Price Coupling of Regions (PCR)

Towards Single European Market: Next Steps

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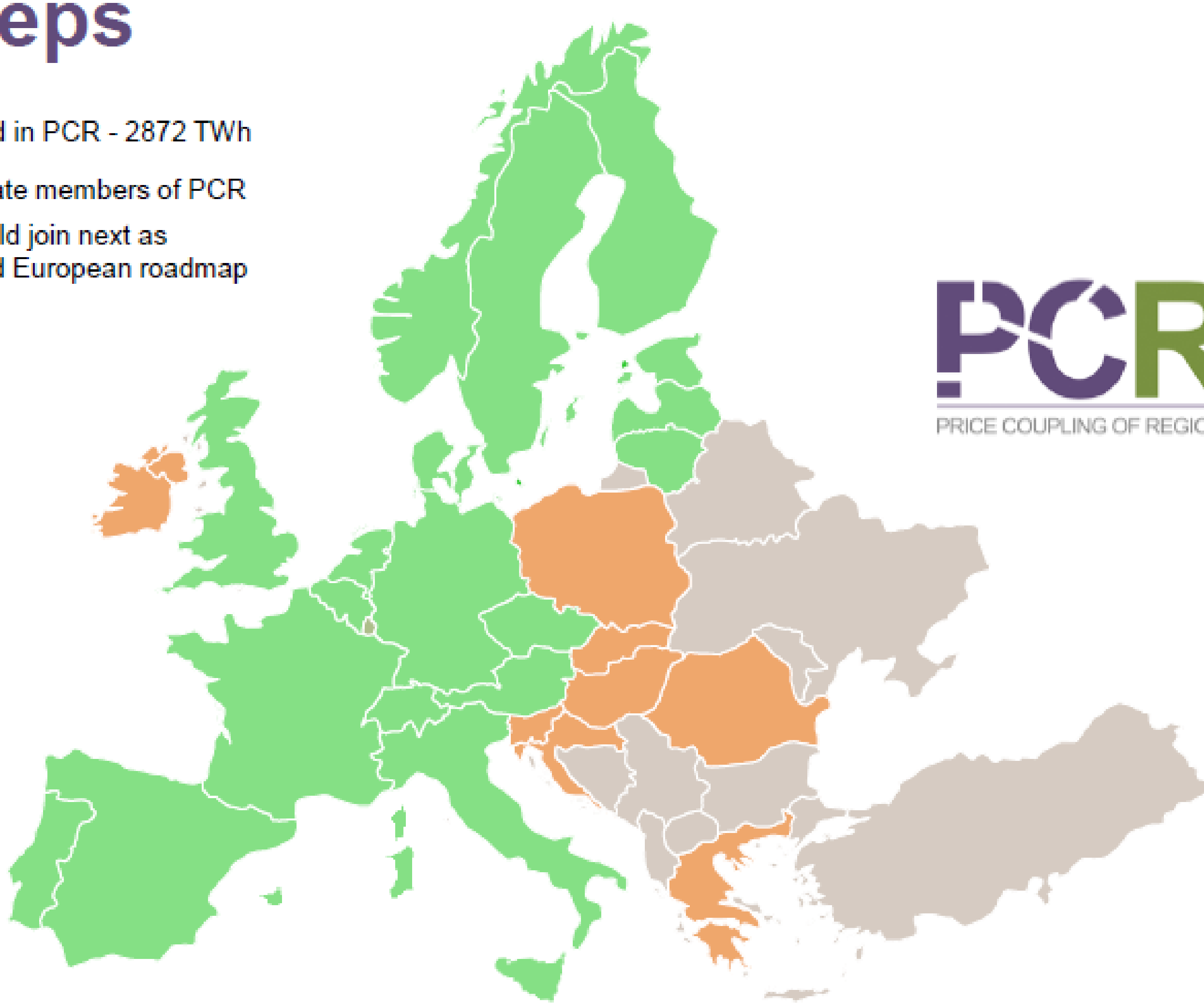
- Markets included in PCR - 2872 TWh
- Markets associate members of PCR
- Markets that could join next as part of an agreed European roadmap



PCR
PRICE COUPLING OF REGIONS

PCR

- Price Coupling of Regions (PCR) is a Market Coupling project focused on the delivery of a common European price coupling solution

- An important part of all regional market coupling projects, linking them all together

- This is to accommodate the overall EU target of a harmonised European electricity market

- Based on three main principles:
  - One single algorithm
  - Robust operation
  - Individual accountability

- **Key Elements: Towards 2014 Integration**

- Coupling of Regions (PCR) is the initiative of seven European Power Exchanges to harmonise the European electricity markets

- **HOW is this done?** By developing a single price coupling algorithm to be used to calculate electricity prices across Europe

The PX involved

- Initiative of seven Power Exchanges: APX-ENDEX, Belpex, EPEX SPOT, GME, Nord Pool Spot, OMIE and OTE, covering the electricity markets in Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Portugal, Spain, Slovenia, Sweden, ~~Switzerland~~ and UK

- Development of a single price coupling algorithm, **Euphemia**. It will be used to calculate electricity prices across Europe. It will also optimise the overall welfare and increase transparency of prices and flows

- Open for other European Power Exchanges wishing to join. PCR is creating a governance structure based on a Co-ownership Agreement and a Co-Operation Agreement among exchanges

- There are several coupling initiatives in progress in different Regions in Europe preparing to use the PCR solution (NWE, CSE, SWE, etc…)

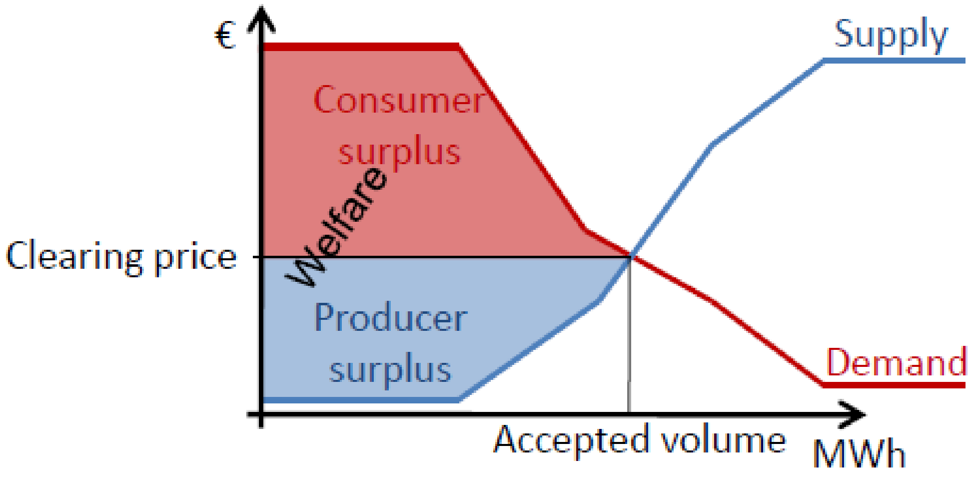
Benefits of European Price Coupling

- The integrated European electricity market will be beneficial due to increased liquidity, efficiency and social welfare
- Guarantees the overall welfare and optimal use of interconnection capacities
- Removes unnecessary risks of trading short-term transmission capacity and energy separately
- All market participants benefit from cross-border capacity
- Encourages liquidity, transparency and efficiency in the power markets across Europe

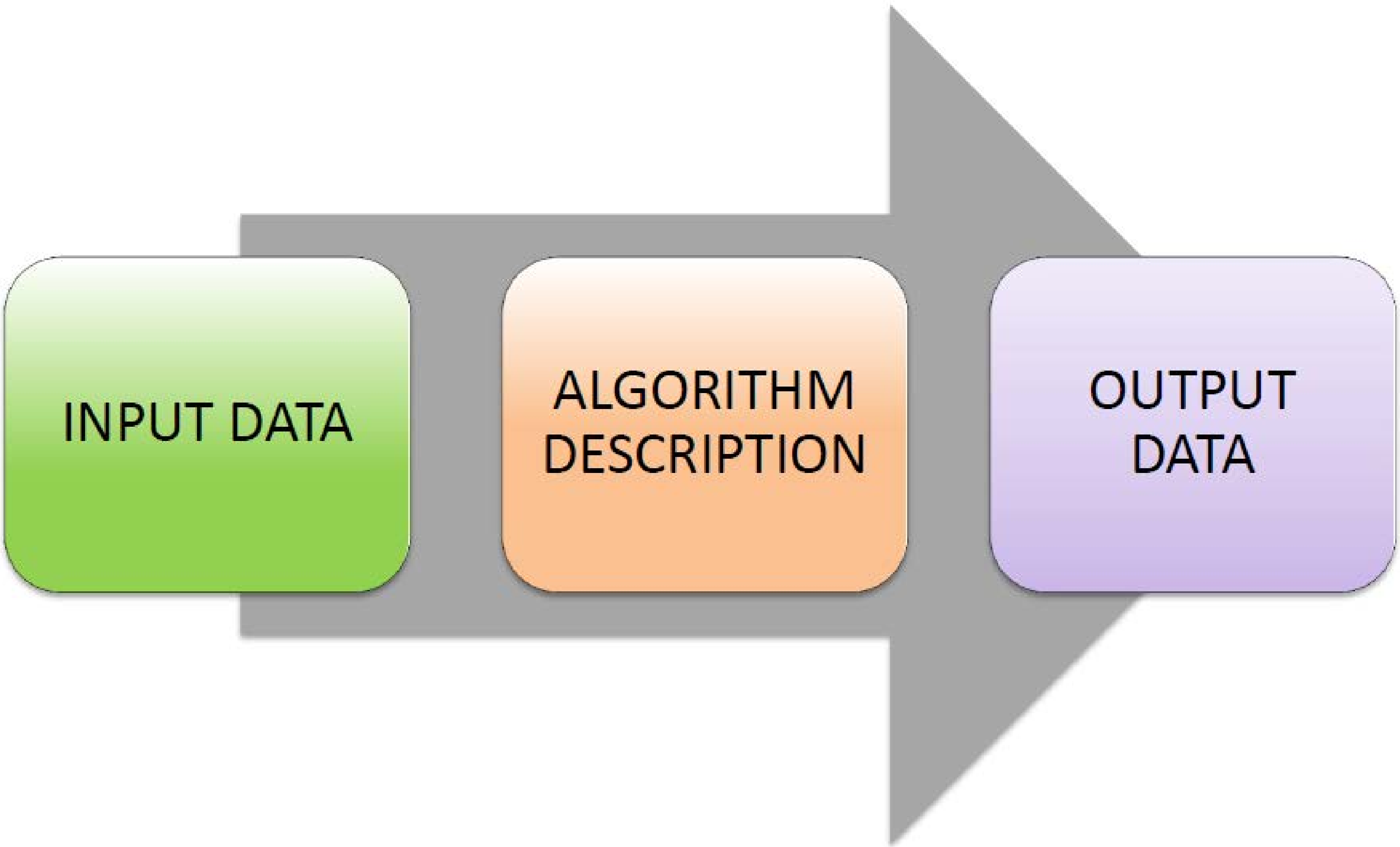
EUPHEMIA

- EUPHEMIA is an algorithm that solves the market coupling problem on the PCR perimeter
- EUPHEMIA stands for: EU + Pan-European Hybrid Electricity Market Integration Algorithm

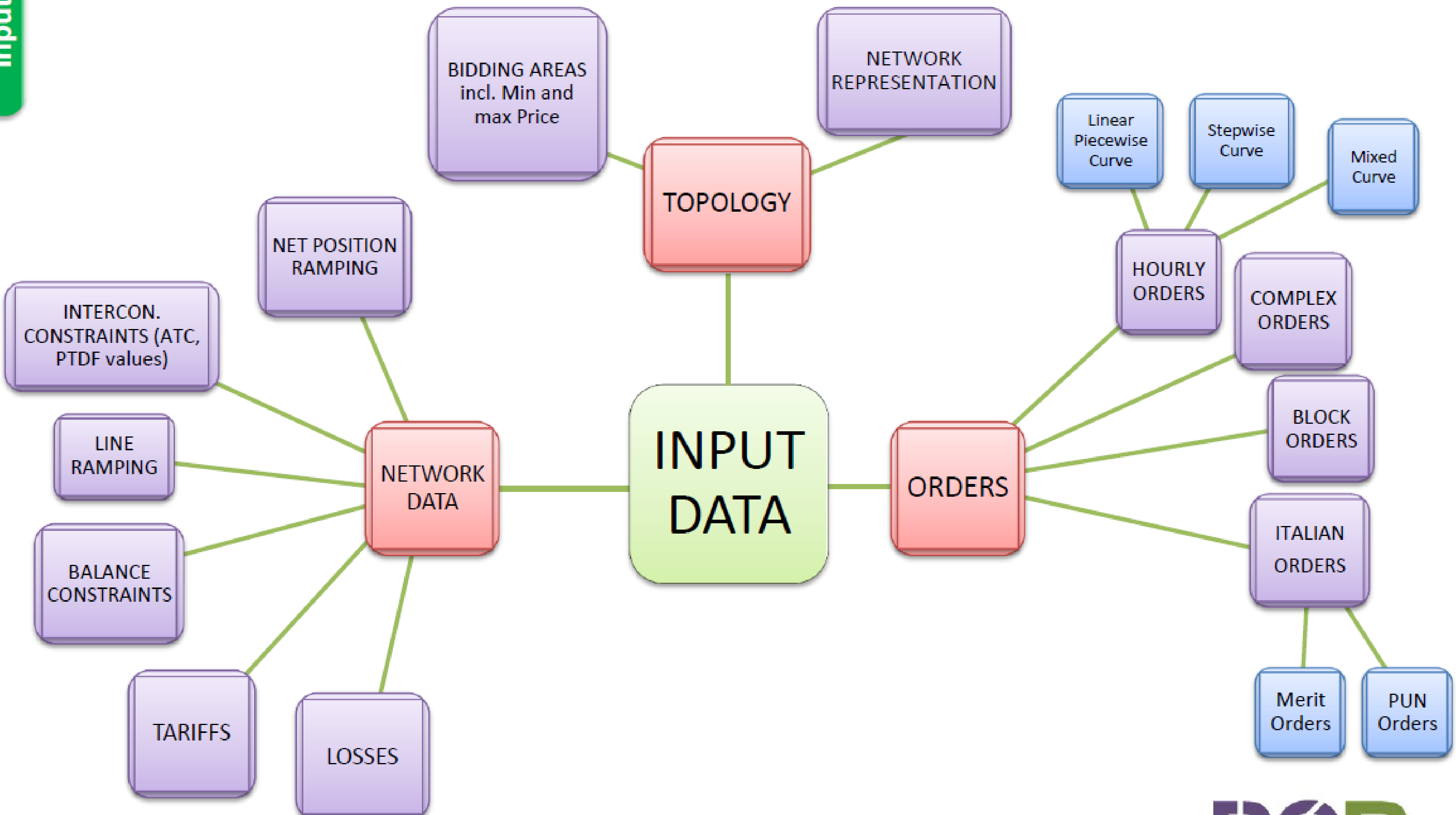
- It maximises the welfare of the solution
  - Most competitive price will arise
  - Overall welfare increases
  - Efficient capacity allocation



General description



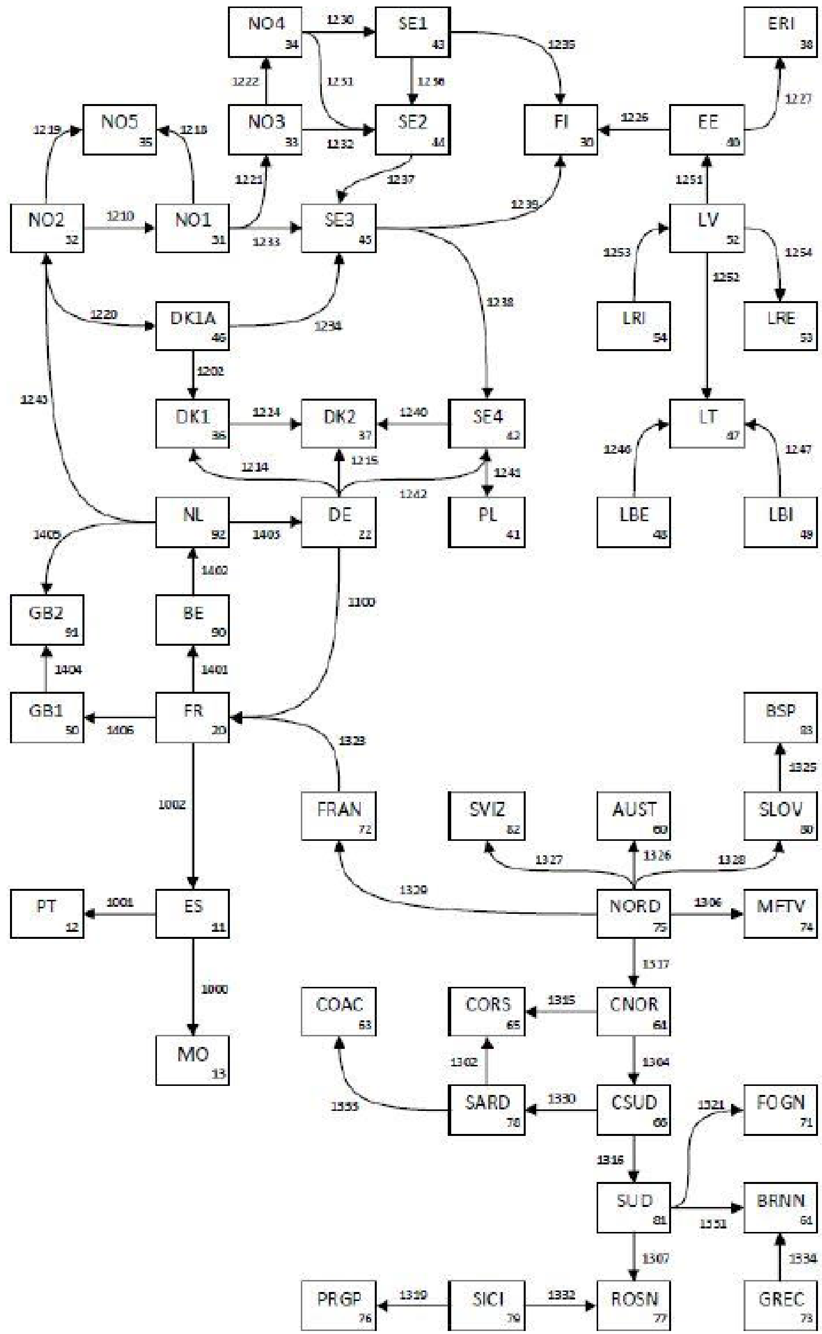
INPUT DATA



PCR
PRICE COUPLING OF REGIONS

Market data

- Each PX (Market) operates several bidding areas
- All bidding areas are matched at the same time
- A different price can be obtained for each bidding area
- The price for the bidding area must respect maximum and minimum pric market boundaries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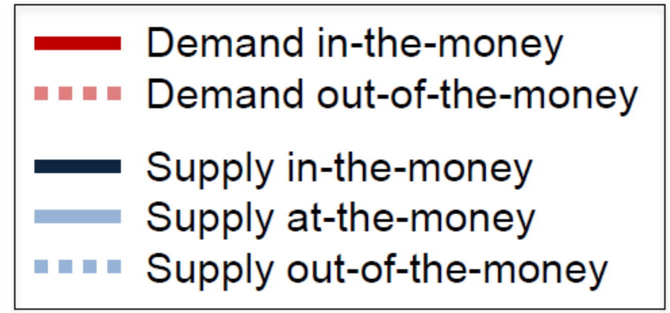
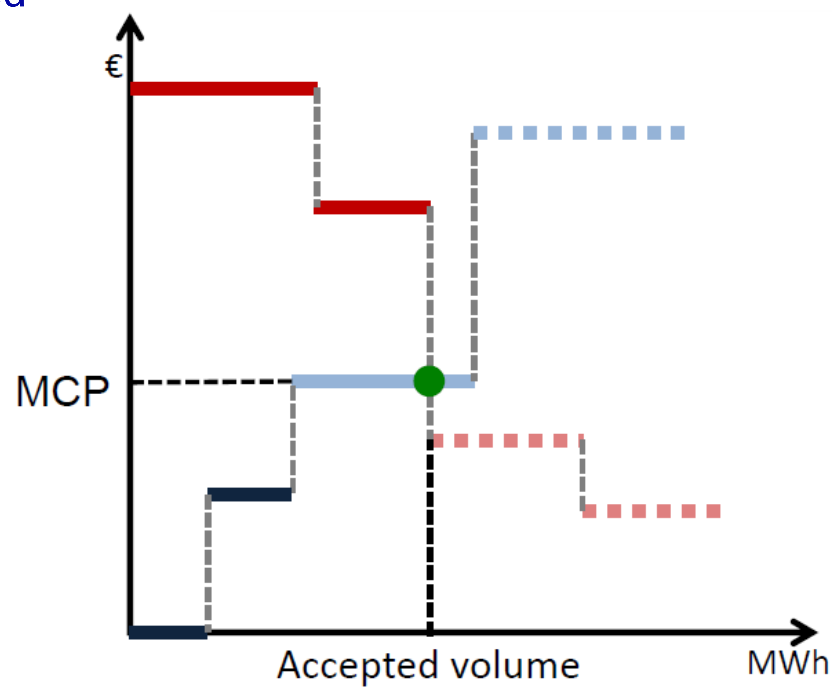
SE1 43
ERI 38
NO5 35
NO3 33
SE2 44
FI 30
EE 40
NO2 32
NO1 31
SE3 45
LV 52
DK1A 46
LRI 54
LRE 53
DK1 36
DK2 37
SE4 42
LT 47
NL 92
DE 22
PL 41
LBE 48
LBI 49
GB2 91
BE 90
GB1 50
FR 20
BSP 83
FRAN 72
SVIZ 82
AUST 60
SLOV 80
PT 12
ES 11
NORD 75
MFTV 74
MO 13
COAC 63
CORS 65
CNOR 61
SARD 78
CSUD 66
FOGN 71
SUD 81
BRNN 61
PRGP 76
SICI 79
ROSN 77
GREC 73

HOURLY STEP ORDERS

- Hourly step orders are defined by
  - A type (buy or sell)
  - A volume
  - A limit price
- EUPHEMIA provides solutions such that
  - Orders in-the-money are fully accepted
    - Supply at price < MCP
    - Demand at price > MCP
  - Orders out-of-the-money are fully rejected
    - Supply at price > MCP
    - Demand at price < MCP
  - Orders at-the-money can be curtailed

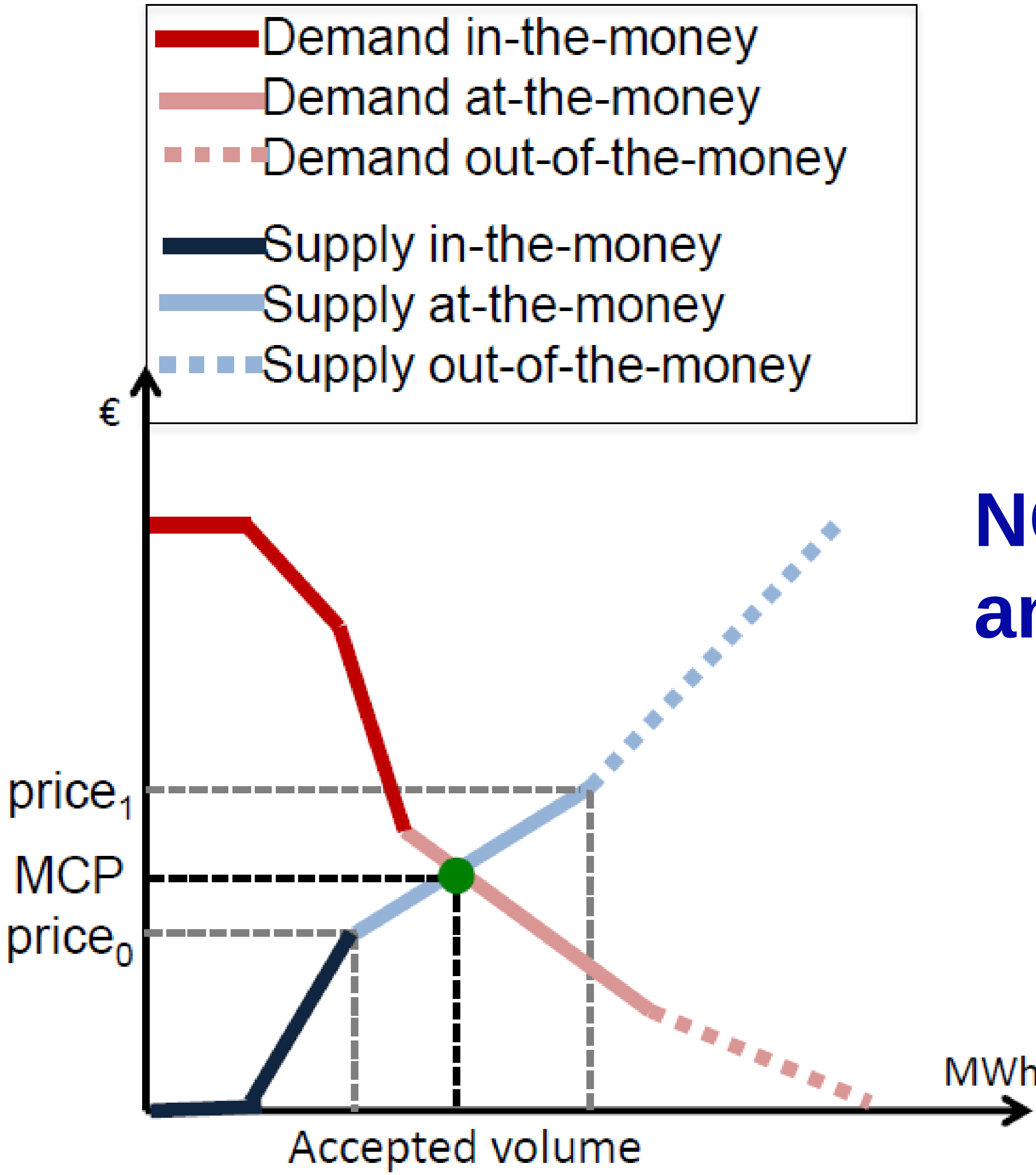




HOURLY LINEAR PIECEWISE ORDERS

- Hourly piecewise orders are defined by
  - A side (buy or sell)
  - A volume
- price0: at which the order starts to be accepted
- price1: at which the order is totally accepted (price1 > price0)

- EUPHEMIA provides solutions such that
  - Orders in-the-money are fully accepted
    - Supply where price1< MCP
    - Demand where price1> MCP
  - Orders out-of-the-money are fully rejected
    - Supply where price0> MCP
    - Demand where price0< MCP
  - Orders at-the-money are accepted to the corresponding proportion
    - Acceptance ratio = (MCP-price0) / (price1-price0)



NORDPOOL and EPEX

REGULAR BLOCK ORDERS

- Regular Block orders are defined by
  - Type (buy or sell)
  - one single price
  - one single volume
  - Period: consecutive hours over which the block spans

- **A regular block order cannot be accepted partially. It is either totally rejected or accepted (Fill-or-Kill condition).**

Example

Type	PERIOD	PRICE	VOLUME
BLOCK BUY	Hours 1-24	40 Euros	200 MWh
BLOCK SELL	Hours 8-12	40 Euros	50 MWh

Profile block order

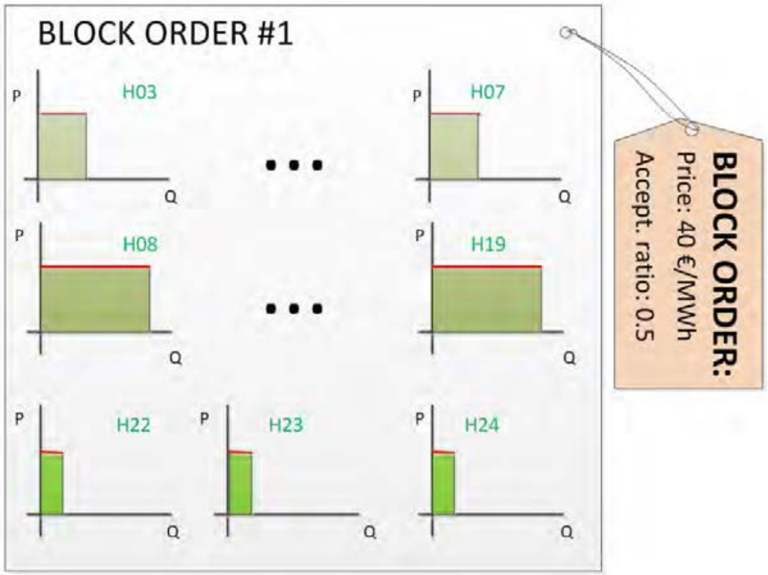
- Profile Block orders are defined by
  - Type (buy or sell)
  - one single price
  - Minimum Acceptance Ratio
  - Period: hours over which the block spans
  - Volume for each hour

- **The Profile Block orders can only be accepted with an acceptance ratio higher or equal than the minimum acceptance ratio**

Example

Block Order #1

- Price: 40 €/MWh
- Minimum acceptance ratio: 0.5
- Intervals: Hours (3-7), hours (8-19) and hours (22-24)
- Volume: 80 MWh in the first interval, 220 MWh in the second one, and 40 MWh in the third one.



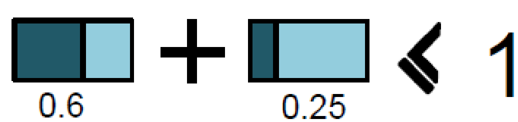
Acceptance of the supply block orders

- if the block volume weighted average market clearing price for the periods during which the block is defined is above the price of the block, then the block can be entirely accepted, which means that all the energy in the block is accepted;
- if the block volume weighted average market clearing price for the periods during which the block is defined is below the price of the block, then the block must be entirely rejected;
- if the block volume weighted average market clearing price for the periods during which the block is defined is exactly the price of the block, then the Block can be either fully rejected, fully accepted or partially accepted, to the extent that the ratio “accepted volume/total submitted volume” is greater than or equal to the minimum acceptance ratio of the block (e.g. 0.5) and equal over all periods.

- For demand blocks, the rules are symmetrical (above$\leftrightarrow$below).

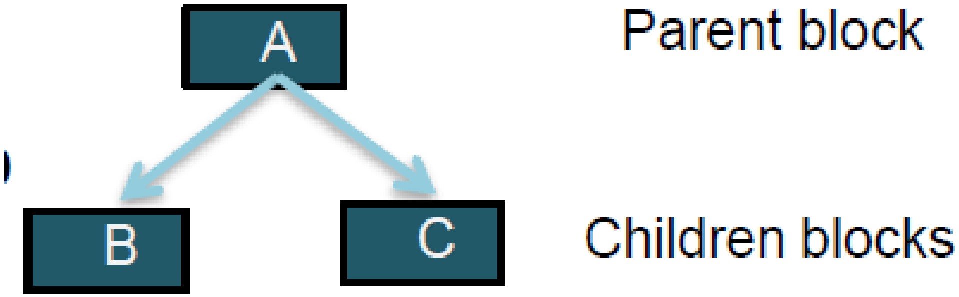
EXCLUSIVE BLOCK ORDERS

- Exclusive Group = Set of Block Orders in which the sum of the accepted ratios cannot exceed 1
  - In the particular case of blocks that have a minimum acceptance ratio of 1 it means that at most one of the blocks of the exclusive group can be accepted.
- Between the different valid combinations of accepted blocks the algorithm chooses the one which maximizes the optimization criterion
- Acceptance rules of Block Orders totally apply



LINKED BLOCK ORDERS

- Block orders can be linked together, i.e. the acceptance of individual block orders can be made dependent on the acceptance of other block orders.
- The block which acceptance depends on the acceptance of another block is called “child block”, whereas the block which conditions the acceptance of other blocks is called “parent block”.



The rules for the acceptance of linked block orders:

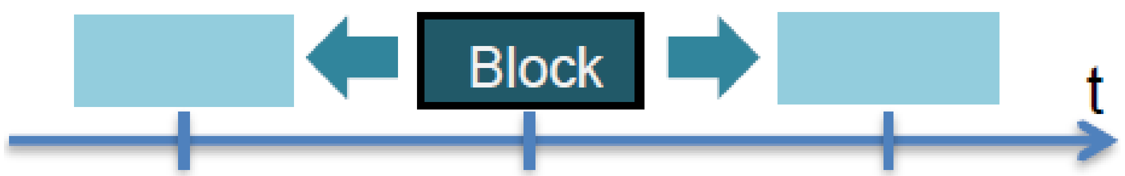
1. The acceptance ratio of a parent block is greater than or equal to the acceptance ratio of its child blocks
2. (Possibly partial) acceptance of child blocks can allow the acceptance of the parent block when:
   1. the surplus of a family is non-negative
   2. leaf blocks (block order without child blocks) do not generate welfare loss
3. A parent block which is *out-of-the-money* can be accepted in case its accepted child blocks provide sufficient surplus to at least compensate the loss of the parent.
4. A partially accepted child block must be *at-the-money* if it has no child blocks that are accepted.
5. A child block which is *out-of-the-money* cannot be accepted even if its accepted parent provides sufficient surplus to compensate the loss of the child, unless the child block is in turn parent of other blocks (in which case rule 3 applies).

Comment

- In an easy common configuration of two linked blocks, the rules are easy.
  - The parent can be accepted alone, but not the child that always needs the acceptance of the parent first.
  - The child can “save” the parent with its surplus, but not the opposite.

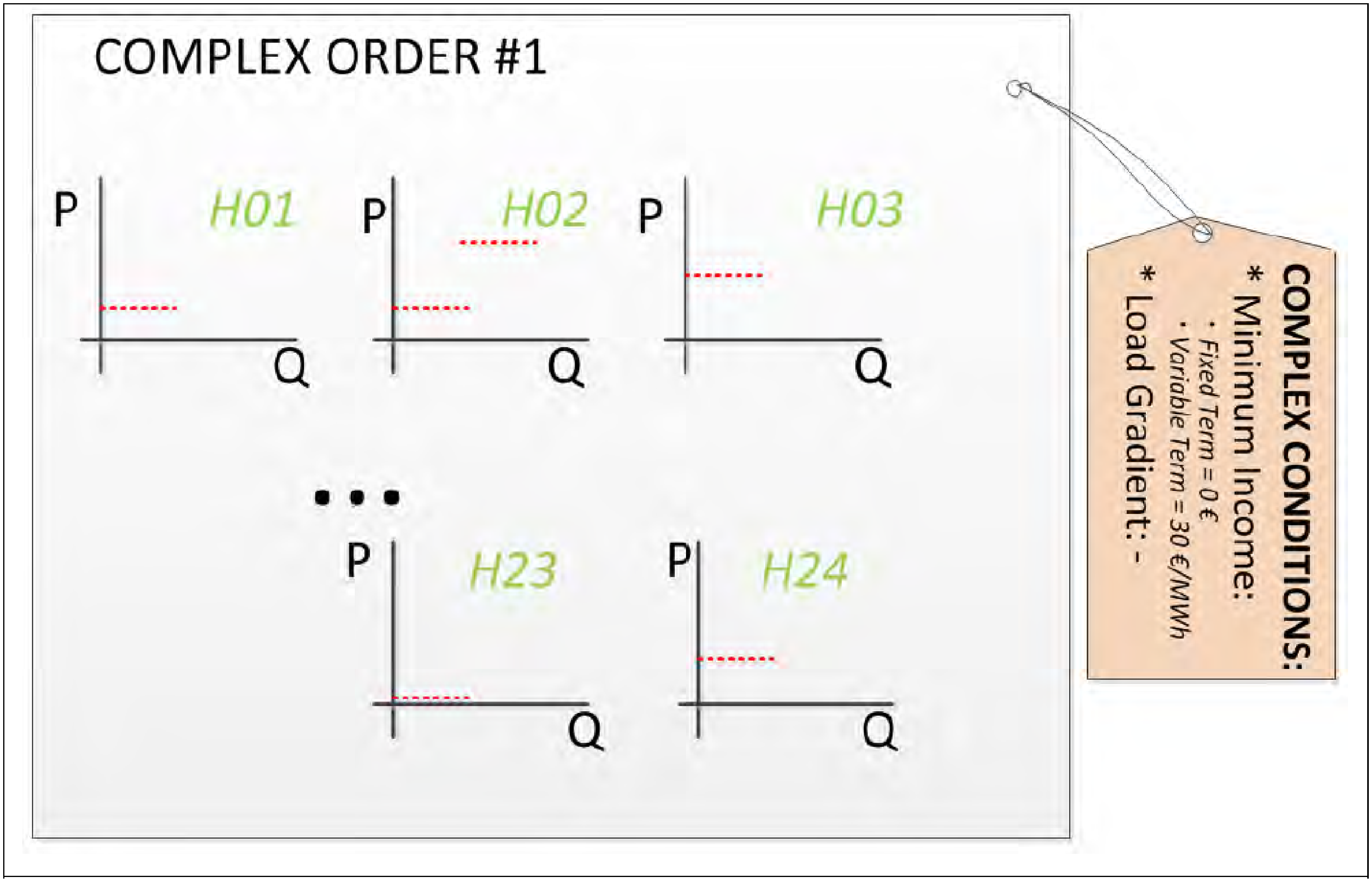
FLEXIBLE HOURLY BLOCK ORDERS

- A flexible “hourly” order is a block order with a fixed price limit, a fixed volume, minimum acceptance ratio of 1, with duration of 1 hour.
- The hour is not defined by the participant but will be determined by the algorithm (hence the name “flexible”).
- The hour in which the flexible hourly order is accepted, is calculated by the algorithm and determined by the optimization criterion



Complex order

- A complex order is a set of simple supply stepwise hourly orders (which are referred to as hourly sub-orders) belonging to a single market participant, spreading out along different periods and are subject to a complex condition that affects the set of hourly sub-orders as a whole.
- Complex conditions are of two types:
  - Minimum Income Orders (MIC)
  - Load Gradient


COMPLEX ORDER #1
P
H01
Q
P
H02
Q
P
H03
Q
...
P
H23
Q
P
H24
Q
COMPLEX CONDITIONS:
* Minimum Income:
• Fixed Term = 0 €
• Variable Term = 30 €/MWh
* Load Gradient: -

COMPLEX ORDERS & MIC ORDERS

- Complex orders (with their set of hourly sub-orders) subject to Minimum Income Condition constraints are called MIC orders (or MICs).
- The Minimum Income economical constraint means that the amount of money collected by the order in all periods must cover its production costs, which is defined by a fix term (representing the startup cost of a power plant) and a variable term multiplied by the total assigned energy (representing the operation cost per MWh of a power plant).
  - FT: Fixed Term in Euros which shows the fixed costs of the whole amount of energy traded in the order
  - VT: Variable Term in Euros per accepted MWh which shows the variable costs of the whole amount of energy traded in the order
- The same acceptance rules for Stepwise Hourly Orders are applied to MIC Orders and the revenue received by an activated MIC must be greater or equal to FT+E*VT

Activation or deactivation of a MIC order

- In the final solution, MIC orders are activated or deactivated (as a whole):
  - In case a MIC order is activated, each of the hourly sub-orders of the MIC behaves like any other hourly order, which means accepted if they are in-the-money and rejected if they are out-of-the-money.
  - In case a MIC order is deactivated, each of the hourly sub-orders of the MIC is fully rejected, even if it is in-the-money
- The final solution given by EUPHEMIA will not contain active MIC orders not fulfilling their Minimum Income Condition constraint (also known as paradoxically accepted MICs).

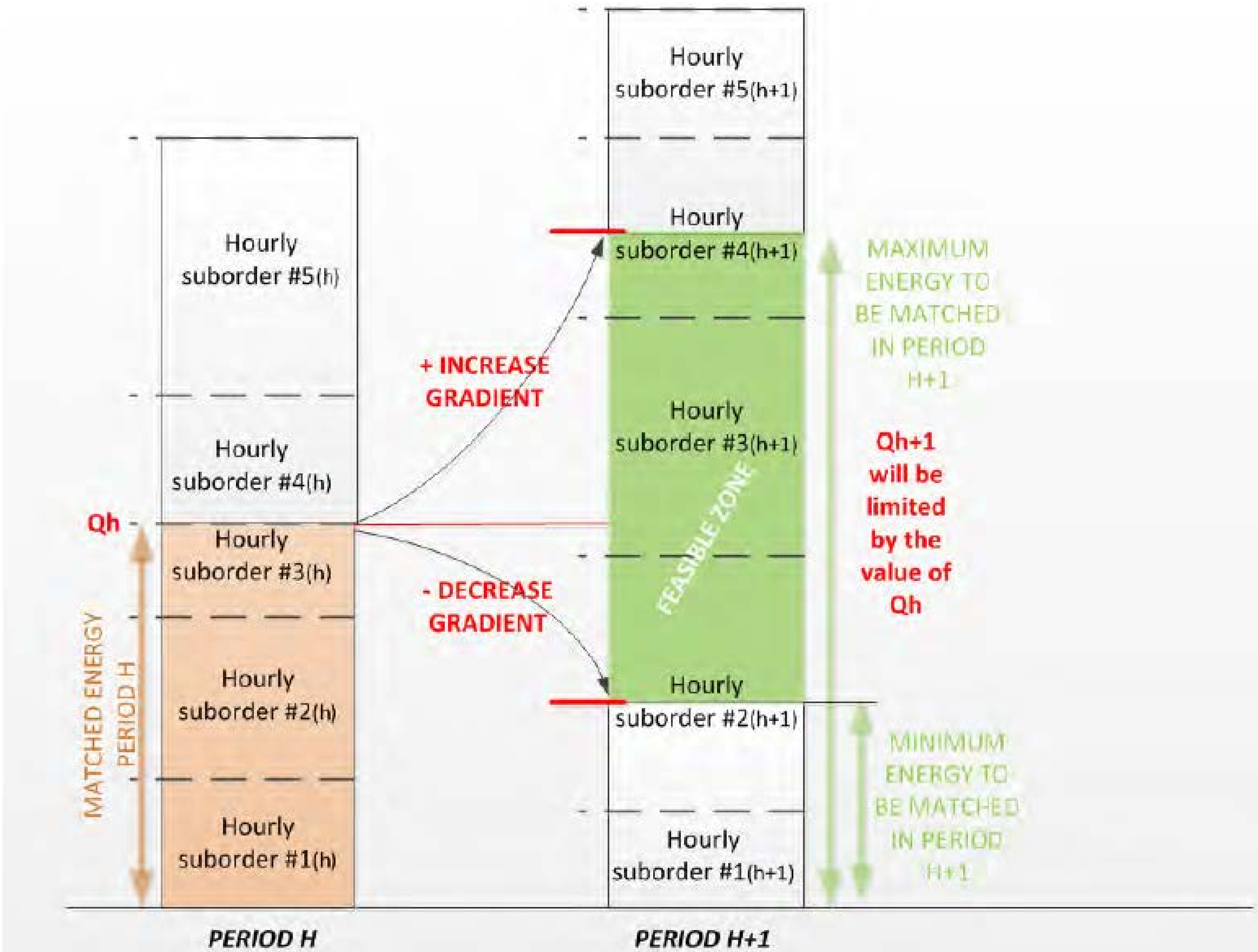
Scheduled Stop condition and MIC order

- In case the owner of a power plant which was running the previous day offers a MIC order to the market, he may not want to have the production unit stopped abruptly in case the MIC is deactivated.
- For the avoidance of this situation, the sender of a MIC has the possibility to define a “scheduled stop”.
- Using a schedule stop will alter the deactivation of the MIC: the deactivation will not imply the automatic rejection of all the hourly sub-orders.
- On the contrary, the first (i.e. the cheapest) hourly sub-order in the periods that contain scheduled stop (up to period 3) will not be rejected but will be treated as any hourly order.

COMPLEX ORDERS & LOAD GRADIENT

- Complex orders (with their set of hourly sub-orders) on which a Load Gradient constraint applies are called Load Gradient Orders.
- Generally speaking, the Load Gradient constraint means that the amount of energy that is matched by the hourly sub-orders belonging to a Load Gradient order in one period is limited by the amount of energy that was matched by the hourly sub-orders in the previous period.
- There is a maximum increment / decrement allowed (the same value for all periods). Period 1 is not constrained.
- A Load Gradient Order (LG) is defined by the next terms:
  - ***Increase Gradient:*** Maximum increase gradient in MWh
  - ***Decrease Gradient:*** Maximum decrease gradient in MWh

Example



Hourly
suborder #5(h+1)
Hourly
suborder #5(h)
Hourly
suborder #4(h+1)
MAXIMUM
ENERGY TO
BE MATCHED
IN PERIOD
H+1
+ INCREASE
GRADIENT
Hourly
suborder #3(h+1)
Hourly
suborder #4(h)
Qh+1
will be
limited
by the
value of
Qh
Qh
Hourly
suborder #3(h)
FEASIBLE ZONE
- DECREASE
GRADIENT
Hourly
suborder #2(h)
Hourly
suborder #2(h+1)
MATCHED ENERGY
PERIOD H
MINIMUM
ENERGY TO
BE MATCHED
IN PERIOD
H+1
Hourly
suborder #1(h)
Hourly
suborder #1(h+1)
PERIOD H
PERIOD H+1

Comments

- Complex orders (with their set of hourly sub-orders) can be subject to both
  - load gradient and
  - minimum income condition (with or without scheduled stop).

PUN

- National demand of Italy (with the exception of storage pumps) is matched to a single purchase price (PUN), regardless of its location
- Expenses coming from the consumers paying the PUN must be equal to the expenses that would have come from consumers with zonal prices (minimum tolerance accepted)
- Acceptance/rejection of buying bids subject to PUN must respect the following conditions
  - Buying bids in-the-money (Offered price > PUN) are fully accepted
  - Buying bids out-of-the-money (Offered price < PUN) are fully rejected
  - Buying bids at-the-money (Offered price = PUN) can be curtailed
- In order to respect the aforementioned requirements, PUN and bidding area prices must be calculated simultaneously (PUN cannot be calculated ex-post)

- Supply Merit orders are selling offers. They are cleared at their bidding area price
- Non-PUN demand orders (pump plants and buying bids on cross-border long term capacities): Buying Bids from pump plants and buying bids in non-Italian national zones* are demand Merit Orders. They are cleared at the price of their bidding area
- PUN Merit Orders: the rest of the buying bids (the ones related to national consumption) are cleared at the common national PUN price (which is different from their bidding area price)
- This PUN price is defined as the average price of GME marginal market prices for its bidding areas, weighted by the purchase quantity assigned to PUN Orders in each bidding area (subject to a tolerance, ϵ). That is:

$$P_{PUN} * \Sigma_z Q_z = \Sigma_z P_z * Q_z + \epsilon$$

Bidding area

- A *bidding area* is the smallest entity representing a given market where orders can be submitted. EUPHEMIA computes a market clearing price for every *bidding area* per period and a corresponding *net position*
  - *net position of a bidding area is* the difference between the matched supply and the matched demand quantities belonging to that *bidding area*
- *Bidding areas* can exchange energy between them in an ATC model a flow based model (Section 4.3) or a hybrid model (hybrid of the other two).
- The *net position* of a *bidding area* can be subject to limitations in the variation between periods

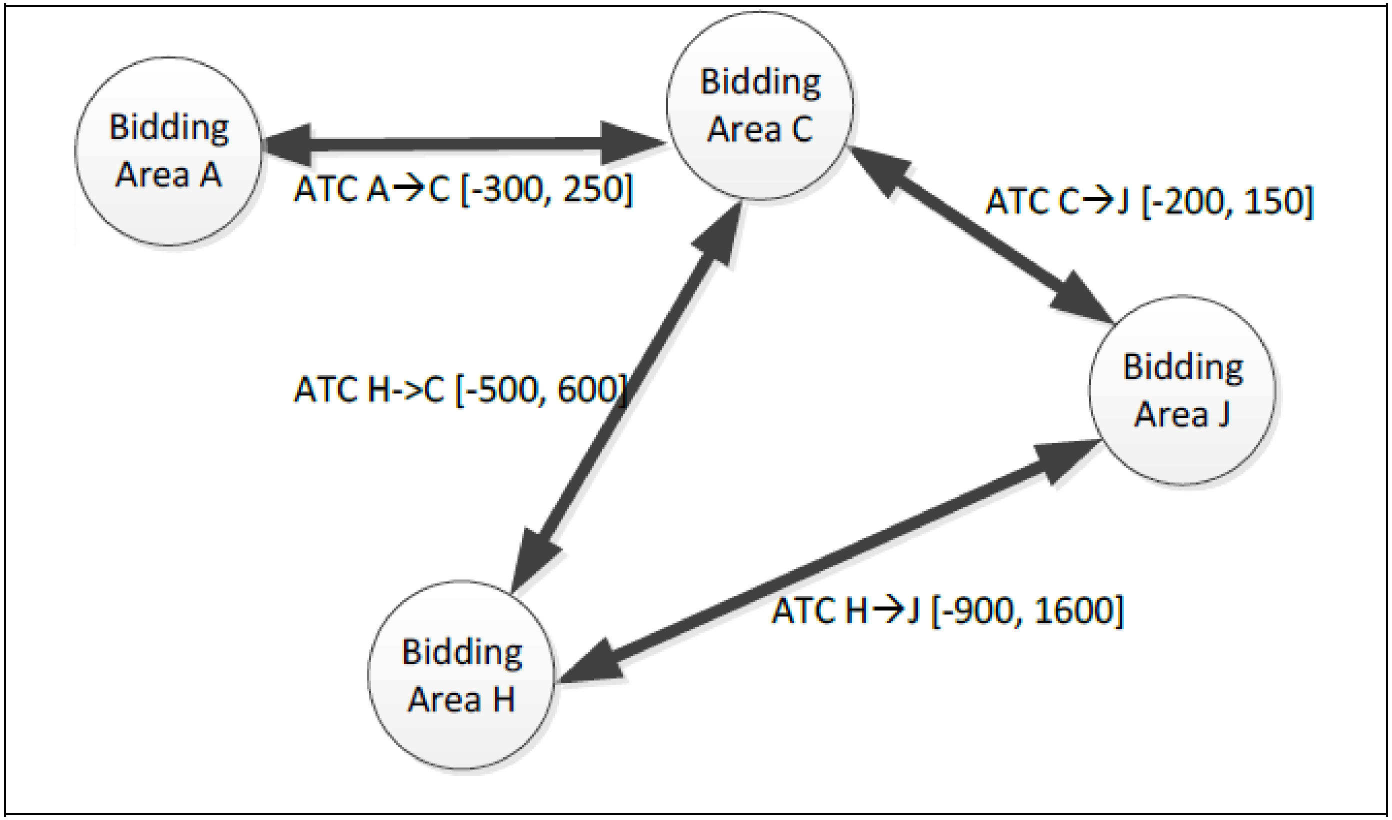
Net position ramping (hourly and daily)

- The algorithm supports the limitation on the variations of the *net position* from one hour to the next. There are two ramping requirements on the *net position*.
  - Hourly *net position* ramping: this is a limit on the variation of the *net position* of a *bidding area* from each hour to the next.
- Daily (or cumulative) *net position* ramping: this is a limit on the amount of reserve capacity used during the day.

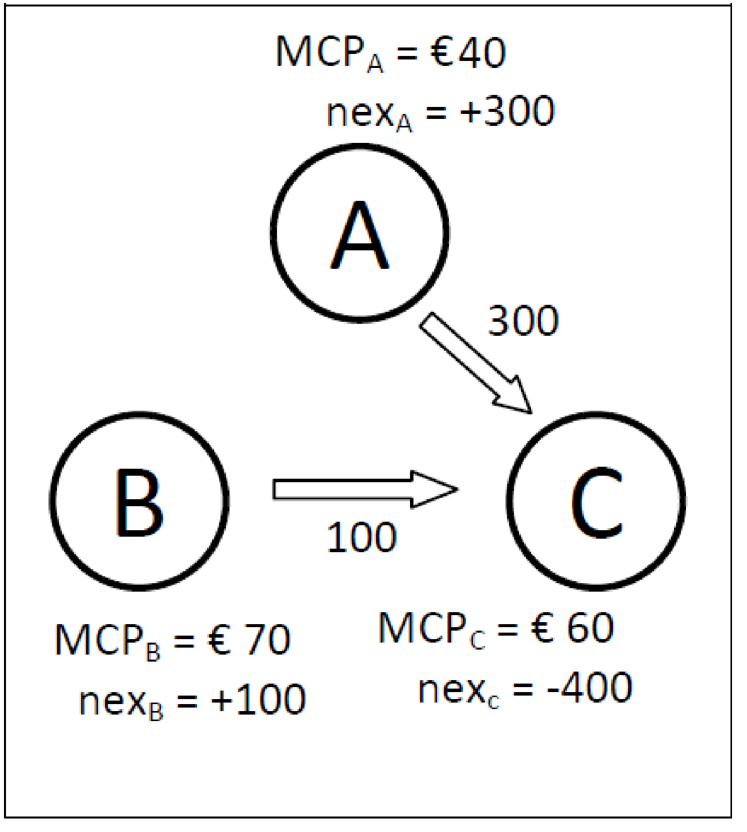
Transmission constraints

- ***ATC network model:*** The network is described as a set of lines interconnecting bidding areas. The nomination of the line can be made up to its Available Transfer Capacity (ATC)
- ***Flow-based network model:*** Also known as PTDF model, with all bidding areas connected in a meshed network. It expresses the constraints arising from Kirchhoff's laws and physical elements of the network in the different contingency scenarios considered by the TSOs. It translates into linear constraints on the net positions of the different bidding areas
- ***Hybrid network model:*** Some bidding areas are connected using the Flow-based network model; the remaining using the ATC network model

ATC


Bidding Area A
Bidding Area C
Bidding Area J
Bidding Area H
ATC A→C [-300, 250]
ATC C→J [-200, 150]
ATC H->C [-500, 600]
ATC H→J [-900, 1600]

FG

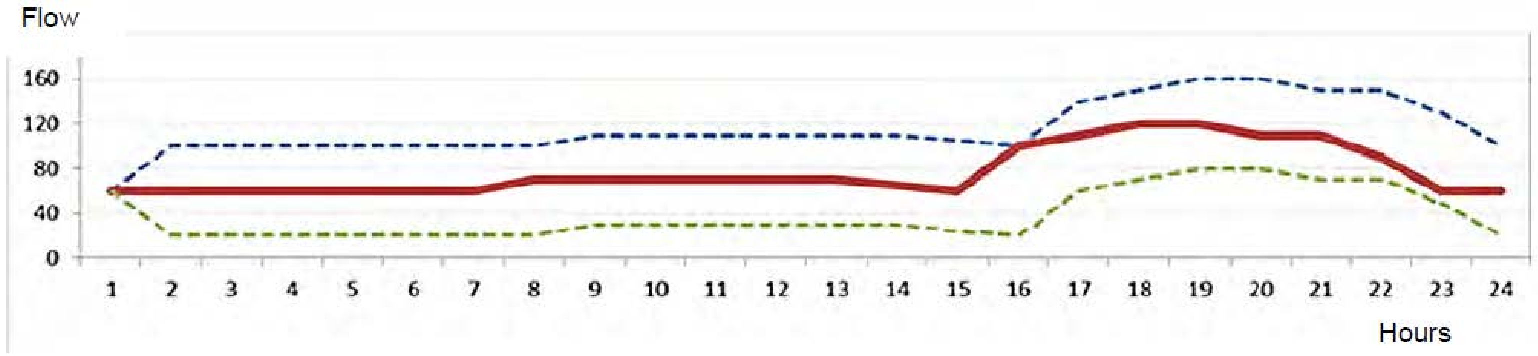


NETWORK DATA AND RAMPING LIMITS

- EUPHEMIA supports a wide range of network restrictions:
  - Ramping limit for individual or sets of lines between consecutive hours
  - Line tariffs
  - Line losses
  - Hourly and daily net position ramping limits for bidding areas

Hourly Flow Ramping Limit on Individual Lines

- The hourly variation of the flows over an interconnector can be constrained by a ramping limit.
- This limitation confines the flow in an “allowed band” between the hours when moving from one hour to the next
- The ramping limit constrains the flow that can pass through the line in hour h depending on the flow that is passing in hour h-1.



Line Ramping Limit definitions

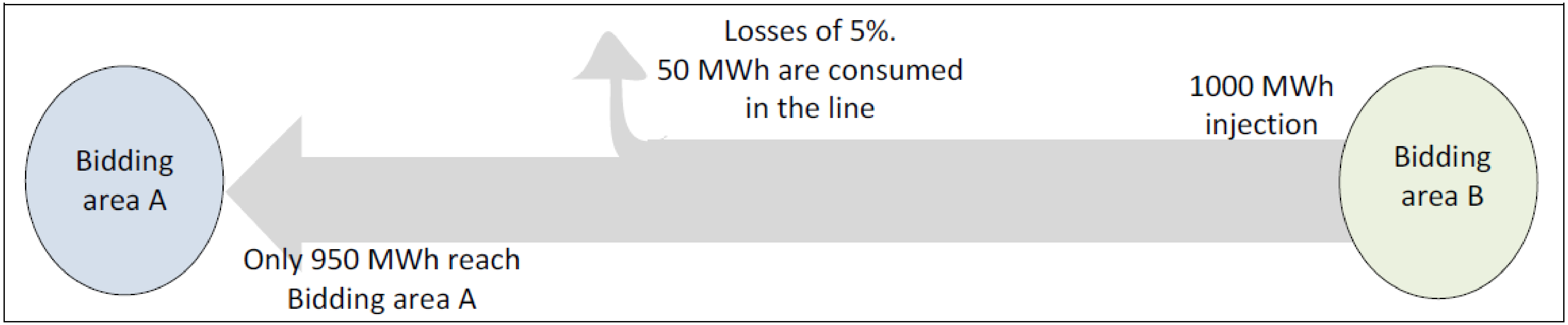
- The ramping limit is defined by: The maximum increment of flow from hour h-1 to hour h (called ramping-up), and the maximum decrement of flow from hour h-1 to hour h (called ramping-down).
- The ramping limit may be different for each period.
- For period 1, the limitation of flow takes into account the value of the flow of the last hour of the previous day.

Hourly Flow Ramping Limit on Line Sets

- Flow ramping constraints can apply to a group of interconnectors at once, i.e. the sum of the flows over a set of lines can be restricted by ramping limits.

Losses

- Flow on a line between *bidding areas* may be subject to losses. In this case, part of the energy that is injected in one side of the line is lost, and the energy received at the end of the cable is less than the energy initially sent



Tariffs

- In an ATC network model, the DC cables (or a controlled line) might be operated by merchant companies, who levy the cost incurred for each passing MWh in the cable.
  - In the algorithm, these costs can be represented as flow tariffs.
- The flow tariff is included as a loss with regard to the *congestion rent*.
- This will show in the results as a threshold for the price difference.
- If the difference between the two corresponding market clearing prices is less than the tariff then the flow will be zero.
- If there is a flow the price difference will be exactly the flow tariff, unless there is congestion.
- Once the price difference exceeds the threshold the *congestion rent* becomes positive.