European Commission


# POTEnCIA

# Model features and characteristics

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**Joint Research Centre**
the European Commission's
in-house science service

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# POTEnCIA

**P**olicy
**O**riented
**T**ool for
**En**ergy and
**C**limate change
**I**mpact
**A**ssessment

# INTRODUCTION

POTEnCIA incorporates a number of ***features*** and ***concepts*** to assess the various *potentialities* of the energy sector with regards to its evolution over time

*Defining the model character*

*Affecting investment decision and operation of equipment*

*Capturing multi-faceted responses of energy users to policy regimes*

> *Actuality is to potentiality, Aristotle tells us, as "someone waking is to someone sleeping, as someone seeing is to a sighted person with his eyes closed, as that which has been shaped out of some matter is to the matter from which it has been shaped" (1048b1–3).*
> *http://plato.stanford.edu/entries/aristotle-metaphysics/#ActPot*
>
> El ser no sólo se toma en el sentido de sustancia, de cualidad, de cuantidad, sino que hay también el ser en ***potencia*** y el ser en acto, el ser relativamente a la acción.*(Aristóteles, Metafísica, libro IX, 1).*
> *http://www.webdianoia.com/aristoteles/aristoteles_meta_4.htm*

They are distinguished between

- Generic model ones
- Demand side specific
- Power generation specific

# Generic model features and concepts

# REPRESENTATIVE ECONOMIC AGENT

Summarises the individual choices of various decision-makers in a sector

Investment decisions and operation of equipment modelled at the level of the representative agent

Each choice is treated as a 'physical entity'

- Number of agents explicitly defined
- Different representations apply across sectors

*The installed equipment needed for the production of one tonne of steel*

*The installed heating uses equipment of a household*

*An electric appliance*

*A car*

*A power plant unit*

Explicit representation of idle equipment or installations

Avoiding erroneous allocation of equipment

Allows identifying the domain for policy implementation

Explicit link between the level of use and the characteristics of the equipment/installation (vintage-specific)

# Annual time steps and vintages

Investment decisions occurring at each point in time form a vintage identified by

- the installation (and its characteristics)
- the number of installations

An installation is defined at the level of the representative agent

- a cluster of energy equipment
  *A steel production unit, a household, but also a car*
- with specific techno-economic and structural characteristics
- its lifetime is equal to the longest lifetime of the underlying energy equipment

Multiple options of installations are available within a vintage

- Newcomers choices are driven by economic criteria

Vintage-specific characteristics dynamically evolve over time

- Not all equipment have the same technical lifetime
- Adoption of non-energy related equipment options is possible throughout the lifetime of a vintage (accumulating effects)

# Capturing behavioural changes

Market acceptance factor

- Reflects deviations from economic optimality (exogenous)
  - *Taking into account market agents preference and risk considerations*
  - *Existing limitations of technical and infrastructure nature*
- Endogenously driven adaptation element that reflects market agents behaviour response
  - *Adjustment in relation to changes in purchase power and/or budgetary constraints (reflecting different dynamics across MS)*
  - *Learning by adopting effect*
  - *Changes in response to non-economic signals obtained through prevailing policy conditions (e.g. collective behaviour effects)*

In the same way it is possible to endogenously consider changes in the economic rationality of investment decision making

i.e. through changes of the elasticities of substitution

Additional formulations for behavioural changes of sector specific nature also apply

*These mechanisms limit the need for exogenous interventions when addressing different policy scenarios*

# SUBJECTIVE FINANCING CAPABILITY

Investment decisions take place on the basis of the ***perceived cost*** of capital

The nominal discount rate

*cost of capital financing when assuming unlimited access to capital and no risk aversion*

The subjective financing capability

- Reflects access to capital and purchase power
- Addresses risk factors/asymmetric information
- Links to budget constraints (differentiated per MS)

Different formulations for the subjective financing capability are available

- *from being deactivated*
- *to being assumed constant and equal across EU Member States*

For commercial investors the perceived cost of capital is equivalent to the ***WACC*** (weighted average cost of capital)

Investment costs are reported on the basis of the nominal discount rate

# Features and concepts applicable to the demand side

# THE REPRESENTATIVE ECONOMIC AGENT

Defined as to better capture sector-specific characteristics

*The number of representative agents evolves over time as a function of macroeconomic activity and demographics*

In ***industry*** it represents the installation needed for one unit of output

*physical tonnes for energy intensive sectors*

*tonnes-equivalent for energy intensive sectors with heterogeneous outputs*

*physical output index for non-energy intensive industries (*and ***agriculture****)*

The approach retained allows distinguishing between

- *structural properties (product characteristics, raw materials etc.), and*
- *energy related equipment characteristics*

and addressing the potential improvements achievable through

- *energy equipment*
- *non-energy related equipment energy saving options*

The comparison across Member States by means of energy related equipment is made possible

# THE REPRESENTATIVE ECONOMIC AGENT

In the ***residential*** the representative economic agent is defined by means of

- a *household installation* for thermal uses (a cluster of space heating, space cooling, water heating and cooking equipment)
- an *appliance/representative device* for specific electricity uses

The concept of a representative device is introduced, defined as a representative package of various appliances

For the ***services*** sector the model considers

- the *representative building cell* for space heating, space cooling, building lighting, ventilation and miscellaneous building technologies
- the *representative consumer* for the other energy uses
  - *capita* as concerns hot water services
  - for catering and commercial refrigeration it is the *frequency of using the service per capita*
  - for street lighting it is the *street lighting point*
  - for ICT and multimedia it is the *representative device*

# THE REPRESENTATIVE ECONOMIC AGENT

In the ***transport*** sector, two definitions are used

- the *vehicle* for passenger cars and power two-wheelers
- the *representative vehicle configuration* for all other transport modes

*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)*

*techno-economic characteristics defined as to reflect the representative vehicle configuration*

The number of representative agents links to the economy through

- the *vehicle ownership ratio* for private road transport
  - the number of passengers per movement determines the corresponding mobility levels
- the annual *flights per capita* in passenger aviation
- the *service requested per capita* (km/capita) on an annual basis for passenger rail and busses and coaches
- the *freight service requested per unit of GDP* for freight transport

For commercial transport, the number of vehicles links to the *realised level of use*

- the number of passengers per movement
- the tonnes per movement

# Industrial sectors

| Energy Intensive | Non-energy intensive |
|---|---|

## Energy Intensive

### Iron and steel
- Integrated steelworks
- Electric arc
- Direct reduced iron (DRI)
- Alkaline electrolysis

### Non-ferrous metals
- Alumina production
- Aluminium primary production
- Aluminium secondary production
- Other non-ferrous metals

### Chemicals
- Basic chemicals
- Other chemicals
- Pharmaceutical products etc.

### Non-metallic minerals
- Cement
- Ceramics & other NMM
- Glass production

### Paper and pulp
- Pulp production
- Paper production
- Printing and media reproduction

## Non-energy intensive

### Food, Beverages and Tobacco
### Transport equipment
### Machinery equipment
### Textiles and Leather
### Wood and wood products
### Other industrial sectors

*Including:*

Mining and quarrying

Construction

Non-specified industries

**Agriculture** treated similar to non-energy intensive industries

# Residential

| Thermal uses | Specific electricity uses |
| --- | --- |

## Thermal uses

Space heating
Space cooling
Water heating
Cooking

Main household types

- central heating with solids
- central heating with diesel oil
- central heating with natural gas
- central heating with LPG
- central heating with biomass and waste
- heat pump households
- electric heating households
- district heating households
- geothermal heating households

43 installation types for thermal uses in households considered

## Specific electricity uses

Lighting
White appliances

- refrigerators and freezers
- washing machines
- tumble dryers
- dishwashers

TV and multimedia
ICT equipment
Other electric appliances

# SERVICES

| Thermal uses | Specific electricity uses |
|---|---|
| Space heating | Street lighting |
| Space cooling | Building lighting |
| Hot water services | Ventilation |
| Catering | Miscellaneous building technologies |
| | Commercial refrigeration |
| | ICT and multimedia |

Each energy use in the services sector is treated separately

# TRANSPORT MODES

| Passenger transport | | Freight transport |
| --- | --- | --- |
| | **Road transport** | |
| Powered 2-wheelers<br>Private cars<br>Buses and coaches | 27 private car options considered | Light commercial vehicles<br>Heavy goods vehicles |
| | **Rail, metro and tram** | |
| Metro and tram, urban light rail<br>Conventional passenger trains<br>High speed passenger trains | | Conventional trains |
| | **Aviation** | |
| Domestic<br>International – Intra-EU<br>International – Extra-EU | | Domestic and International - Intra-EU<br>International – Extra-EU |
| | **Coastal shipping and inland waterways** | |
| | Domestic coastal shipping<br>Inland waterways | |
| | **Bunkers** | |
| | Bunkers – Intra-EU<br>Bunkers – Extra-EU | |

# Representing the sectoral structure

In each sector an explicit structure is defined

- Formulated by means of a ***nested-tree structure***
  - *flexible implementation across the different sectors*
- Decomposing energy use at the level of
  - *processes*
  - *energy end-uses*
  - *technology options, and*
  - *associated energy forms*
- Reflecting the energy equipment installed as to satisfy the service needs of the representative agent

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

# REPRESENTING THE SECTORAL STRUCTURE

In each sector an explicit structure is defined

- Formulated by means of a ***nested-tree structure***
  - *flexible implementation across the different sectors*
- Decomposing energy use at the level of
  - *processes*
  - *energy end-uses*
  - *technology options, and*
  - *associated energy forms*
- Reflecting the energy equipment installed as to satisfy the service needs of the representative agent

- The explicit characteristics of an installation span the whole tree
  - *Techno-economic characteristics of the energy equipment*
  - *Infrastructure related characteristics*
  - ***Size*** *of the equipment*



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# THE "SIZE" OF THE ENERGY EQUIPMENT

It is defined differently across sectors

*kW installed*

- *industrial uses*
- *all thermal uses in buildings*

*A unit*

- *for appliances*
- *electric devices*
- *private road transport (vehicle)*

*The annual mileage*

*foreseen for a representative vehicle configuration for all commercial transport modes*

For new installations, size evolves over time as a function of

- technical developments (exogenously defined) , e.g. downsizing of boilers
- societal characteristics that apply mainly to equipment used by private consumers
  - surface area of a representative household
  - engine size of the representative car
- the level of adoption of *non-energy related equipment options*
  - implying the need for a smaller installation with regards to energy equipment

The size of the energy equipment in existing installations cannot change unless when normal replacement occurs

# Investment decision making

Follows the nested tree structure

- The drivers for the decision making at each level of the tree are

  *the techno-economic characteristics of the alternative options*

  *their market acceptance factor*

  *the size of equipment installed*

  *the* ***desired level of operation*** *of the equipment*

- Substitutability/complementarity of the options available at each level is explicitly addressed

The shares of the various options, *describing the representative agent decision*, are obtained through a *nested multinomial logit formulation*

The domain of newcomers (new installations) is defined as the

*total installations (t)*

*- existing stock (t-1)*

*+ normal replacement (t)*

*+ premature replacement (t)*



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# 'DESIRED' AND 'REALISED' LEVEL OF USE

*Desired level of use*

- *reflects the comfort standard ("welfare target") of the representative agent*
- *links to macroeconomic and demographic assumptions*
- *it also takes into account*
  - *the penetration rate of the equipment*
  - *possible saturation limits*

*acts in investment decision making*

*Realised level of use*

- *adjusts the desired level in response to the policy framework*
- *agents flexibility to adapt is explicitly considered*
- *vintage and energy equipment specific*
  - *linking to the technical characteristics*

*determines the operation of the installed equipment*

Defined by means of:

***Hours of operation***: All sectors except transport

- in industry and agriculture the technical specificities of the corresponding production process (exogenously defined) determine the operation of the energy equipment
- in buildings no inter-linkage applies across different end uses

***Annual mileage***: Private transport modes

***Occupancy rate/Load factor***: Commercial transport modes

# ENDOGENOUS TECHNOLOGY DYNAMICS

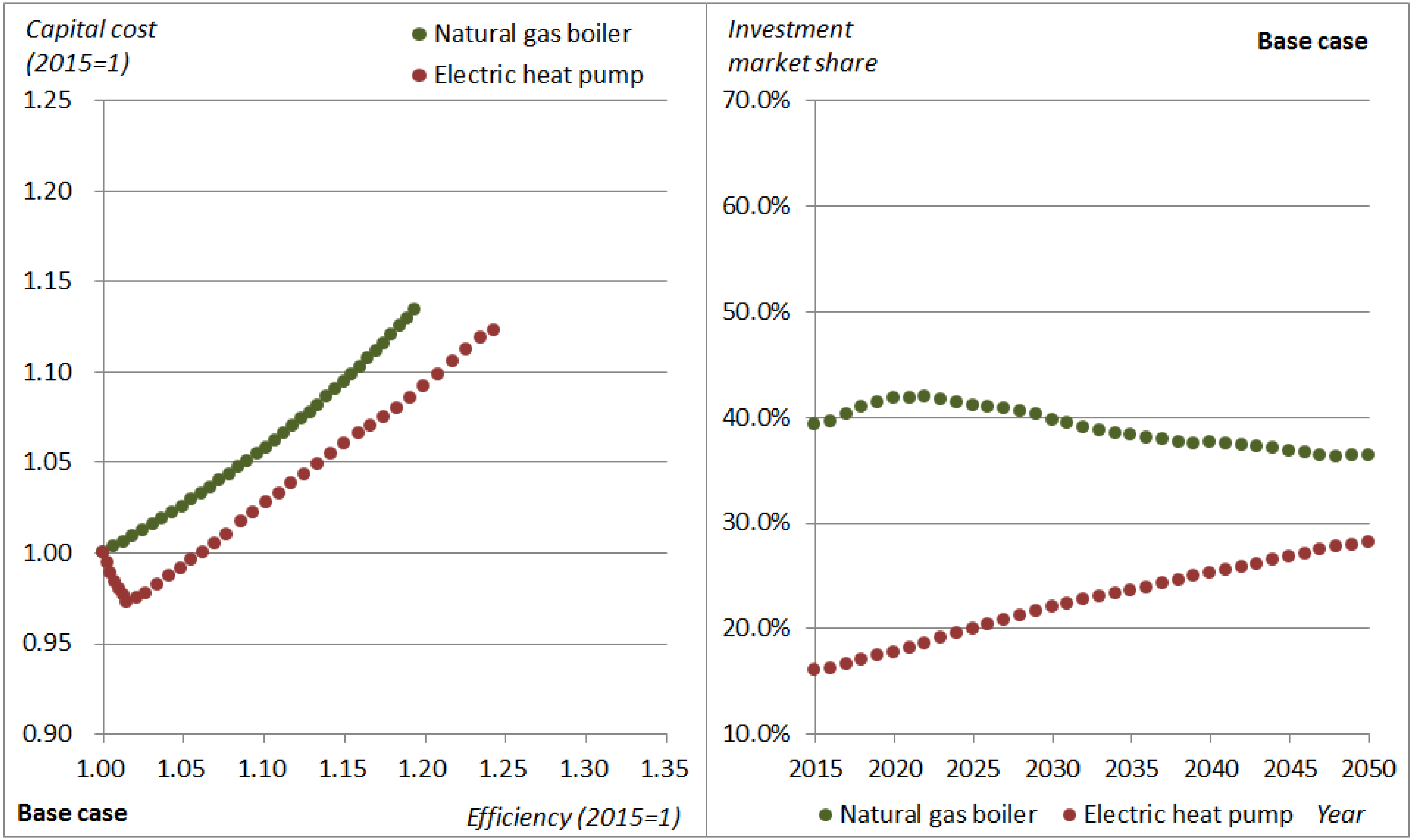
At the level of technology options three technologies choices are available

- Dynamically evolving over time towards a theoretical optimum (backstop)
- The pace of efficiency improvements also links to the deployment of the option
    - *If a technology option becomes unattractive its technology progress slows down*
- The techno-economic characteristics are a function of the distance to the backstop and the pace of moving towards it
- Learning and deployment effects are endogenously captured

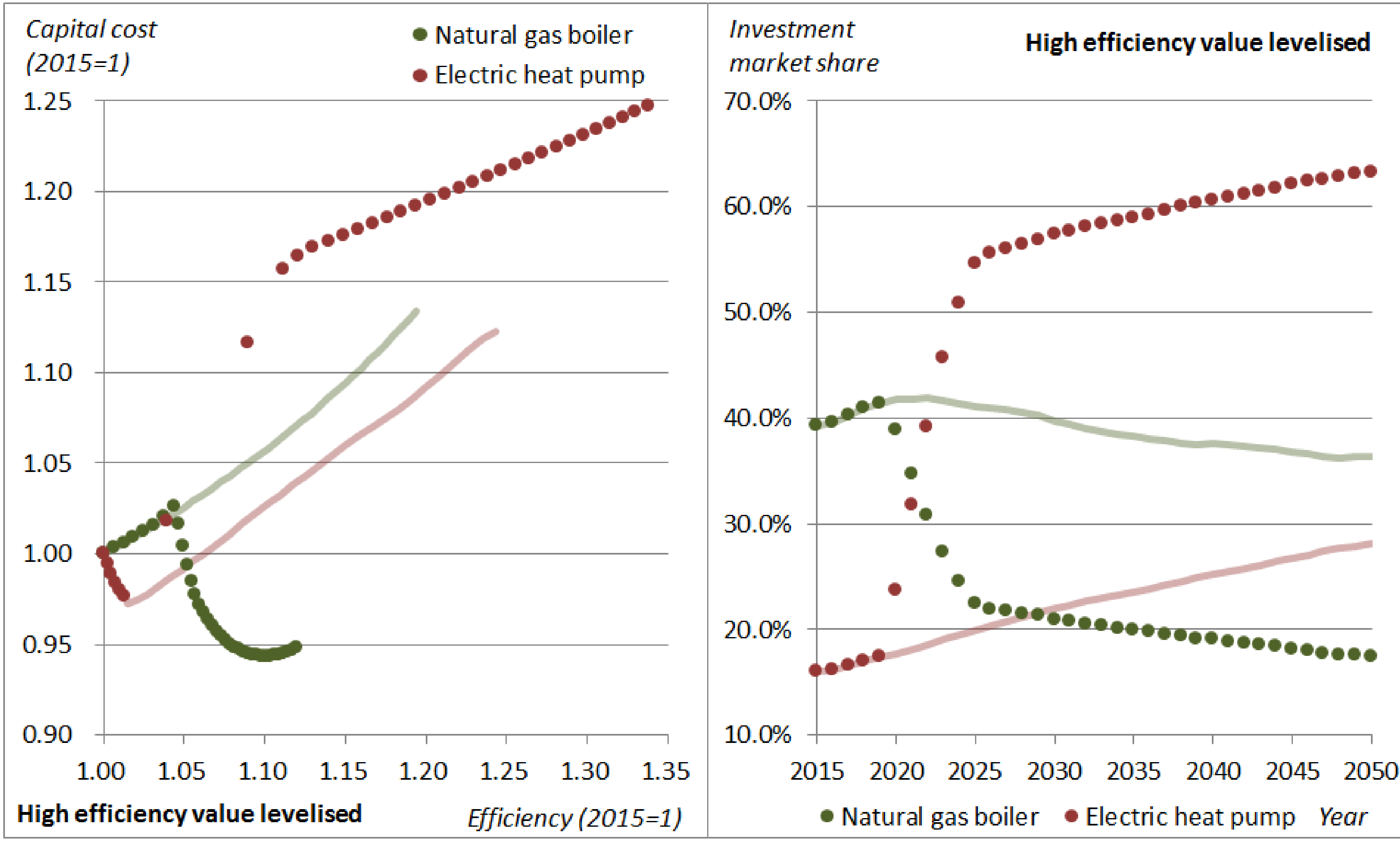
The formulation allows for the explicit representation of minimum standards

Country-specific efficiency characteristics for the existing stock are also reflected on its economic characteristics

# Endogenous technology dynamics (an example)



# Endogenous technology dynamics (an example)



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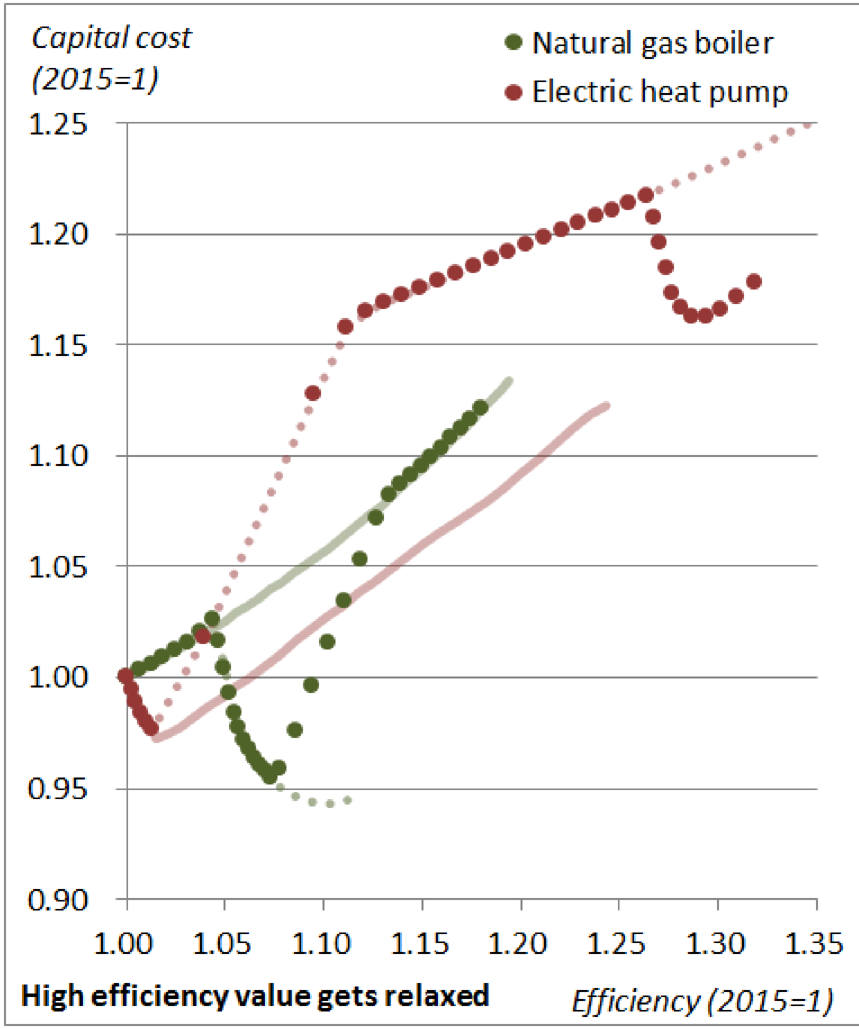


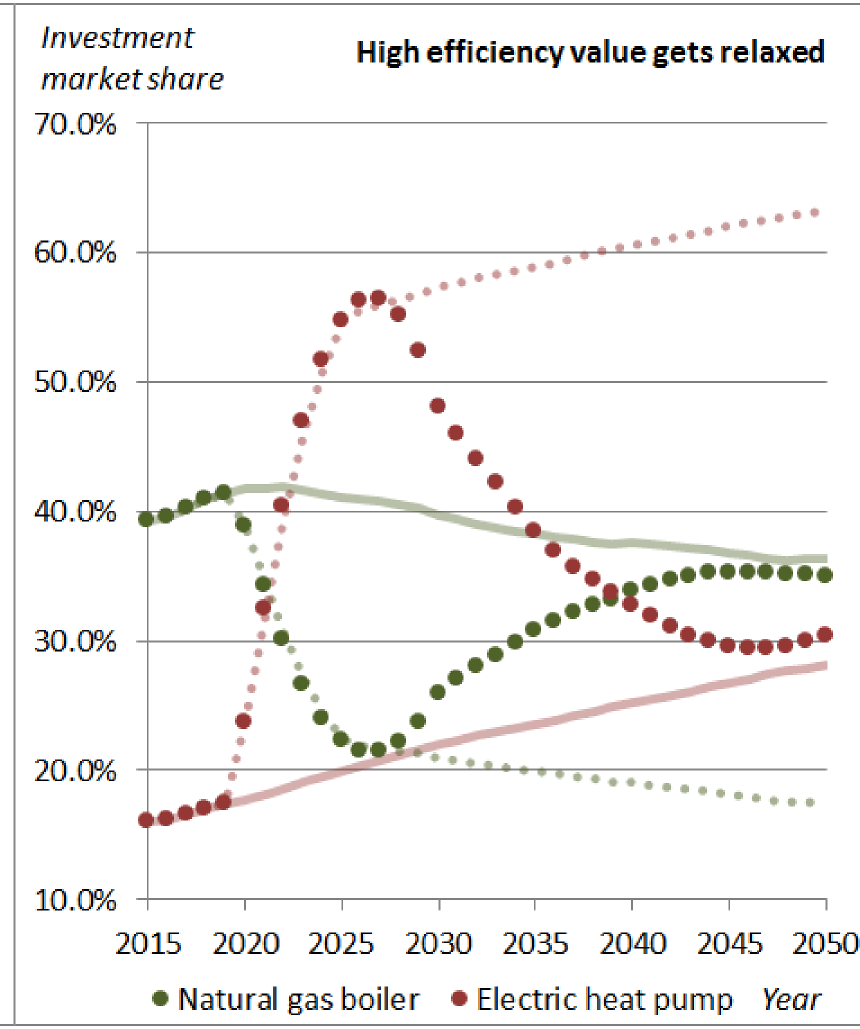




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# Infrastructure Efficiency Parameter

The **IEP** reflects investment in non-energy related equipment

Energy saving potential is end-use specific

The level of exploitation of the savings potential is determined by comparing

- *their corresponding costs*
  - non-linear cost formulation that dynamically changes in relation to the already exploited energy saving potential

- *the cost savings occurring from the need for installations of a smaller size and consequently the lower energy consumption*
  - including stranded costs, induced by the underutilisation of the already installed energy equipment

Consecutive (over time) investment in non-energy related equipment options within a specific vintage accumulate to its characteristics

The age of a vintage is also taken into account as to reflect the unwillingness of agents to perform additional investment

- *recently constructed*
- *with a short remaining payback period*

# Premature replacement of equipment

It occurs at the level of an installation (representative agent)

The decision is based on the comparison of

- the net present value of a new installation plus the induced stranded costs of the equipment that will be prematurely replaced
- the operating costs of the existing vintage for its remaining lifetime plus a fraction of the net present value of the new installation, reflecting the period following the normal replacement of the installed equipment

The current year's operating costs are considered

The current formulation assumes a direct comparison of costs

- *in the case that the new installation is less costly premature replacement of the existing vintage is performed*
- *alternative formulations (for example in the form of a logit function) may also apply*

Specific policy initiatives can be explicitly introduced (e.g. subsidies on capital costs of cars) as to accelerate the premature replacement

Stranded and policy support costs are explicitly quantified and assigned to the year in which the replacement takes place

# The Structural Response Parameter (SRP)

Acts towards capturing structural responses to policy assumptions

Applies on the number of representative agents

which initially links solely to exogenous macroeconomic and demographic assumptions

Driven by changes in the cost of the energy related service

- sector specific, and
- relative to other agents that offer the same service (e.g. passenger transport)

Different interpretations apply across sectors

- in industry and agriculture the SRP can be interpreted as an indicator of changes in the mix and the quality of the output products
  - leading to a revision of the volume of production
  - the sector’s productivity (value added per unit of output) also changes
- in the residential sector it implies a revision of the number of inhabitants per household and/or the penetration rate of electric appliances/devices
- similarly, in the service sector it implies a revision in the number of building cells and/or on the intensity of requesting a service by representative consumers
- in transport it reflects
  - changes of the level of mobility within each mode
  - also capturing possible modal shifts in response to prevailing policy conditions

# The Behavioural Response Parameter (BRP)

Reflects changes in the agents' behaviour driven by policy assumptions

Applies on the level of use of the energy equipment

Changes considered are of *temporary nature*

- issues related to management and organisation in industrial production
- setting of the thermostat in a building
- changes in the driving style
- improved logistics etc.

It triggers indirect changes in the variable operating costs of an installation

Depending on the policies in place the BRP may act towards further enhancing their effect or partly counterbalancing it

- a taxation policy may not only lead to a lower level of use of the energy equipment but also to a better use of the equipment
- a minimum efficiency standards policy may lead to a less rational use of the energy equipment, which partly counterbalances the related efficiency benefits, as a result of the drop in operating costs

Through the BRP rebound effects can be quantified

# Identifying the energy service needs

The energy service needs of a representative agent are the product of

- the size of the different energy equipment options that form an installation, and
- the realised level of use of the corresponding equipment

In each point in time, for each vintage and for all the different formulations of installations, POTEnCIA explicitly quantifies

- the energy service requirements of the corresponding representative agent
- the energy savings obtained through the IEP
- the energy consumed and the corresponding $CO_2$ emissions emitted
- the structural and techno-economic characteristics of the installation
  - *capturing changes in the size of the energy equipment (IEP effect)*
  - *linking to possible normal replacement of parts of an installation*
- the installation-specific fixed and operating costs
- the related cost of investment in non-energy related equipment options (incl. stranded costs of energy equipment when applicable)

  *this cost applies at the moment of occurrence, i.e. it is not treated by means of annuities*

# AGGREGATE FIGURES AT THE SECTOR LEVEL

The corresponding total figures are calculated by *proportionally* allocating the representative agents that operate their installation/equipment across the existing installations in the different vintages

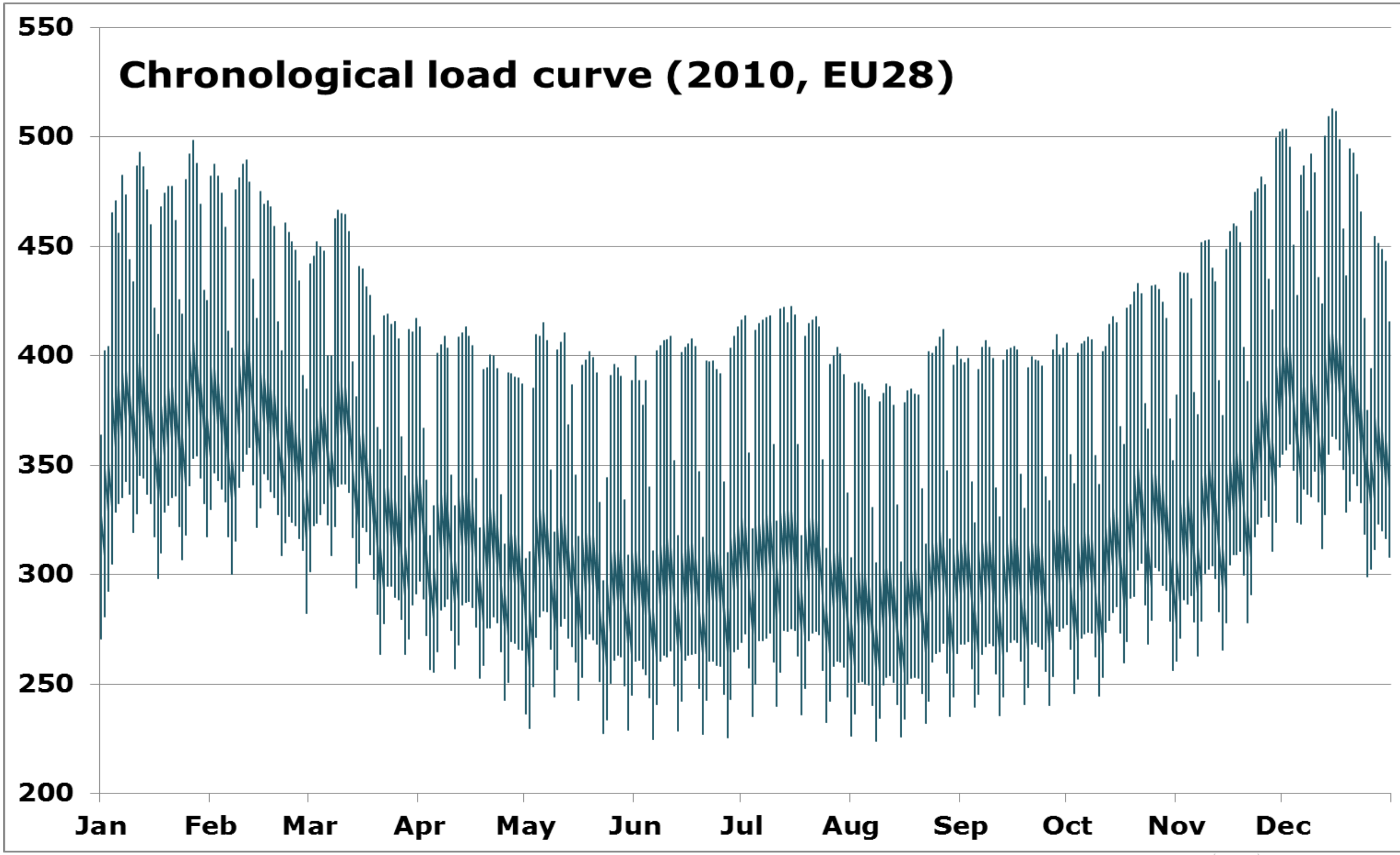
- with regards to total system fixed costs the costs of the idle installations is also taken into account
- costs related to premature replacement of equipment are also explicitly calculated;
  - as in the case of IEP related costs they apply at the moment of occurrence

*The explicit characteristics and costs of the different vintages are quantified, but no competition is considered across vintages in POTEnCIA*

# Features and concepts applicable to power generation

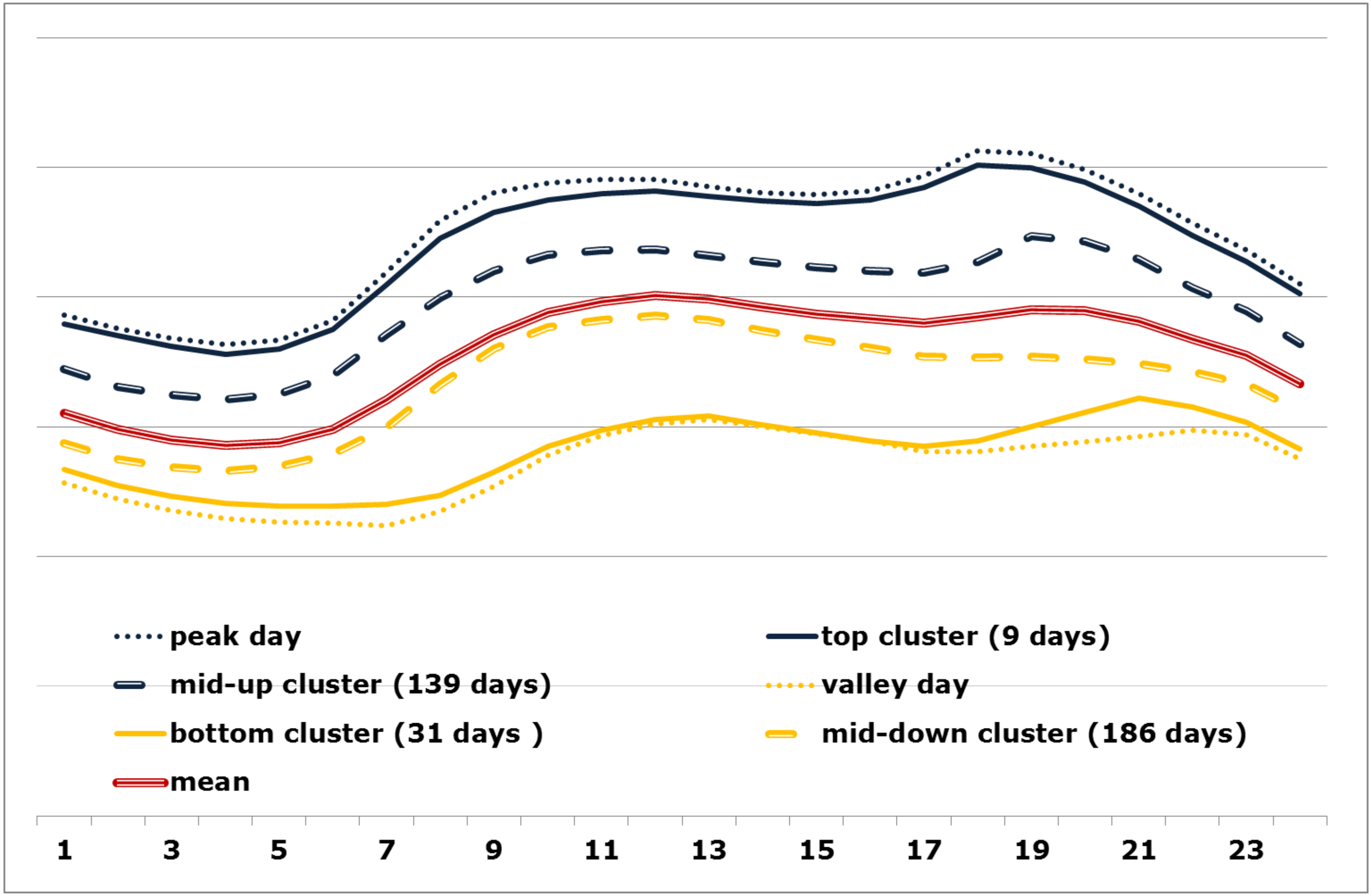
# DEFINING THE REPRESENTATIVE DAY'S LOAD

ENTSO-E provides information on an hourly basis for the load (GW)



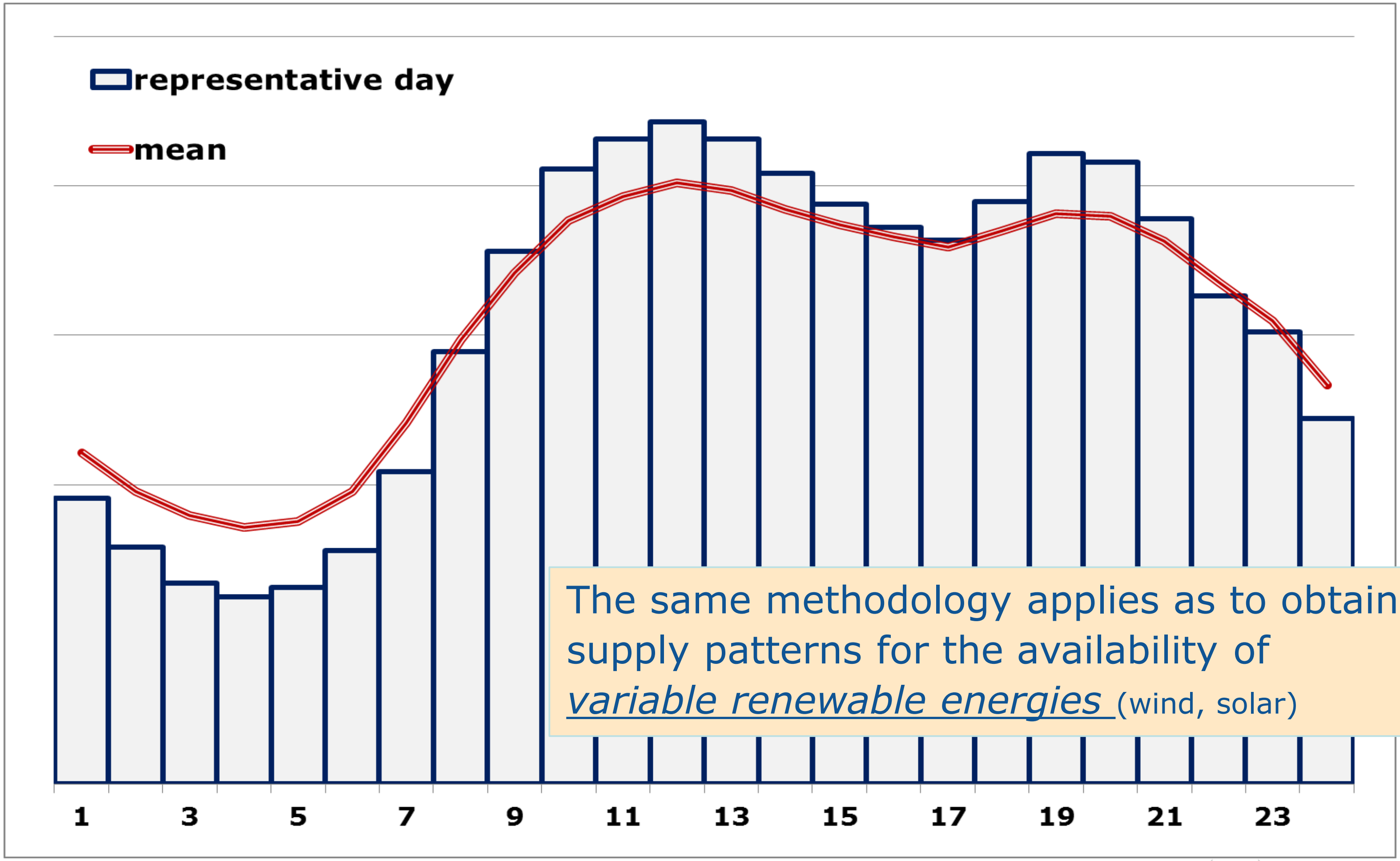
# Defining the representative day's load

Daily patterns are identified and grouped into ***clusters*** of days (with similar characteristics)



# DEFINING THE REPRESENTATIVE DAY'S LOAD

Their frequency of occurrence is used as to obtain the *representative day's load pattern*




The same methodology applies as to obtain supply patterns for the availability of *variable renewable energies* (wind, solar)



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# Linking to the demand side

In the demand side load *hourly load patterns* are exogenously defined

- Sector and energy end-use specific
- Reflecting the operating regimes of the energy end-uses

The aggregate demand load of electricity is matched to the representative day's load pattern through a *correction factor* (hour of the day specific)

*This correction factor is assumed to prevail over the projection period, i.e. it acts in revising the initial load patterns*

The future evolution of the shape of the demand load depends on

- changes in the contribution and the technical characteristics of the equipment at the level of end-uses
- changes in the shape of the load patterns reflecting demand side management policies

> such changes can be exogenously introduced or endogenously driven in response to *price signals*



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# LOAD REGIMES

POTEnCIA considers simultaneously both

- the chronological (hourly) load pattern of the demand and
- different load regimes (ranging from the base load to the peak load)

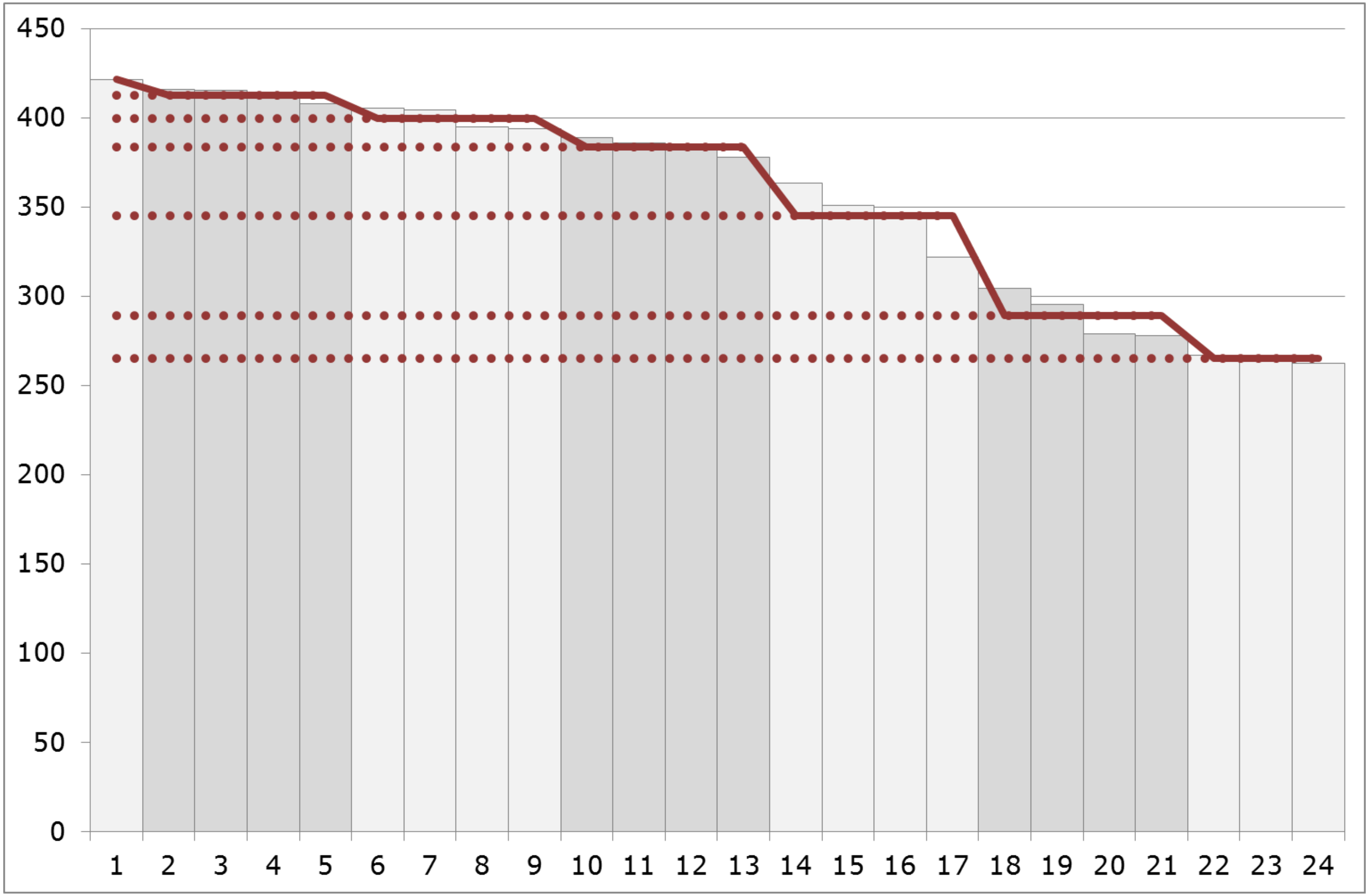
The chronological load curve is transformed into ***load regimes*** for power plants operation

- Re-ordering in a descending order of loads
- Seven load regimes considered
- The hours of occurrence of each load regime apply on the operation of power plants

Load regimes also contribute in identifying and reflecting

- suboptimal operation of power plants (*spinning mode* effects)
- *power plants contribution in in terms of electricity and in terms of load*
  *e.g. solar power plants operated in base load can only satisfy electricity needs*
- *bundling of units* within a load regime
  *wind turbines (typically producing electricity for 5-6 hours daily) can be considered as also satisfying load in the base if bundled together*
  *bundling also applies for thermal power plants (size, type and load regime dependent)*

# Load regimes



# Treatment of variable renewable energies

Variable renewable energies (VRES) are considered in POTEnCIA as part of the power plants operation problem

Solar energy, wind energy but also hydro power plants (run of river, reservoirs and pumping)

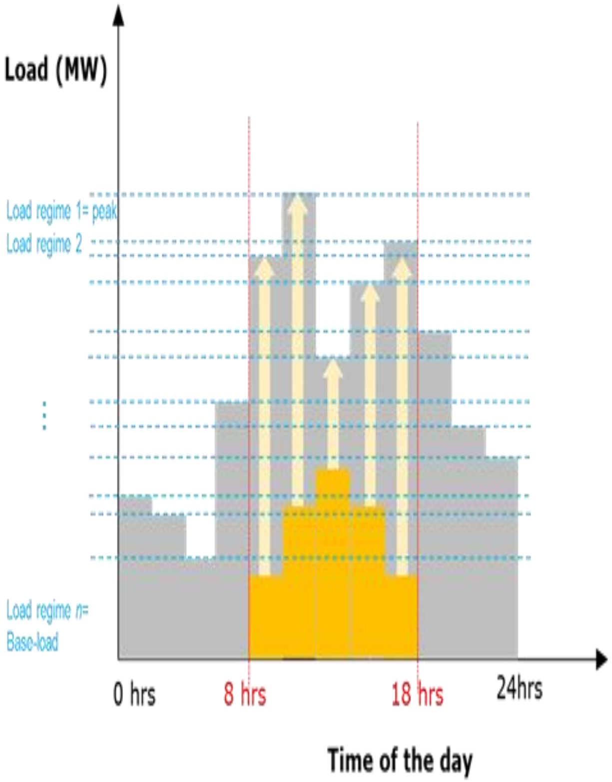
The contribution of VRES in the various time segments and load regimes is based on economic criteria under constraints of resources availability

- accounting for the *opportunity costs* induced in the competing traditional technologies
    - system costs arising from ramping and from spinning of other power plant types
- respecting constraint that reflect the potential contribution of VRES on an hourly basis
- ensuring the power generation *system stability*

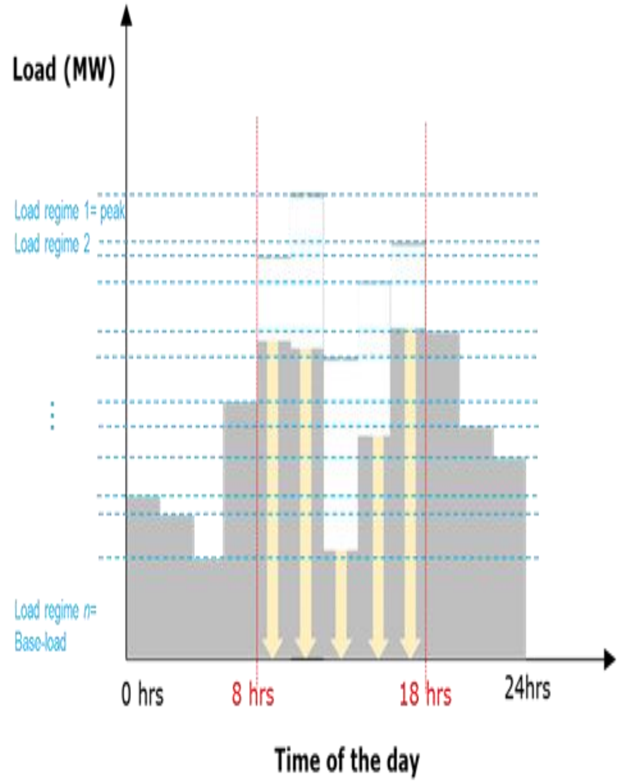
The approach retained allows:

- distinguishing between electricity and load contribution of VRES
    - *Natural availability* patterns are respected
- identifying possible curtailment of VRES
- quantifying the impact of VRES operation on traditional technologies

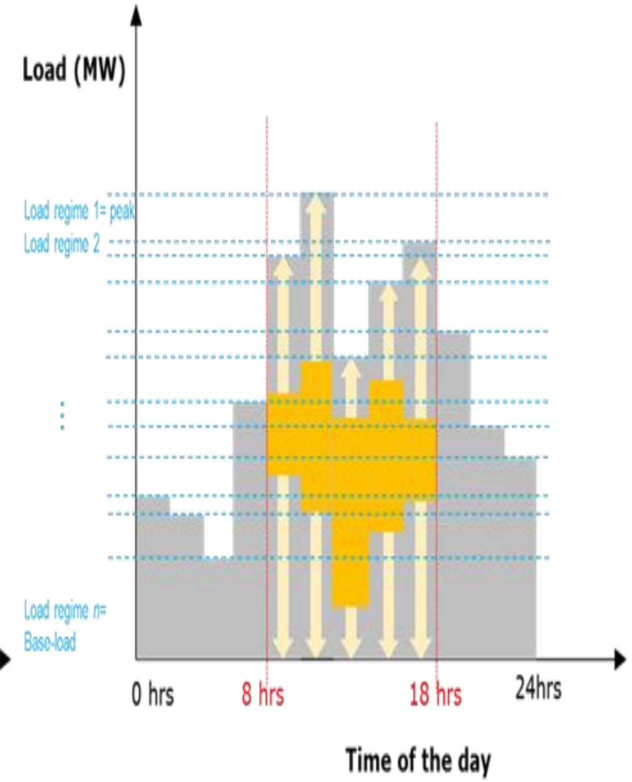
# Variable renewable energies (an example)




Strict merit order




Residual Load Curve (RLC)

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# SIMULATING POWER PLANTS OPERATION

Mimicking a **unit commitment** approach accounting for

- the unit's characteristics
  - size (and technical availability)
  - minimum stable load
  - techno-economic characteristics (load regime dependent)
- resources availability constraints
- power plants operation specifications
  - technically optimum hours of operation (reflecting operation with nominal efficiency)
  - giving rise to bundling of capacities for thermal units
- the policy framework

A **portfolio management approach** is followed

- multinomial logit formulation
- load regime specific
- grid operators preference reflected: from pure merit order to a diversified portfolio approach

The adoption of the portfolio management approach allows capturing the variety of similar units beyond the levels of disaggregation in POTEnCIA

# The simulation of power plants operation

The ***dispatching process*** involves four distinct steps

1. Calculation of operating costs depending on the operating mode of the power plant

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. Explicit ranking order of power plant types

   *performed simultaneously across all load regimes and for all power plant types*

4. Simulation of the power plant units operation
   - Mandatory production requirements
     - *priority dispatching*
     - *linking to indigenous resources availability*
     - *policy quotas*
     - *CHP electricity*
   - Economic dispatching in meeting the remaining load

# POWER PLANTS UNIT OPERATING COSTS CALCULATION

## Stationary operating costs

*Based on nominal techno-economic characteristics of power plant units*

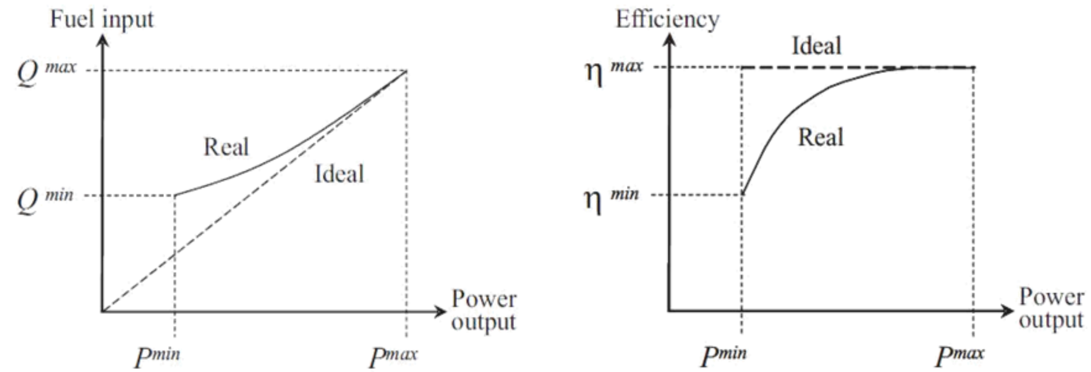
- Power plant efficiency
- Rate of own consumption
- Variable operating cost
- Fuel cost
- Policy costs (ETS price, renewable value etc.)

## Operating mode related costs reflecting cycling

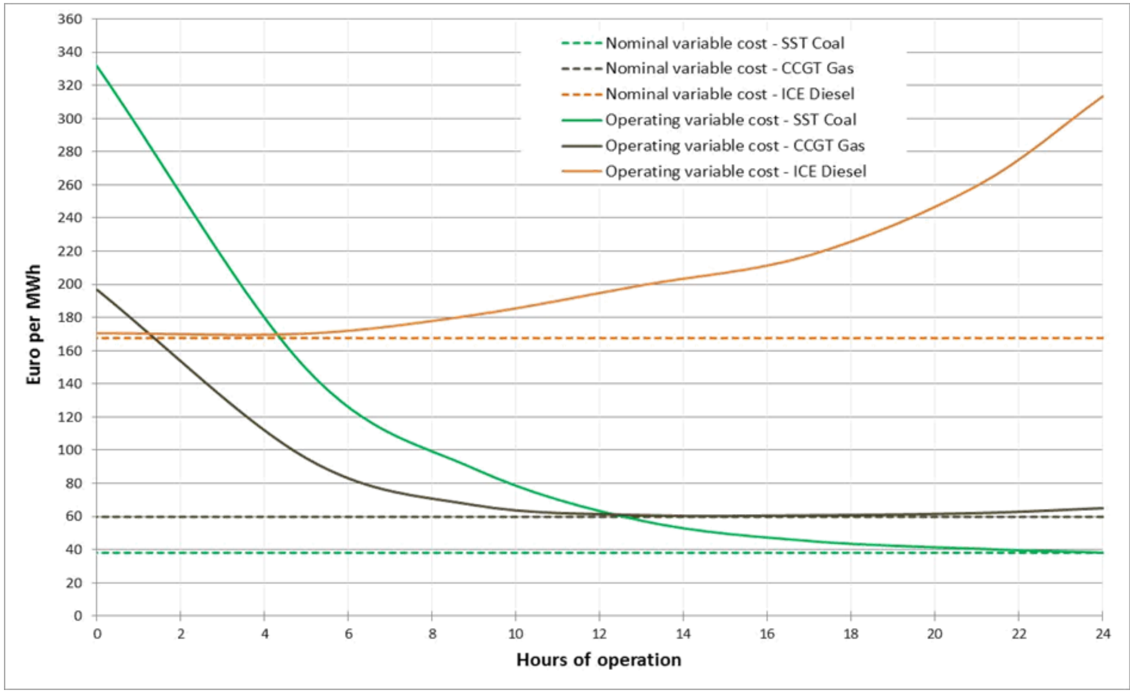
*Part load operation (spinning reserve)*

*Start-ups and shut downs*

- wearing off of equipment effect
- increased own consumption effect




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



# DESIRED GENERATION OF POWER PLANTS

The ***multinomial logit function*** gives rise to a *desired market shares* of the various power plant options within each load regime

These market shares can be interpreted as the probability of choosing a certain power generation option compared to the available alternatives

The **desired generation** of a power plant type within a load regime is calculated as the product of

- the desired market share;
- the load of the specific regime; and
- the operating hours attributed to the regime

This means that the desired generation is unconstrained by means of capacity availability, rate of use, fuel and resource availability etc.

The **ranking order** of the power plant types is then determined

- derived through a descending ordering of power plant types desired generation across all regimes

# Power plants operation

Following the ranking order power plants are put into operation

The next constraints are explicitly considered

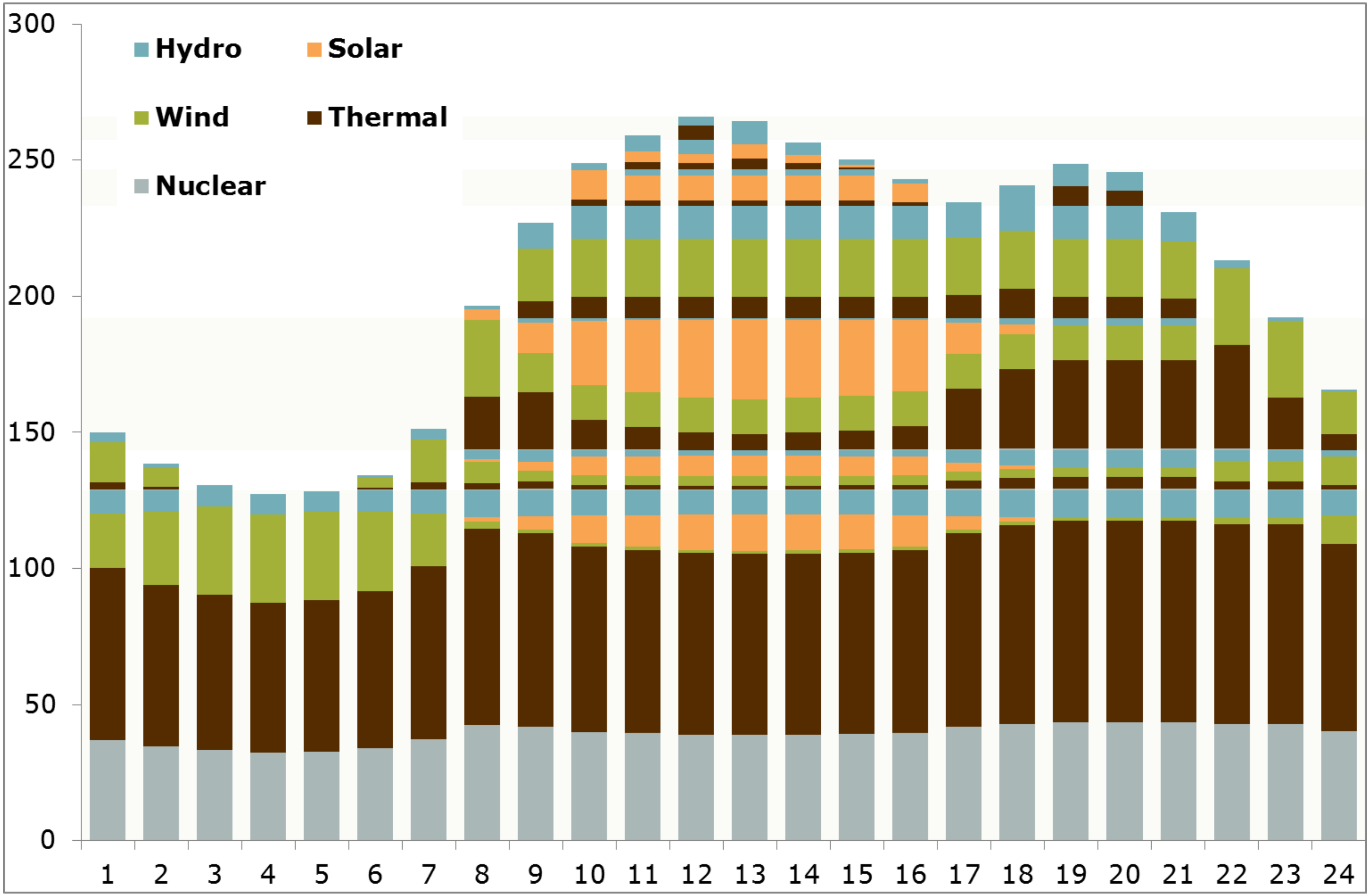
- desired generation
- number of units available
- minimum stable load of operation of a unit
- bundling of units
- resource availability and natural supply patterns

Power plants put in operation may act in satisfying electricity generation only or simultaneously electricity and load

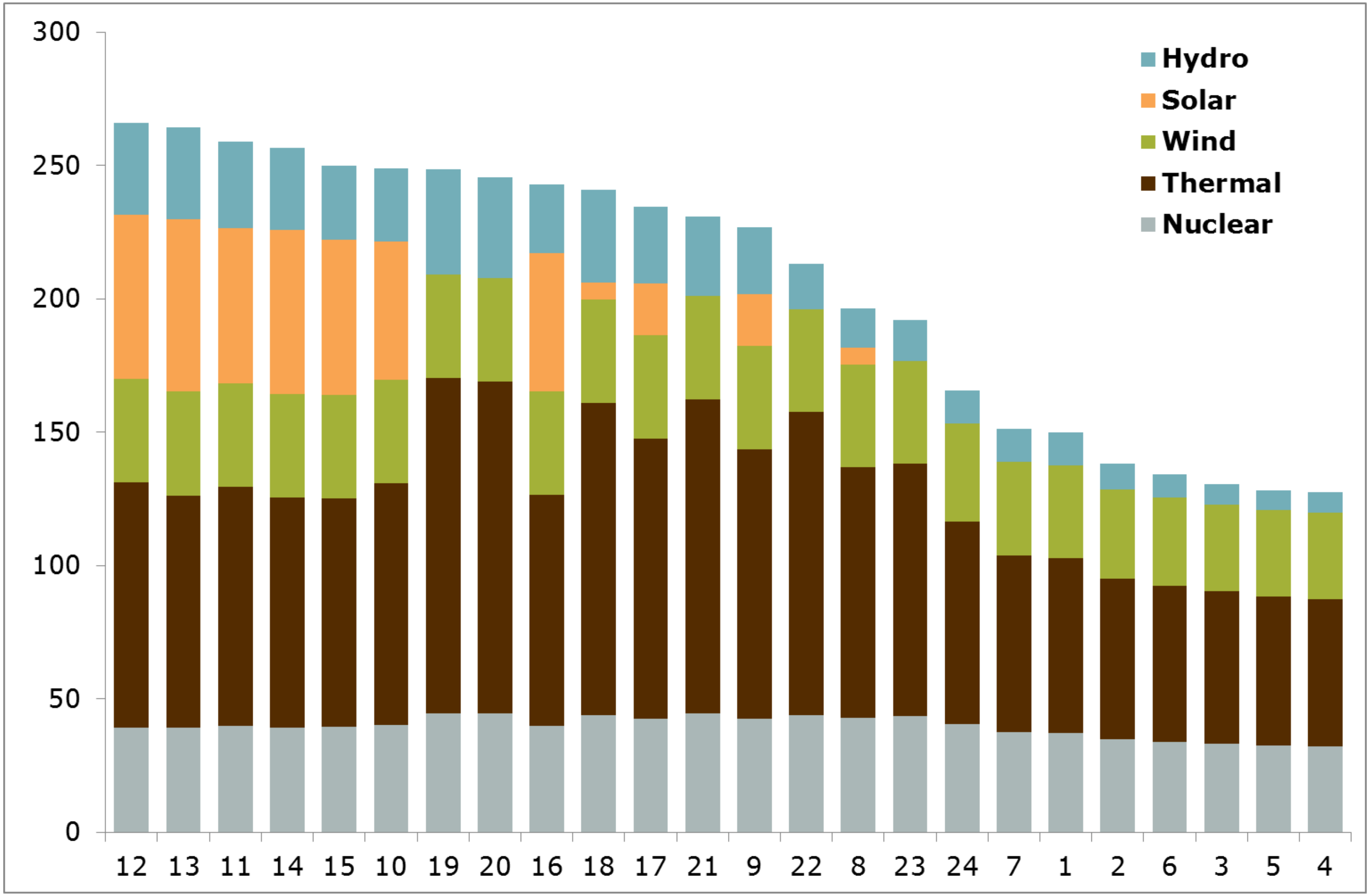
After each step the stock of the power plants option put in operation and the corresponding fuel availability are revised

The process is recursive until either satisfying the load or exhausting the available units

# POWER PLANTS OPERATION (AN EXAMPLE)



# POWER PLANTS OPERATION (AN EXAMPLE)



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# Power plants operation output

The methodology implemented allows to obtain information on

- the number of units in operation and the unused ones
- the possible bundling of units within a specific load regime
- the actual hours of use of the units in operation
  - *capturing part load conditions*
  - *spinning mode identified*
- the fuel consumption, $CO_2$ emissions and related operating costs
  - *within each load regime and by hour*
  - *explicit calculation of their quantities stemming from the operation of power plant units in a non-optimal mode*

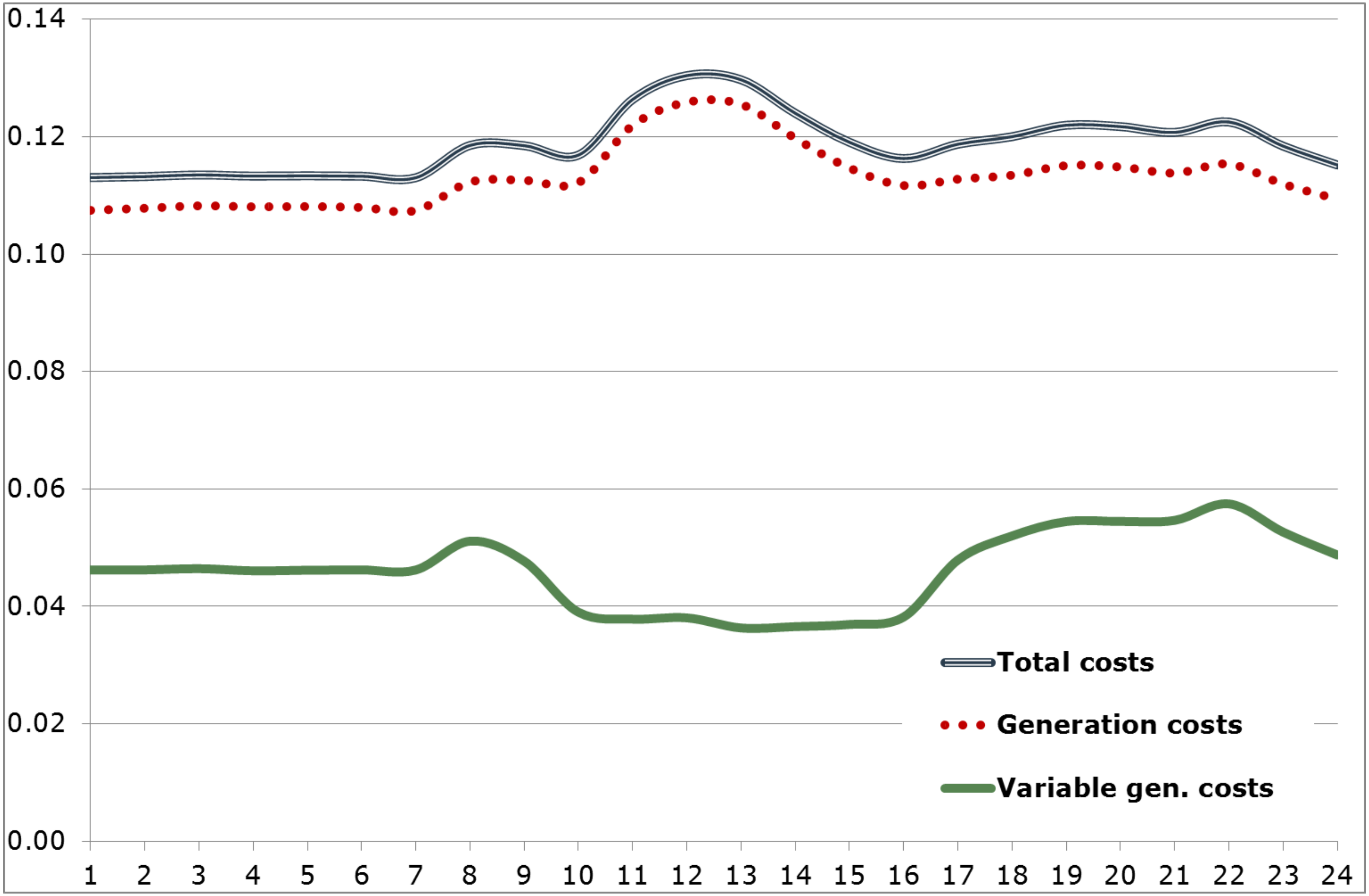
Consumer specific costs calculated assuming full cost recovery and considering their specific load profile

- possible to quantify signals to demand segments towards load shifting (DSM)
- transmission and distribution costs are endogenously quantified (hourly pattern)

Mark-ups apply as to derive the pre-tax electricity prices (tariffs at consumer's level)

End-user prices obtained after applying tax rates

# Electricity generation costs (an example)



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# Capacity planning

Investment takes place in *multiples of unit sizes*

- Mimicking a mixed integer programming approach
  - Strongly affecting the evolution of the power plants park, especially for small countries
- Preferences for delaying or advancing investment can be reflected
  - Linking to the policy regime
- Underinvestment may occur

The load profile of investment needs is defined by

- the load profile of decommissioned capacities, and
- the load pattern of the evolving demand load curve

Market shares in each load regime identified making use of a *nested multinomial logit formulation*

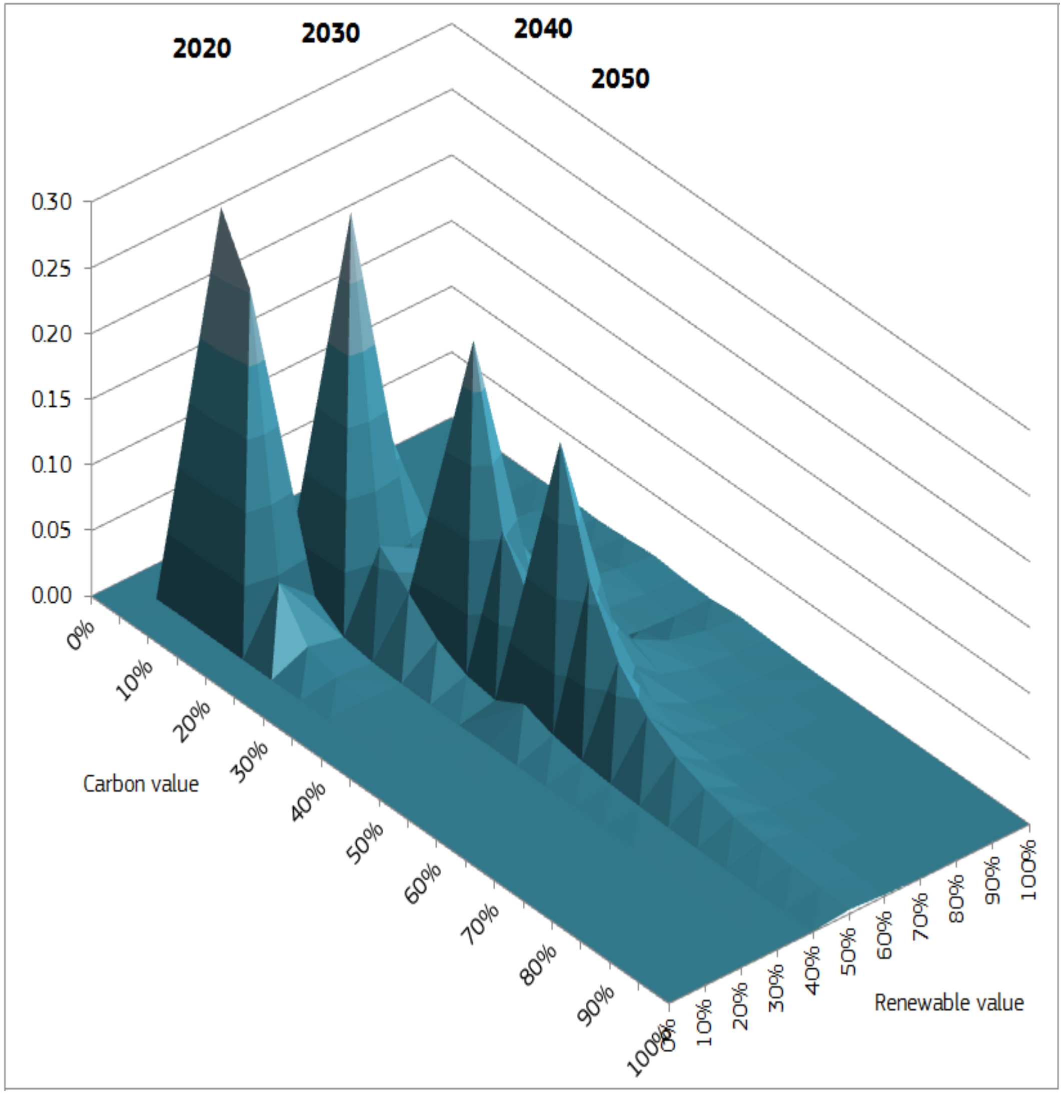
- up to four typical size classes
- technology options
- fuel types
- electricity-only and cogeneration plants
- power plants with/without CCS equipment

# Dynamic recursive foresight with imperfect information

Capacity planning considers by default uncertainty for the policy framework

For a typical market agent a set of policy options combinations is defined

- The envisaged future policy framework links to prevailing policy assumptions
- The weighted distribution of the expectations of the market agent applies on investment decisions



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# "Points of view" in capacity planning

Dedicated producers: their decision reflects the fulfilment of a specific load pattern

- *demand or resource availability driven (IPPs fall in this category)*
- *weighted distribution of expectations dealt with by means of number of producers*
- *overall decision obtained combining those of the different load regimes*

Multiple market agents: individual investment choices in view of the overall load profile

- *load regimes decisions form a new problem at the aggregate level*
- *different expectations dealt with by means of number of producers*

Central decision planners: central investment choice in view of the overall load profile

- *instead of multiple individual decisions, one single decision that encompasses various assumptions with regards to the different possible evolutions of the system*

# Capacity planning output

Investment identified by means of units

- size specific
- obtained by applying the aggregated market shares on the capacity needs

The default setting considers the central decision planners option in implementing the investment decision

- Exogenous weights may apply as to define different contributions for the different "points of view"

Economically realisable potentials may be endogenously revised in the presence of specific policy regimes

- Technical potentials form the upper limit
- Surpassing the initial economically realisable potential leads to non-linear increase in costs

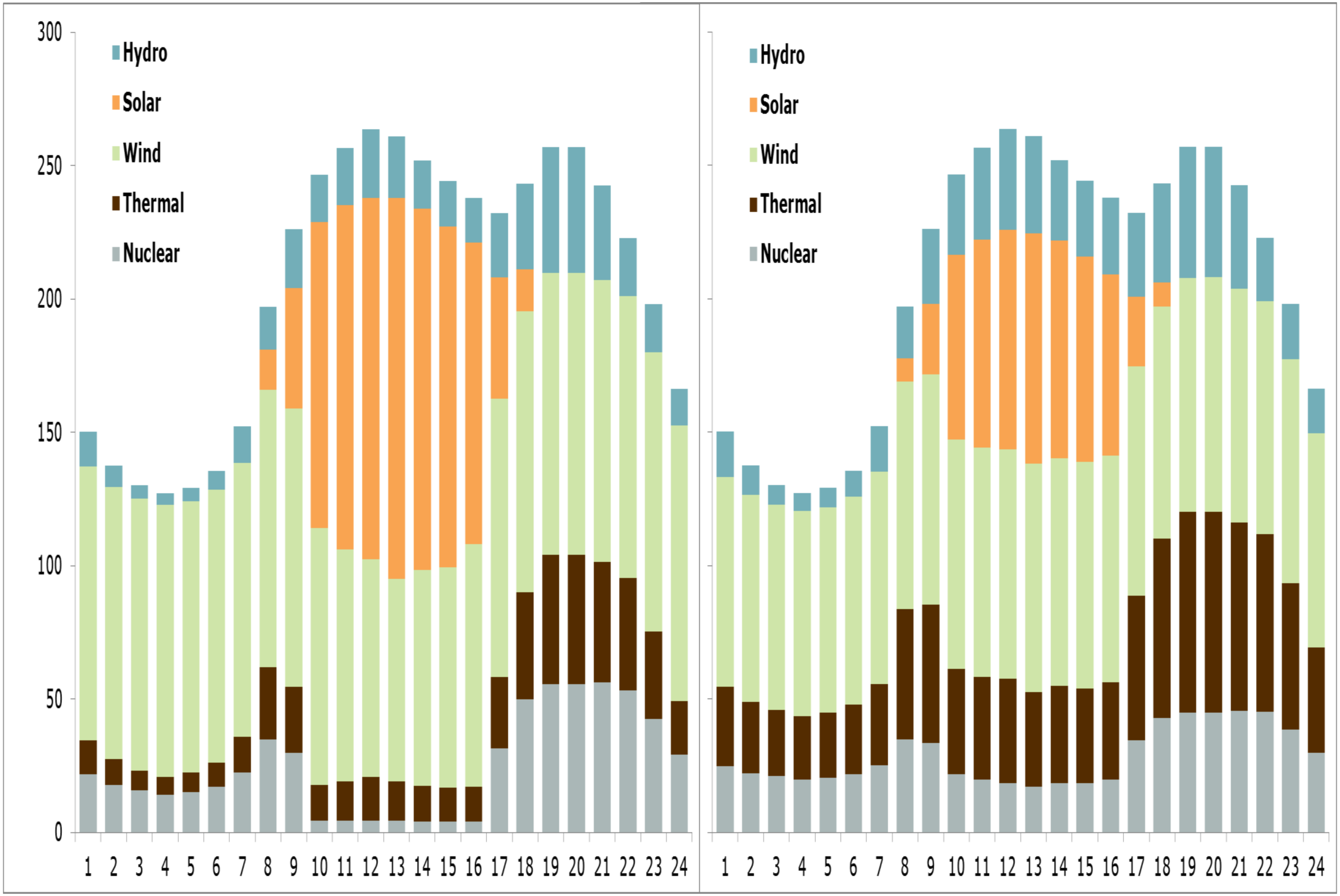
# System stability considerations

Explicit consideration of system stability implemented through

- *Endogenous* calculation of the reserve margin
  - *boundary conditions for the total installed capacity versus peak load apply*
  - *the total capacity in use versus the total capacity installed forms another boundary condition*

- The **system stability indicator** provides a signal to the investment decision-making
  - *defined by means of the capacity in operation compared to peak load*
  - *the attractiveness for power plants that satisfy electricity and not load reduces as the system stability indicator increases*

  *i.e. investors favour more power plants options that contribute to reliable load*



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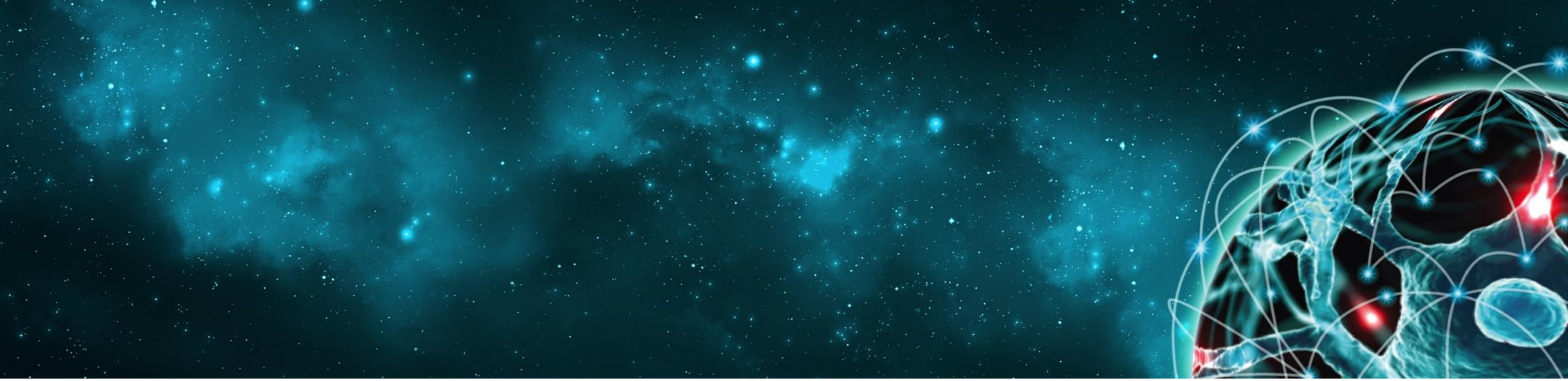

# Thank you for your attention

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