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Basic chemicals | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Chemicals: Feedstock | Chemicals: Feedstock (raw material) | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Naphtha |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | Chemicals: Steam processing | Chemicals: Steam processing | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | Chemicals: Furnaces | Chemicals: Furnaces - Thermal | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Chemicals: Furnaces - Electric | Industry: Electric |
| | Chemicals: Process cooling | Chemicals: Process cooling - Thermal | Industry: Natural gas |
| | | Chemicals: Process cooling - Steam | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Chemicals: Process cooling - Electric | Industry: Electric |
| | Chemicals: Generic electric process | Chemicals: Generic electric process | Industry: Electric |

## Other chemicals

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Other chemicals | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Chemicals: High enthalpy heat processing | Chemicals: High enthalpy heat - Steam | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Chemicals: High enthalpy heat - Electric (microwa | Industry: Electric |
| | Chemicals: Furnaces | Chemicals: Furnaces - Thermal | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Chemicals: Furnaces - Electric | Industry: Electric |
| | Chemicals: Process cooling | Chemicals: Process cooling - Thermal | Industry: Natural gas |
| | | Chemicals: Process cooling - Steam | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Chemicals: Process cooling - Electric | Industry: Electric |
| | Chemicals: Generic electric process | Chemicals: Generic electric process | Industry: Electric |

## *Basic pharmaceutical products*

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Basic pharmaceutical products | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Chemicals: High enthalpy heat processing | Chemicals: High enthalpy heat - Steam | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Chemicals: High enthalpy heat - Electric (microwa | Industry: Electric |
| | Chemicals: Furnaces | Chemicals: Furnaces - Thermal | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Chemicals: Furnaces - Electric | Industry: Electric |
| | Chemicals: Process cooling | Chemicals: Process cooling - Thermal | Industry: Natural gas |
| | | Chemicals: Process cooling - Steam | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Chemicals: Process cooling - Electric | Industry: Electric |
| | Chemicals: Generic electric process | Chemicals: Generic electric process | Industry: Electric |

### *Non-metallic mineral Industry*

Cement

Ceramics & other non-metallic minerals

Glass production

## *Cement*

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Cement | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Cement: Preparation of raw materials | Cement: Grinding, milling of raw material | Industry: Electric |
| | Cement: Pre-heating and pre-calcination | Cement: pre-processing - Fuel use | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Biomass |
| | | Cement: pre-processing - Steam | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | Cement: Kilns | Cement: Clinker production | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Biomass |
| | Cement: Finishing processes | Cement: Grinding, packaging | Industry: Electric |

## Ceramics & other non-metallic minerals

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Ceramics & other NMM | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Ceramics: Preparation of raw materials | Ceramics: Mixing of raw material | Industry: Electric |
| | Ceramics: Drying and sintering of raw material | Ceramics: Thermal drying and sintering | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Ceramics: Steam drying and sintering | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Ceramics: Microwave drying and sintering | Industry: Electric |
| | Ceramics: Primary production process | Ceramics: Thermal kiln | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Biomass |
| | | Ceramics: Electric kiln | Industry: Electric |
| | Ceramics: Product finishing | Ceramics: Thermal furnace | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Ceramics: Electric furnace | Industry: Electric |

## Glass production

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Glass production | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Glass: Melting tank | Glass: Thermal melting tank | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Glass: Electric melting tank | Industry: Electric |
| | Glass: Forming | Glass: Forming | Industry: Electric |
| | Glass: Annealing | Glass: Annealing - Thermal | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Glass: Annealing - Electric | Industry: Electric |
| | Glass: Finishing processes | Glass: Finishing processes | Industry: Electric |

### *Paper and pulp Industry*

Pulp production

Paper production

Printing and reproduction of recorded media

## Pulp production

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Pulp production | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Pulp: Preparation | Pulp: Wood preparation, grinding | Industry: Electric |
| | Pulp: Pulping | Pulp: Pulping thermal | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Pulp: Pulping electric | Industry: Electric |
| | Pulp: Cleaning | Pulp: Bleaching | Industry: Electric |

## Paper production

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Paper production | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Paper: Stock preparation | Paper: Stock preparation - Thermal | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Paper: Stock preparation - Mechanical | Industry: Electric |
| | Paper: Paper machine | Paper: Paper machine - Steam use | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Paper: Paper machine - Electricity | Industry: Electric |
| | Paper: Product finishing | Paper: Product finishing - Steam use | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Paper: Product finishing - Electricity | Industry: Electric |

## *Printing and reproduction of recorded media*

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Printing and reproduction of recorded media | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Printing and publishing | Printing and publishing | Industry: Electric |

### *Non-energy intensive industries*

Food, beverages and tobacco

Transport equipment

Machinery equipment

Textiles and Leather

Wood and wood products

Other industrial sectors

## *Food, beverages and tobacco*

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Food, beverages and tobacco (1/2) | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Food: Oven (direct heat) | Food: Direct Heat - Thermal | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Food: Direct Heat - Electric | Industry: Electric |
| | | Food: Direct Heat - Microwave | Industry: Electric |
| | Food: Specific process heat | Food: Process Heat - Thermal | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Food: Process Heat - Electric | Industry: Electric |
| | | Food: Process Heat - Microwave | Industry: Electric |
| | Food: Steam processing | Food: Steam processing | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |

## *Food, beverages and tobacco - continued*

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Food, beverages and tobacco (2/2) | Food: Drying | Food: Thermal drying | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Food: Steam drying | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Food: Electric drying | Industry: Electric |
| | | Food: Freeze drying | Industry: Electric |
| | | Food: Microwave drying | Industry: Electric |
| | Food: Process cooling and refrigeration | Food: Thermal cooling | Industry: Natural gas |
| | | Food: Steam cooling | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Food: Electric cooling | Industry: Electric |
| | Food: Processing machinery | Food: Electric machinery | Industry: Electric |

## *Transport equipment*

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Transport equipment | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Trans. Eq.: Foundries | Trans. Eq.: Thermal foundries | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Trans. Eq.: Electric foundries | Industry: Electric |
| | Trans. Eq.: Connection techniques | Trans. Eq.: Thermal connection | Industry: Natural gas |
| | | Trans. Eq.: Electric connection | Industry: Electric |
| | Trans. Eq.: Heat treatment | Trans. Eq.: Heat treatment - Thermal | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Trans. Eq.: Heat treatment - Electric | Industry: Electric |
| | Trans. Eq.: Steam processing | Trans. Eq.: Steam processing | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | Trans. Eq.: General machinery | Trans. Eq.: Electric machinery | Industry: Electric |
| | Trans. Eq.: Product finishing | Trans. Eq.: Electric product finishing | Industry: Electric |

## Machinery equipment

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Machinery equipment | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Mach. Eq.: Foundries | Mach. Eq.: Thermal foundries | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Mach. Eq.: Electric foundries | Industry: Electric |
| | Mach. Eq.: Connection techniques | Mach. Eq.: Thermal connection | Industry: Natural gas |
| | | Mach. Eq.: Electric connection | Industry: Electric |
| | Mach. Eq.: Heat treatment | Mach. Eq.: Heat treatment - Thermal | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Mach. Eq.: Heat treatment - Electric | Industry: Electric |
| | Mach. Eq.: Steam processing | Mach. Eq.: Steam processing | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | Mach. Eq.: General machinery | Mach. Eq.: Electric machinery | Industry: Electric |
| | Mach. Eq.: Product finishing | Mach. Eq.: Electric product finishing | Industry: Electric |

## Textiles and Leather

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Textiles and Leather | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Textiles: Pretreatment with steam | Textiles: Pretreatment with steam | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | Textiles: Wet processing with steam | Textiles: Wet processing with steam | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | Textiles: General machinery | Textiles: Electric general machinery | Industry: Electric |
| | Textiles: Drying | Textiles: Thermal drying | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Textiles: Steam drying | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Textiles: Electric drying | Industry: Electric |
| | | Textiles: Microwave drying | Industry: Electric |
| | Textiles: Product finishing | Textiles: Electric product finishing | Industry: Electric |

## *Wood and wood products*

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Wood and wood products | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Wood: Specific processes with steam | Wood: Specific processes with steam | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | Wood: Electric mechanical processes | Wood: Electric mechanical processes | Industry: Electric |
| | Wood: Drying | Wood: Thermal drying | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Wood: Steam drying | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Wood: Electric drying | Industry: Electric |
| | | Wood: Microwave drying | Industry: Electric |
| | Wood: Product finishing | Wood: Electric product finishing | Industry: Electric |

## Other industrial sectors

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Other industrial sectors (1/2) | Industry: Lighting | Industry: Lighting | Industry: Lighting - High consumption |
| | | | Industry: Lighting - Fluorescent |
| | | | Industry: Lighting - LEDs |
| | | | Industry: Lighting - Innovative technology |
| | Industry: Low enthalpy heat | Industry: Low enthalpy heat - Thermal | Industry: Low enthalpy heat - Diesel oil |
| | | | Industry: Low enthalpy heat - Natural gas |
| | | | Industry: Low enthalpy heat - Solar |
| | | Industry: Low enthalpy heat - Heat pumps | Industry: Low enthalpy heat - Heat pump |
| | Industry: Air Compressors | Industry: Air Compressors | Industry: Air compressors - type 1 |
| | | | Industry: Air compressors - type 2 |
| | Industry: Motor drives | Industry: Motor drives | Industry: Electric motor - type 1 |
| | | | Industry: Electric motor - type 2 |
| | Industry: Fans and pumps | Industry: Fans and pumps | Industry: Fans and pumps - type 1 |
| | | | Industry: Fans and pumps - type 2 |
| | Other Industrial sectors: Steam processing | Other Industrial sectors: Steam processing | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | Other Industrial sectors: Process heating | Other Industrial sectors: Thermal processing | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Other Industrial sectors: Electric processing | Industry: Electric |
| | Other Industrial sectors: Drying | Other Industries: Thermal drying | Industry: Solids |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Natural gas |
| | | Other Industries: Steam drying | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Other Industries: Electric drying | Industry: Electric |

## *Other industrial sectors - continued*

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Other industrial sectors (2/2) | Other Industrial sectors: Process Cooling | Other Industries: Thermal cooling | Industry: Natural gas |
| | | Other Industries: Steam cooling | Industry: Solids |
| | | | Industry: RFG |
| | | | Industry: LPG |
| | | | Industry: Diesel oil |
| | | | Industry: Residual fuel oil |
| | | | Industry: Other liquids |
| | | | Industry: Natural gas |
| | | | Industry: Derived gasses |
| | | | Industry: Biomass |
| | | | Industry: Steam distributed |
| | | Other Industries: Electric cooling | Industry: Electric |
| | Other Industrial sectors: Diesel motors | Other Industrial sectors: Diesel motors | Industry: Diesel oil |
| | Other Industrial sectors: Electric machinery | Other Industrial sectors: Electric machinery | Industry: Electric |

## Annex I.2 Residential sector

Thermal uses

Specific electricity uses

## *Thermal uses*

| Subsector | Process | Combined end-use | Stand-alone end-use | Technology option |
|---|---|---|---|---|
| Residential: Solid fuels heating household | Space heating, water heating (solid fuels household) | Solid fuels boiler / SHD wh | Space heating | Solid fuels boiler |
| | | | Water heating | Space heating device (solid fuels boiler) |
| | | Solid fuels boiler / LPG wh | Space heating | Solid fuels boiler |
| | | | Water heating | LPG water heater |
| | | Solid fuels boiler / LPG+solar wh | Space heating | Solid fuels boiler |
| | | | Water heating | Solar-LPG water heater |
| | | Solid fuels boiler / electric wh | Space heating | Solid fuels boiler |
| | | | Water heating | Electric water heater |
| | | Solid fuels boiler / solar-electric wh | Space heating | Solid fuels boiler |
| | | | Water heating | Solar-Electric water heater |
| | Space cooling | Space cooling | | Air conditioning |
| | Cooking | Cooking | | Cooking Solids |
| | | | | Cooking LPG |
| | | | | Cooking Electric |
| Residential: LPG heating household | Space heating, water heating (LPG household) | LPG boiler / SHD wh | Space heating | LPG boiler |
| | | | Water heating | Space heating device (LPG) |
| | | LPG boiler / SHD+solar wh | Space heating | LPG boiler |
| | | | Water heating | Space heating device (LPG) + Solar |
| | | LPG boiler / electric wh | Space heating | LPG boiler |
| | | | Water heating | Electric water heater |
| | | LPG boiler / solar-electric wh | Space heating | LPG boiler |
| | | | Water heating | Solar-Electric water heater |
| | | LPG micro-CHP / micro-CHP+solar wh | Space heating | Micro - CHP LPG |
| | | | Water heating | Micro-CHP device (LPG) |
| | Space cooling | Space cooling | | Air conditioning |
| | Cooking | Cooking | | Cooking LPG |
| | | | | Cooking Electric |
| Residential: Diesel oil heating household | Space heating, water heating (oil household) | Oil boiler / SHD wh | Space heating | Oil boiler |
| | | | Water heating | Space heating device (oil) |
| | | Oil boiler / SHD+solar wh | Space heating | Oil boiler |
| | | | Water heating | Space heating device (oil) + Solar |
| | | Oil boiler / electric wh | Space heating | Oil boiler |
| | | | Water heating | Electric water heater |
| | | Oil boiler / solar-electric wh | Space heating | Oil boiler |
| | | | Water heating | Solar-Electric water heater |
| | | Oil micro-CHP / micro-CHP+solar wh | Space heating | Micro - CHP oil |
| | | | Water heating | Micro-CHP device (oil) |
| | Space cooling | Space cooling | | Air conditioning |
| | Cooking | Cooking | | Cooking LPG |
| | | | | Cooking Electric |
| Residential: Natural gas heating household | Space heating, water heating (natural gas household) | Natural gas boiler / SHD wh | Space heating | Natural gas boiler |
| | | | Water heating | Space heating device (natural gas) |
| | | Natural gas boiler / SHD+solar wh | Space heating | Natural gas boiler |
| | | | Water heating | Space heating device (natural gas) + Solar |
| | | Natural gas boiler / electric wh | Space heating | Natural gas boiler |
| | | | Water heating | Electric water heater |
| | | Natural gas boiler / solar-electric wh | Space heating | Natural gas boiler |
| | | | Water heating | Solar-Electric water heater |
| | | Natural gas micro-CHP / micro-CHP+solar wh | Space heating | Micro - CHP natural gas |
| | | | Water heating | Micro-CHP device (natural gas) |
| | Space cooling | Space cooling | | Air conditioning |
| | Cooking | Cooking | | Cooking Natural gas |
| | | | | Cooking Electric |

## *Thermal uses - continued*

| Subsector | Process | Combined end-use | Stand-alone end-use | Technology option |
|---|---|---|---|---|
| Residential: Biomass heating household | Space heating, water heating (biomass household) | Biomass boiler / SHD wh | Space heating | Biomass boiler |
| | | | Water heating | Space heating device (biomass boiler) |
| | | Biomass boiler / SHD+solar wh | Space heating | Biomass boiler |
| | | | Water heating | Space heating device (biomass boiler) + Solar |
| | | Biomass boiler / LPG wh | Space heating | Biomass boiler |
| | | | Water heating | LPG water heater |
| | | Biomass boiler / LPG+solar wh | Space heating | Biomass boiler |
| | | | Water heating | Solar-LPG water heater |
| | | Biomass boiler / electric wh | Space heating | Biomass boiler |
| | | | Water heating | Electric water heater |
| | | Biomass boiler / solar-electric wh | Space heating | Biomass boiler |
| | | | Water heating | Solar-Electric water heater |
| | | Biomass micro-CHP / micro-CHP+solar wh | Space heating | Micro - CHP biomass |
| | | | Water heating | Micro-CHP device (biomass) |
| | Space cooling | Space cooling | | Air conditioning |
| | Cooking | Cooking | | Cooking Biomass |
| | | | | Cooking LPG |
| | | | | Cooking Electric |
| Residential: Geothermal heating household | Space heating, water heating (geothermal household) | Geothermal heating / SHD wh | Space heating | Geothermal heat exchanger |
| | | | Water heating | Geothermal water heater |
| | | Geothermal heating / SHD+solar wh | Space heating | Geothermal heat exchanger |
| | | | Water heating | Geothermal water heater + Solar |
| | | Geothermal heating / electric wh | Space heating | Geothermal heat exchanger |
| | | | Water heating | Electric water heater |
| | | Geothermal heating / solar-electric wh | Space heating | Geothermal heat exchanger |
| | | | Water heating | Solar-Electric water heater |
| | Space cooling | Space cooling | | Air conditioning |
| | Cooking | Cooking | | Cooking LPG |
| | | | | Cooking Electric |
| Residential: District heating household | Space heating, water heating (district heating household) | District heating / SHD wh | Space heating | District heating |
| | | | Water heating | District heating water heater |
| | | District heating / SHD+solar wh | Space heating | District heating |
| | | | Water heating | District heating water heater + Solar |
| | | District heating / electric wh | Space heating | District heating |
| | | | Water heating | Electric water heater |
| | | District heating / solar-electric wh | Space heating | District heating |
| | | | Water heating | Solar-Electric water heater |
| | Space cooling | Space cooling | | Air conditioning |
| | Cooking | Cooking | | Cooking LPG |
| | | | | Cooking Electric |
| Residential: Electric heat pump heating hou. | Space heating, water heating (electric heat pump household) | Electric heat pump / LPG wh | Space heating | Electric heat pump |
| | | | Water heating | LPG water heater |
| | | Electric heat pump / LPG+solar wh | Space heating | Electric heat pump |
| | | | Water heating | Solar-LPG water heater |
| | | Electric heat pump / electric wh | Space heating | Electric heat pump |
| | | | Water heating | Electric water heater |
| | | Electric heat pump / solar-electric wh | Space heating | Electric heat pump |
| | | | Water heating | Solar-Electric water heater |
| | Space cooling | Space cooling | | Electric heat pump cooling |
| | Cooking | Cooking | | Cooking LPG |
| | | | | Cooking Electric |

## *Thermal uses - continued*

| Subsector | Process | Combined end-use | Stand-alone end-use | Technology option |
|---|---|---|---|---|
| Residential: Electric heating households | Space heating, water heating (electric household) | Electric heaters / LPG wh | Space heating | Electric heaters |
| | | | Water heating | LPG water heater |
| | | Electric heaters / LPG+solar wh | Space heating | Electric heaters |
| | | | Water heating | Solar-LPG water heater |
| | | Electric heaters / electric wh | Space heating | Electric heaters |
| | | | Water heating | Electric water heater |
| | | Electric heaters / solar-electric wh | Space heating | Electric heaters |
| | | | Water heating | Solar-Electric water heater |
| | Space cooling | Space cooling | | Air conditioning |
| | Cooking | Cooking | | Cooking LPG |
| | | | | Cooking Electric |

## *Specific electricity uses*

| | | | |
|---|---|---|---|
| Residential: Specific electricity uses (standalone sectors) | Household Lighting | Household Lighting | Lighting - High consumption |
| | | | Lighting - Fluorescent |
| | | | Lighting - LEDs |
| | | | Lighting - Innovative |
| | Refrigerators and freezers | Refrigerators and freezers | Refr. & freezers |
| | Washing machine | Washing machine | Washing Machine |
| | Clothes dryer | Clothes dryer | Clothes dryer |
| | Dishwasher | Dishwasher | Dishwasher |
| | TV and multimedia | TV and multimedia | TV & MM |
| | ICT equipment | ICT equipment | ICT |
| | Other appliances | Other appliances | Other appliances |

## Annex I.3 Services sector

Thermal uses

- Space heating
- Space cooling
- Hot water services
- Catering

Specific electricity uses

## *Thermal uses*

### Space heating

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Services: Heating | Space heating | Space heating | Conventional boiler-Solids |
| | | | Conventional boiler-LPG |
| | | | Micro-CHP-LPG |
| | | | Conventional boiler-Diesel oil |
| | | | Micro-CHP-Diesel oil |
| | | | Conventional boiler-Natural gas |
| | | | Micro-CHP-Natural gas |
| | | | Heat pump-Natural gas |
| | | | Conventional boiler-Biomass |
| | | | Micro-CHP-Biomass |
| | | | Direct geothermal |
| | | | District heating |
| | | | Space heating - Electric |
| | | | Heat pump-Electric |

### Space cooling

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Services: Cooling | Space cooling | Space cooling | Cooling Air conditioning |
| | | | Cooling Heat pump-Natural gas |
| | | | Cooling Heat pump-Electric |

### Hot water services

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Services: Hot water services | Hot water services | Hot Water services | Water heater boiler-Solids |
| | | | Water heater boiler-LPG |
| | | | Water heater boiler-Diesel oil |
| | | | Water heater boiler-Natural gas |
| | | | Water heater boiler-Biomass |
| | | | Water heater via District heating |
| | | | Water heater Electric |
| | | | Water heater boiler-Solids + Solar |
| | | | Water heater boiler-LPG + Solar |
| | | | Water heater boiler-Diesel oil + Solar |
| | | | Water heater boiler-Natural gas + Solar |
| | | | Water heater boiler-Biomass + Solar |
| | | | Water heater via District heating + Solar |
| | | | Water heater Electric + Solar |

### Catering

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Services: Catering | Catering | Catering | Catering - LPG |
| | | | Catering - Natural gas |
| | | | Catering - Biomass |
| | | | Catering - Electric |

## *Specific electricity uses*

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Services: Specific electricity uses (standalone sectors) | Ventilation and others | Ventilation and others | Ventilation - Electric |
| | Street lighting | Street lighting | Street Lighting - High consumption |
| | | | Street Lighting - Advanced high intens discharge |
| | | | Street Lighting - LEDs |
| | | | Street Lighting - Innovative |
| | Building lighting | Building lighting | Building Lighting - High consumption |
| | | | Building Lighting - Fluorescent |
| | | | Building Lighting - LEDs |
| | | | Building Lighting - Innovative |
| | Commercial Refrigeration | Commercial Refrigeration | Refrigeration equipment |
| | Miscellaneous building technologies | Miscellaneous building technologies | Building appliances |
| | ICT and multimedia | ICT and multimedia | ICT and multimedia |

# Annex I.4 Agriculture

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Agriculture | Lighting | Lighting | Lighting - High consumption |
| | | | Lighting - Fluorescent |
| | | | Lighting - LEDs |
| | | | Lighting - Innovative technology |
| | Low enthalpy heat | Low enthalpy heat - Thermal | Low enthalpy heat - Diesel oil |
| | | | Low enthalpy heat - Natural gas |
| | | | Low enthalpy heat - Geothermal |
| | | | Low enthalpy heat - Distributed heat |
| | | | Low enthalpy heat - Solar |
| | | Low enthalpy heat - Heat pumps | Low enthalpy heat - Heat pump |
| | Ventilation | Ventilation | Ventilation |
| | Motor drives | Motor drives | Electric motor - type 1 |
| | | | Electric motor - type 2 |
| | Specific heat uses | Specific heat uses | Solids |
| | | | LPG |
| | | | Diesel oil |
| | | | Fuel oil |
| | | | Natural gas |
| | | | Biomass |
| | | | Geothermal |
| | Farming machine drives | Farming machine drives | Diesel oil |
| | Pumping devices (incl. irrigation systems) | Pumping devices diesel | Pumping Diesel |
| | | Pumping devices electric | Pumping Electric |
| | Specific electricity uses | Specific electricity uses | Specific electricity uses |

## Annex I.5 Transport sectors and Bunkers

### *Road transport*

Road transport - Powered 2-wheelers

Road transport - Private cars

Road transport - Buses and coaches

Road transport - Light commercial vehicles

Road transport - Heavy duty vehicles (Trucks and Lorries)

## Road transport - Powered 2-wheelers

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Road tr. - Passenger - Powered 2-wheelers | Road tr. - Passenger - Powered 2-wheelers | Road ptr. - p2w - Internal combustion engine (micro & mild hybrid options included) | Road p2w - Spark ignition - Gasoline |
| | | | Road p2w - Compression ignition - Diesel |
| | | | Road p2w - Compression ignition - Gasoline (HCCI) |
| | | Road ptr. - p2w - Plug-in Hybrid ICE | Road p2w - Spark ignition - Gasoline |
| | | Road ptr. - p2w - Electric Battery with/without range extender | Road p2w - Pure Electric |
| | | | Road p2w - Electric with range extender - Gasoline |
| | | | Road p2w - Electric with range extender - Diesel |
| | | Road ptr. - p2w - Electric - Fuel cell | Road p2w - Fuel cell - Hydrogen |

## Road transport - Private cars

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Road tr. - Passenger - Private cars | Road tr. - Passenger - Private cars | Road ptr. - car - Internal combustion engine (micro & mild hybrid options included) | Road car - Spark ignition - LPG |
| | | | Road car - Spark ignition - Gasoline |
| | | | Road car - Spark ignition - Natural gas |
| | | | Road car - Spark ignition - Ethanol (FFV) |
| | | | Road car - Compression ignition - Diesel |
| | | | Road car - Compression ignition - Gasoline (HCCI) |
| | | | Road car - Low-T combustion |
| | | Road ptr. - car - Full Hybrid ICE | Road car - Spark ignition - LPG |
| | | | Road car - Spark ignition - Gasoline |
| | | | Road car - Spark ignition - Natural gas |
| | | | Road car - Spark ignition - Ethanol (FFV) |
| | | | Road car - Compression ignition - Diesel |
| | | | Road car - Compression ignition - Gasoline (HCCI) |
| | | | Road car - Low-T combustion |
| | | Road ptr. - car - Plug-in Hybrid ICE | Road car - Spark ignition - LPG |
| | | | Road car - Spark ignition - Gasoline |
| | | | Road car - Spark ignition - Natural gas |
| | | | Road car - Spark ignition - Ethanol (FFV) |
| | | | Road car - Compression ignition - Diesel |
| | | | Road car - Compression ignition - Gasoline (HCCI) |
| | | | Road car - Low-T combustion |
| | | Road ptr. - car - Electric Battery with/without range extender | Road car - Pure Electric |
| | | | Road car - Electric with range extender - Gasoline |
| | | | Road car - Electric with range extender - Diesel |
| | | | Road car - Electric with range extender - Natural gas |
| | | Road ptr. - car - Electric - Fuel cell | Road car - Fuel cell - Hydrogen |
| | | | Road car - Fuel cell - Methanol |

## Road transport - Buses and coaches

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Road tr. - Passenger - Buses and coaches | Road tr. - Passenger - Buses and coaches | Road ptr. - bus - Internal combustion engine (micro & mild hybrid options included) | Road bus - Spark ignition - LPG |
| | | | Road bus - Spark ignition - Gasoline |
| | | | Road bus - Spark ignition - Natural gas |
| | | | Road bus - Compression ignition - Diesel |
| | | | Road bus - Compression ignition - Gasoline (HCCI) |
| | | | Road bus - Compression ignition - Ethanol |
| | | Road ptr. - bus - Full Hybrid ICE | Road bus - Spark ignition - LPG |
| | | | Road bus - Spark ignition - Gasoline |
| | | | Road bus - Spark ignition - Natural gas |
| | | | Road bus - Compression ignition - Diesel |
| | | | Road bus - Compression ignition - Gasoline (HCCI) |
| | | | Road bus - Compression ignition - Ethanol |
| | | Road ptr. - bus - Plug-in Hybrid ICE | Road bus - Spark ignition - LPG |
| | | | Road bus - Spark ignition - Gasoline |
| | | | Road bus - Spark ignition - Natural gas |
| | | | Road bus - Compression ignition - Diesel |
| | | | Road bus - Compression ignition - Gasoline (HCCI) |
| | | | Road bus - Compression ignition - Ethanol |
| | | Road ptr. - bus - Electric Battery with/without range extender | Road bus - Pure Electric |
| | | | Road bus - Electric with range extender - Gasoline |
| | | | Road bus - Electric with range extender - Diesel |
| | | | Road bus - Electric with range extender - Natural gas |
| | | Road ptr. - bus - Electric - Fuel cell | Road bus - Fuel cell - Hydrogen |
| | | | Road bus - Fuel cell - Methanol |

## Road transport - Light commercial vehicles

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Road tr. - Freight - Light commercial vehicles | Road tr. - Freight - Light commercial vehicles | Road ftr. - lcv - Internal combustion engine (micro & mild hybrid options included) | Road lcv - Spark ignition - LPG |
| | | | Road lcv - Spark ignition - Gasoline |
| | | | Road lcv - Spark ignition - Natural gas |
| | | | Road lcv - Spark ignition - Ethanol (FFV) |
| | | | Road lcv - Compression ignition - Diesel |
| | | | Road lcv - Compression ignition - Gasoline (HCCI) |
| | | | Road lcv - Low-T combustion |
| | | Road ftr. - lcv - Full Hybrid ICE | Road lcv - Spark ignition - LPG |
| | | | Road lcv - Spark ignition - Gasoline |
| | | | Road lcv - Spark ignition - Natural gas |
| | | | Road lcv - Spark ignition - Ethanol (FFV) |
| | | | Road lcv - Compression ignition - Diesel |
| | | | Road lcv - Compression ignition - Gasoline (HCCI) |
| | | | Road lcv - Low-T combustion |
| | | Road ftr. - lcv - Plug-in Hybrid ICE | Road lcv - Spark ignition - LPG |
| | | | Road lcv - Spark ignition - Gasoline |
| | | | Road lcv - Spark ignition - Natural gas |
| | | | Road lcv - Spark ignition - Ethanol (FFV) |
| | | | Road lcv - Compression ignition - Diesel |
| | | | Road lcv - Compression ignition - Gasoline (HCCI) |
| | | | Road lcv - Low-T combustion |
| | | Road ftr. - lcv - Electric Battery with/without range extender | Road lcv - Pure Electric |
| | | | Road lcv - Electric with range extender - Gasoline |
| | | | Road lcv - Electric with range extender - Diesel |
| | | | Road lcv - Electric with range extender - Natural gas |
| | | Road ftr. - lcv - Electric - Fuel cell | Road lcv - Fuel cell - Hydrogen |
| | | | Road lcv - Fuel cell - Methanol |

## Road transport - Heavy duty vehicles (Trucks and Lorries)

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Road tr. - Freight - Heavy duty vehicles (Trucks and Lorries) | Road tr. - Freight - Heavy duty vehicles (Trucks and Lorries) | Road ftr. - hdv - Internal combustion engine (micro & mild hybrid options included) | Road hdv - Compression ignition - Diesel |
| | | | Road hdv - Compression ignition - Gasoline (HCCI) |
| | | | Road hdv - Compression ignition - Natural gas |
| | | | Road hdv - Low-T combustion |
| | | Road ftr. - hdv - Full Hybrid ICE | Road hdv - Compression ignition - Diesel |
| | | | Road hdv - Compression ignition - Gasoline (HCCI) |
| | | | Road hdv - Compression ignition - Natural gas |
| | | | Road hdv - Low-T combustion |
| | | Road ftr. - hdv - Electric Battery with/without range extender | Road hdv - Pure Electric |
| | | | Road hdv - Electric with range extender - Gasoline |
| | | | Road hdv - Electric with range extender - Diesel |
| | | | Road hdv - Electric with range extender - Natural gas |
| | | Road ftr. - hdv - Electric - Fuel cell | Road hdv - Fuel cell - Hydrogen |
| | | | Road hdv - Fuel cell - Methanol |

## Rail transport

### Rail transport - Conventional passenger trains

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Rail - CPT. | Rail tr. - Conventional passenger trains | Conventional rail compression ignition | Rail p - Diesel |
| | | Conventional rail electric | Rail p - Electric |

### Rail transport - High speed passenger trains

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Rail - HSPT | Rail tr. - High speed passenger train | High speed electric | Rail p - High speed - Electric |

### Rail transport - Metro and tram, urban light rail

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Rail - Metro | Rail tr. - Metro and tram, urban light rail | Urban electric | Rail p - Urban - Electric |

### Rail transport - Conventional freight trains

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Rail - CFT | Rail tr. - Conventional freight trains | Conventional rail compression ignition | Rail f - Diesel |
| | | Conventional rail electric | Rail f - Electric |

## Aviation

### Aviation - Domestic passenger transport

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Aviation - Passenger Domestic | Aviation - Passenger Domestic | Conventional engine - kerosene | Aviation pd - Conventional engine - Kerosene |
| | | Open rotor - kerosene | Aviation pd - Open rotor - Kerosene |
| | | Battery electric aircraft (plus range extender) | Aviation pd - Battery electric aircraft (plus range extender) |
| | | Fuel cell electric aircraft | Aviation pd - Fuel cell electric aircraft |

### Aviation - International Intra-EU passenger transport

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Aviation - Passenger Intra-EU | Aviation - Passenger International - Intra-EU | Conventional engine - kerosene | Aviation pi - Conventional engine - Kerosene |
| | | Open rotor - kerosene | Aviation pi - Open rotor - Kerosene |
| | | Battery electric aircraft (plus range extender) | Aviation pi - Battery electric aircraft (plus range extender) |
| | | Fuel cell electric aircraft | Aviation pi - Fuel cell electric aircraft |

### Aviation - International Extra-EU passenger transport

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Aviation - Passenger Extra-EU | Aviation - Passenger International - Extra-EU | Conventional engine - kerosene | Aviation pe - Conventional engine - Kerosene |
| | | Open rotor - kerosene | Aviation pe - Open rotor - Kerosene |
| | | Battery electric aircraft (plus range extender) | Aviation pe - Battery electric aircraft (plus range extender) |
| | | Fuel cell electric aircraft | Aviation pe - Fuel cell electric aircraft |

### Aviation - International Intra-EU and domestic freight transport

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Aviation - Freight Intra-EU | Aviation - Freight International - Intra-EU | Conventional engine - kerosene | Aviation fi - Conventional engine - Kerosene |
| | | Open rotor - kerosene | Aviation fi - Open rotor - Kerosene |
| | | Battery electric aircraft (plus range extender) | Aviation fi - Battery electric aircraft (plus range extender) |
| | | Fuel cell electric aircraft | Aviation fi - Fuel cell electric aircraft |

### Aviation - International Extra-EU freight transport

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Aviation - Freight Extra-EU | Aviation - Freight International - Extra-EU | Conventional engine - kerosene | Aviation fe - Conventional engine - Kerosene |
| | | Open rotor - kerosene | Aviation fe - Open rotor - Kerosene |
| | | Battery electric aircraft (plus range extender) | Aviation fe - Battery electric aircraft (plus range extender) |
| | | Fuel cell electric aircraft | Aviation fe - Fuel cell electric aircraft |

## Coastal shipping and Inland waterways

### Domestic coastal shipping

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Domestic coastal shipping | Domestic coastal shipping | Domestic coastal shipping - Conventional vessel - Compression ignition | Shipping dc - Compression ignition - Conventional |
| | | | Shipping dc - Compression ignition - Diesel oil |
| | | | Shipping dc - Compression ignition - Natural gas |
| | | Domestic coastal shipping - Electric vessel - Fuel cell | Shipping dc - Fuel cell electric vessel - Natural gas |
| | | | Shipping dc - Fuel cell electric vessel - Hydrogen |
| | | | Shipping dc - Fuel cell electric vessel - Direct methanol |

### Inland waterways

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Inland waterways | Inland waterways | Inland waterways - Conventional vessel - Compression ignition | Shipping iw - Compression ignition - Conventional |
| | | | Shipping iw - Compression ignition - Diesel oil |
| | | | Shipping iw - Compression ignition - Natural gas |
| | | Inland waterways - Electric vessel - Fuel cell | Shipping iw - Fuel cell electric vessel - Natural gas |
| | | | Shipping iw - Fuel cell electric vessel - Hydrogen |
| | | | Shipping iw - Fuel cell electric vessel - Direct methanol |

## Bunkers

### Bunkers - International Intra-EU transport

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Bunkers - Intra-EU | Bunkers - Intra-EU | Bunkers - Intra-EU - Conventional vessel - Compression ignition | Shipping bi - Compression ignition - Conventional |
| | | | Shipping bi - Compression ignition - Diesel oil |
| | | | Shipping bi - Compression ignition - Natural gas |
| | | Bunkers - Intra-EU - Electric vessel - Fuel cell | Shipping bi - Fuel cell electric vessel - Natural gas |
| | | | Shipping bi - Fuel cell electric vessel - Hydrogen |
| | | | Shipping bi - Fuel cell electric vessel - Direct methanol |

### Bunkers - International Extra-EU transport

| Subsector | Process | Combined end-use / Stand-alone end-use | Technology option |
|---|---|---|---|
| Bunkers - Extra-EU | Bunkers - Extra-EU | Bunkers - Extra-EU - Conventional vessel - Compression ignition | Shipping be - Compression ignition - Conventional |
| | | | Shipping be - Compression ignition - Diesel oil |
| | | | Shipping be - Compression ignition - Natural gas |
| | | Bunkers - Extra-EU - Electric vessel - Fuel cell | Shipping be - Fuel cell electric vessel - Natural gas |
| | | | Shipping be - Fuel cell electric vessel - Hydrogen |
| | | | Shipping be - Fuel cell electric vessel - Direct methanol |

# ANNEX II  Correspondence to NACE codes

| Model Description | NACE code | NACE Description |
|---|---|---|
| Gross domestic product | B1GM | Gross domestic product at market prices |
| Household consumption expenditure | P31_S14_S15 | Household and NPISH final consumption expenditure |
| Gross value added | B1G | Gross value added (at basic prices) |
| Agriculture, forestry and fishing | A | Agriculture, forestry and fishing |
| Mining and quarrying | B | Mining and quarrying |
| Services | C33, E, G to U | |
| Heat-use intensive services | H,I,O,P,Q,R | |
| | H | Transportation and storage |
| | I | Accommodation and food service activities |
| | O | Public administration and defence; compulsory social security |
| | P | Education |
| | Q | Human health and social work activities |
| | R | Arts, entertainment and recreation |
| Offices | J,K,L,M,N,S,T,U | |
| | J | Information and communication |
| | K | Financial and insurance activities |
| | L | Real estate activities |
| | M | Professional, scientific and technical activities |
| | N | Administrative and support service activities |
| | S | Other service activities |
| | T | Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use |
| | U | Activities of extraterritorial organisations and bodies |
| Trade | C33,E,G | |
| | C33 | Repair and installation of machinery and equipment |
| | E | Water supply; sewerage, waste management and remediation activities |
| | G | Wholesale and retail trade; repair of motor vehicles and motorcycles |
| Energy sector | C19, D | |
| | C19 | Manufacture of coke and refined petroleum products |
| | D | Electricity, gas, steam and air conditioning supply |
| Construction | F | Construction |

| Model Description | NACE code | NACE Description |
| --- | --- | --- |
| Manufacturing | C excluding C33 | |
| Basic metals | C24 | |
| | C24 | Manufacture of basic metals |
| Iron and steel | | |
| | C241 | Manufacture of basic iron and steel and of ferro-alloys |
| | C242 | Manufacture of tubes, pipes, hollow profiles and related fittings, of steel |
| | C243 | Manufacture of other products of first processing of steel |
| | C2451 | Casting of iron |
| | C2452 | Casting of steel |
| Non-ferrous metals | | |
| Alumina production | | |
| Aluminium production | | |
| Other non-ferrous metals | | |
| | C2442 | Aluminium production |
| | C2453 | Casting of light metals |
| | C2441 | Precious metals production |
| | C2443 | Lead, zinc and tin production |
| | C2444 | Copper production |
| | C2445 | Other non-ferrous metal production |
| | C2446 | Processing of nuclear fuel |
| | C2454 | Casting of other non-ferrous metals |
| Chemicals Industry | C20, C21 | |
| Chemicals and chemical products | C20 | |
| | C20 | Manufacture of chemicals and chemical products |
| Basic chemicals | | |
| | C2013 | Manufacture of other inorganic basic chemicals |
| | C2014 | Manufacture of other organic basic chemicals |
| | C2015 | Manufacture of fertilisers and nitrogen compounds |
| | C2016 | Manufacture of plastics in primary forms |
| Other chemicals | | |
| | C2011 | Manufacture of industrial gases |
| | C2012 | Manufacture of dyes and pigments |
| | C202 | Manufacture of pesticides and other agrochemical products |
| | C203 | Manufacture of paints, varnishes and similar coatings, printing ink and mastics |
| | C204 | Manufacture of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations |
| | C205 | Manufacture of other chemical products |
| | C206 | Manufacture of man-made fibres |
| Pharmaceutical products etc. | C21 | |
| | C21 | Manufacture of basic pharmaceutical products and pharmaceutical preparations |

| | | |
|---|---|---|
| Non-metallic mineral products | C23 | |
| | C23 | Manufacture of other non-metallic mineral products |
| Cement | | |
| | C235 | Manufacture of cement, lime and plaster |
| | C236 | Manufacture of articles of concrete, cement and plaster |
| Glass production | | |
| | C231 | Manufacture of glass and glass products |
| Ceramics & other NMM | | |
| | C232 | Manufacture of refractory products |
| | C233 | Manufacture of clay building materials |
| | C234 | Manufacture of other porcelain and ceramic products |
| | C237 | Cutting, shaping and finishing of stone |
| | C239 | Manufacture of abrasive products and non-metallic mineral products n.e.c. |
| Pulp, paper and printing | C17, C18 | |
| Paper and paper products | C17 | Manufacture of paper and paper products |
| Pulp production | C1711 | Manufacture of pulp |
| Paper production | C1712 | Manufacture of paper and paperboard |
| | C172 | Manufacture of articles of paper and paperboard |
| Printing and media reproduction | C18 | Printing and reproduction of recorded media |
| Food, beverages and tobacco | C10_C12 | Manufacture of food products; beverages and tobacco products |
| Transport Equipment | C29_C30 | Manufacture of motor vehicles, trailers, semi-trailers and of other transport equipment |
| Machinery Equipment | C25, C26, C27, C28 | |
| | C25 | Manufacture of fabricated metal products, except machinery and equipment |
| | C26 | Manufacture of computer, electronic and optical products |
| | C27 | Manufacture of electrical equipment |
| | C28 | Manufacture of machinery and equipment n.e.c. |
| Textiles and leather | C13_C15 | |
| | C13_C15 | Manufacture of textiles, wearing apparel, leather and related products |
| Wood and wood products | C16 | |
| | C16 | Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials |
| Non specified industries | C22, C31_C32 | |
| | C22 | Manufacture of rubber and plastic products |
| | C31_C32 | Manufacture of furniture; other manufacturing |

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## List of abbreviations and definitions

AA: Administrative Agreement

BRP: Behavioural Response Parameter

CCS: Carbon Capture and Storage

DRI: Direct Reduced Iron (DRI)

ECCET: Economics of Climate Change, Energy and Transport

ENTSO-E: European Network of Transmission System Operators for Electricity

ETS: Emissions Trading Scheme

FAME: Fatty Acid Methyl Ester

GDP: Gross Domestic Product

ICT: Information and Communication Technology

IEP: Infrastructure Efficiency Parameter

JRC-IDEES: JRC Integrated Database of the European Energy System

NPV: Net Present Value

O&M: Operation and Maintenance

POTEnCIA: Policy Oriented Tool for Energy and Climate Change Impact Assessment

PSP: Production Structure Parameter

RES: Renewable Energy Systems

SRP: Structural Response Parameter

TGC: Tradable Green Certificates

UNFCCC: United Nations Framework Convention on Climate Change

WACC: Weighted Average Cost of Capital

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