Energy Economics

Energy market module (focus on electricity markets)

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Textbook: Perez Arriaga, Regulation of the power sector, pp.341-379

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Constrained market clearing

Constrained SMP mechanism

- **Definition:** A congestion occurs when a transmission line is used at its maximum capacity. Transactions on the power market may even exceed the above-mentioned capacity, and make it unfeasible to execute them "physically"
- **Market impact:** market results based on demand/supply matching is not fully dispatchable

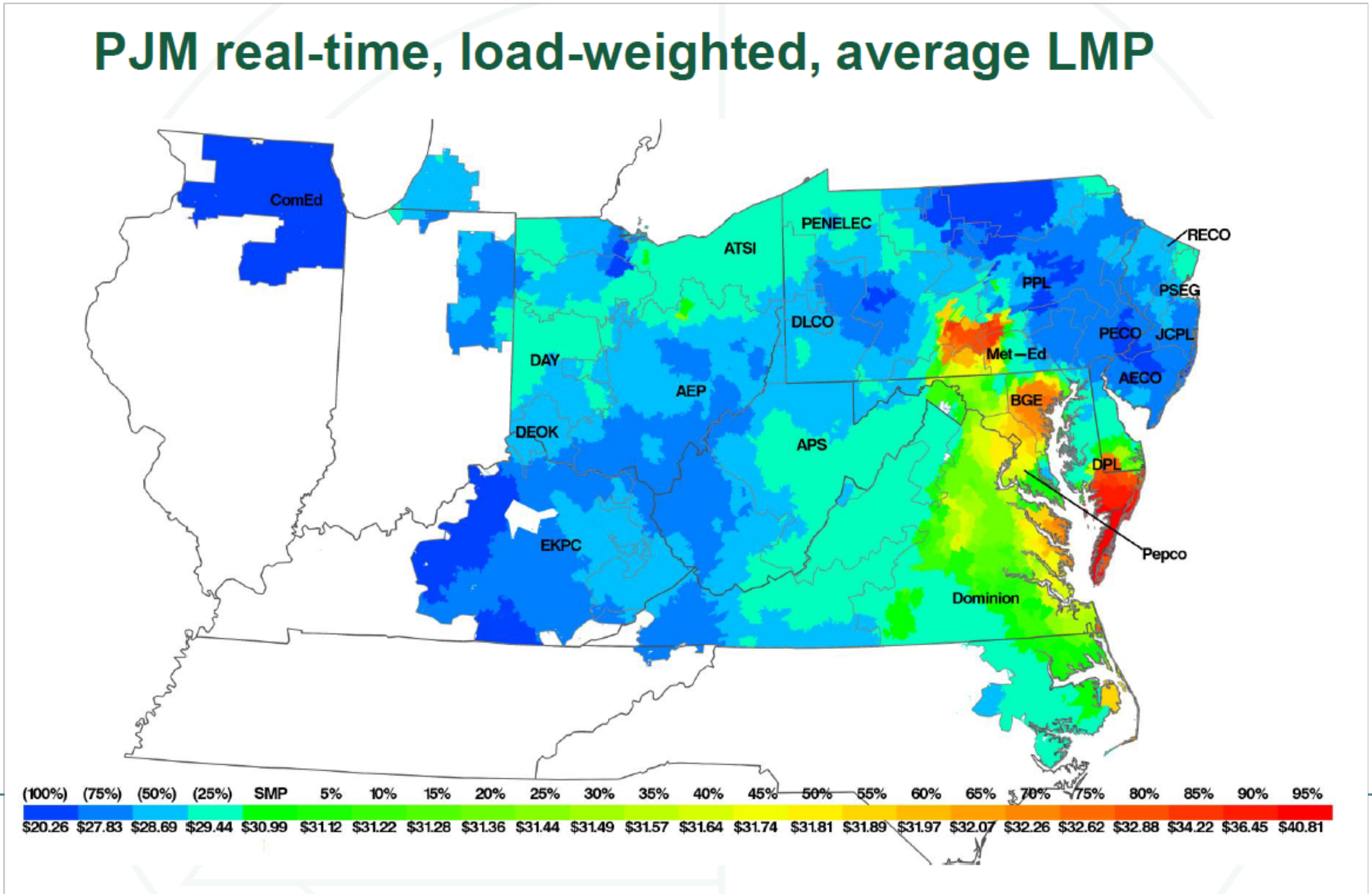
Ex-post resolution

1. ***Counter trading***: The transmission system operator (TSO) buys "services" for solving congestions on a dedicated market
2. **Redispatching**: The TSO curtails capacity to solve congestions (a problem of compensation arises)

Ex-ante resolution

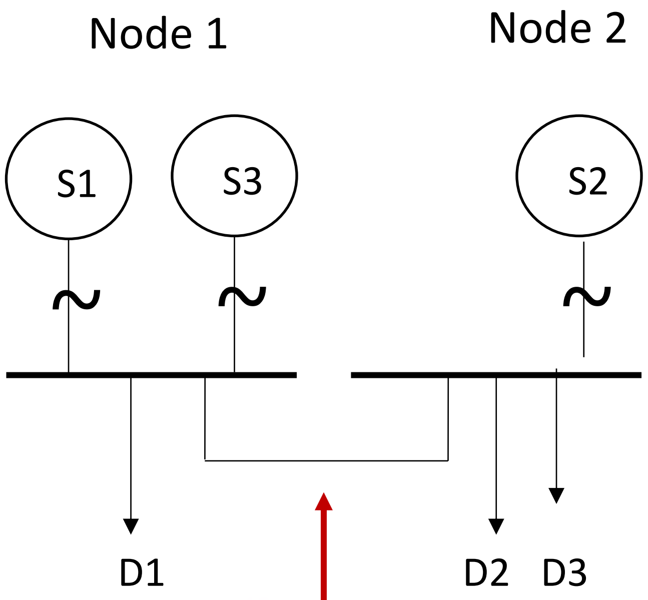
1. ***Nodal price(es. PJM, Ercot)***
   - *Market price arises in each injection/withdrawn point*
   - *Price differentials include congestion costs.*
   - *Algorithms for pricing are complex, price is not transparent, managing the system is rather difficult, but efficiency is the maximum possible.*
2. ***Zonal price (Nordpool, GME)***
   - *Market is divided into market zones.*
   - *If power flows exceed the grid's maximum capacity the market splits into several sub-markets (depending on the number of the zones) and a price originates for each of them.*

Constrained SMP mechanism: example PJM

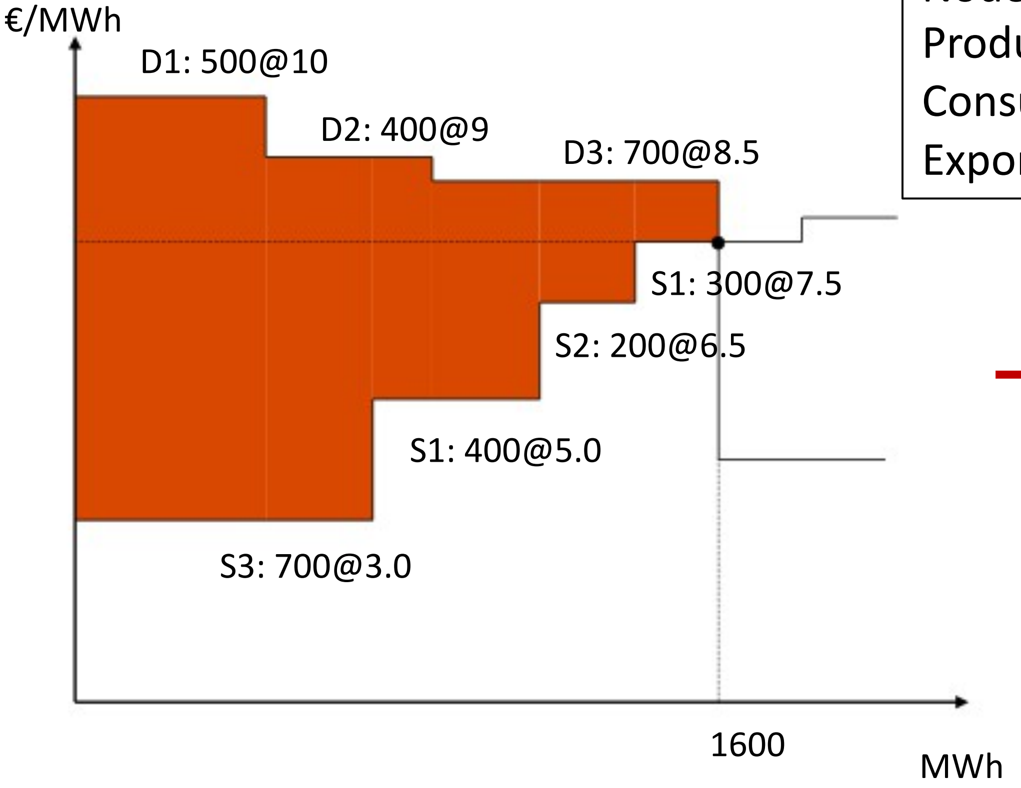


Constrained SMP mechanism: example Nordpool

Constrained SMP mechanism



Limited interconnection capacity = **800 MW**



Node 1:
Production: 1400
Consumption: 500
Export: 900

Node 2:
Production: 200
Consumption: 1100
Import: 900

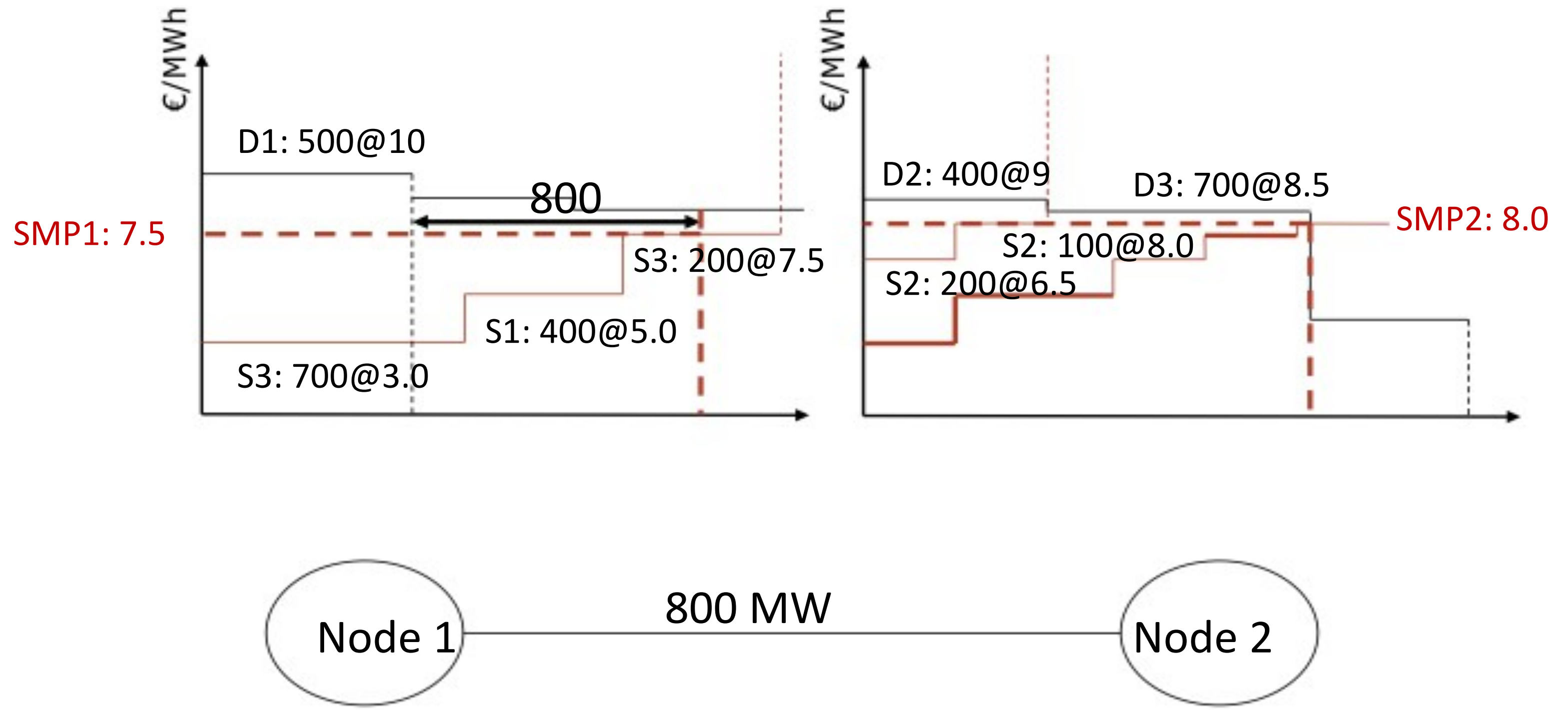
Market result violates the physical constraint

Economic merit order result must be modified

Constrained SMP mechanism

- The line flow limit splits the system into two markets, one at each node
- The economic generation at node 1 is used to the extent physically feasible to meet the load at node 2
- The demand in node 1 is modified to incorporate the demand from node 2
- The remaining demand at node 2 is supplied locally
- The two markets have different clearing prices (higher in the importing node than in the exporting one)

Constrained SMP mechanism



- If unconstrained solution is not feasible, the market is splitted
- In each market zone marginal supplier belong to the that zone

Constrained SMP mechanism

Player	Accepted quantity (MWh)	Price (€/MWh)	Revenues (€)	Costs (€)	Variation
S1	600	7.5	4500		-750
S2	300	8.0	2400		900
S3	700	7.5	5250		0
D1	500	7.5		3750	0
D2	400	8.0		3200	200
D3	700	8.0		5600	350
Total	1600		12150	12550	

Market splitting transfer to market participants price signals on overcapacity/shortage:

- Suppliers/Customers in net export zones reduces revenues (price/quantity effect)/costs
- Customers/Suppliers in net import zones increase costs/revenues

↓

Price signal effect to address investments in electricity production capacity

Constrained SMP mechanism: congestion rent

Congestion rent:

- Difference between the amounts paid by buyers and the amounts received by sellers
- It is collected by the TSO
- It is part of the total surplus

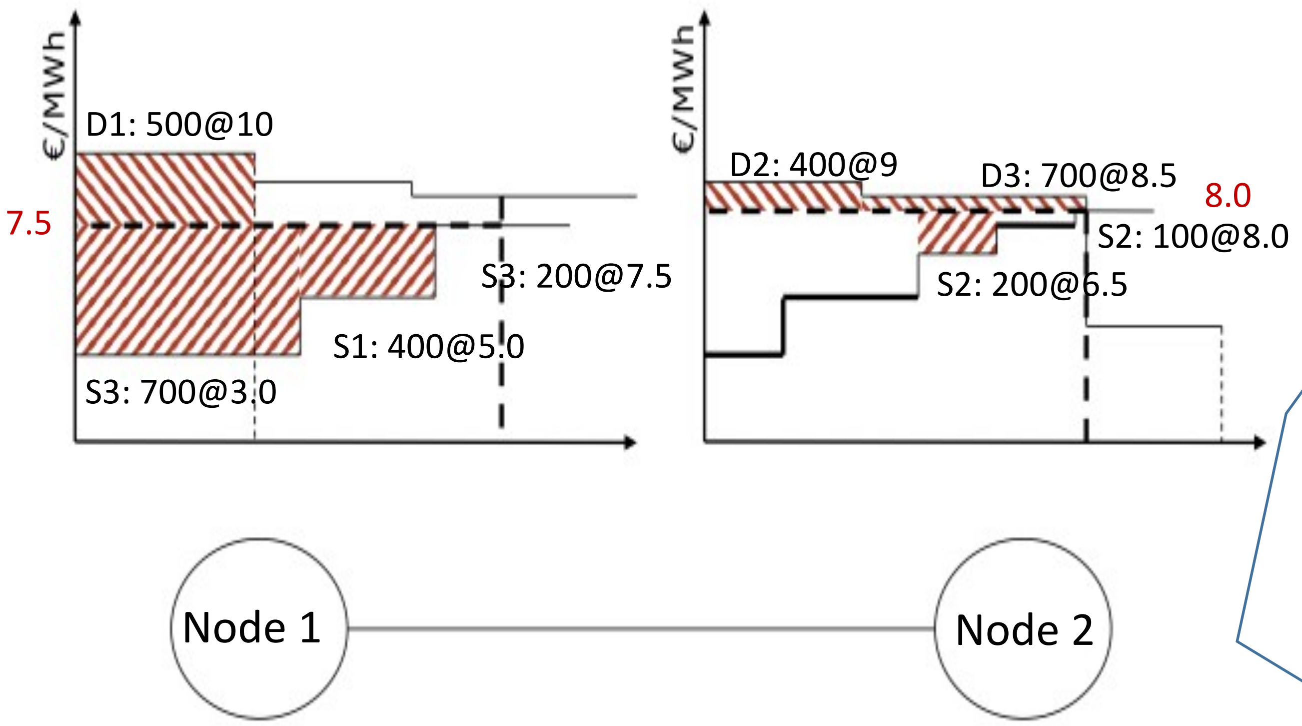
$$k = \sum_{i=1}^{n} SMP_i(Q_{Di}) - \sum_{j=1}^{m} SMP_j(Q_{Sj})$$

$$\bar{S} = \overline{S^D} - \overline{S^S} + k$$

Constrained total surplus

Constrained SMP mechanism: congestion rent

Constrained Surplus calculation



Sellers	Surplus	Buyers	Surplus
S1	1000	D1	1250
S2	300	D2	400
S3	3150	D3	350
Total	4450		2000
Congestion rent	12550-12150=400		
Total surplus	4450+2000+400=6850		

Maximum interconnection flows times zonal difference in price: 800 MW x (0.5 €/MWh) = 400 €

Constrained SMP mechanism: congestion costs

Congestion cost:

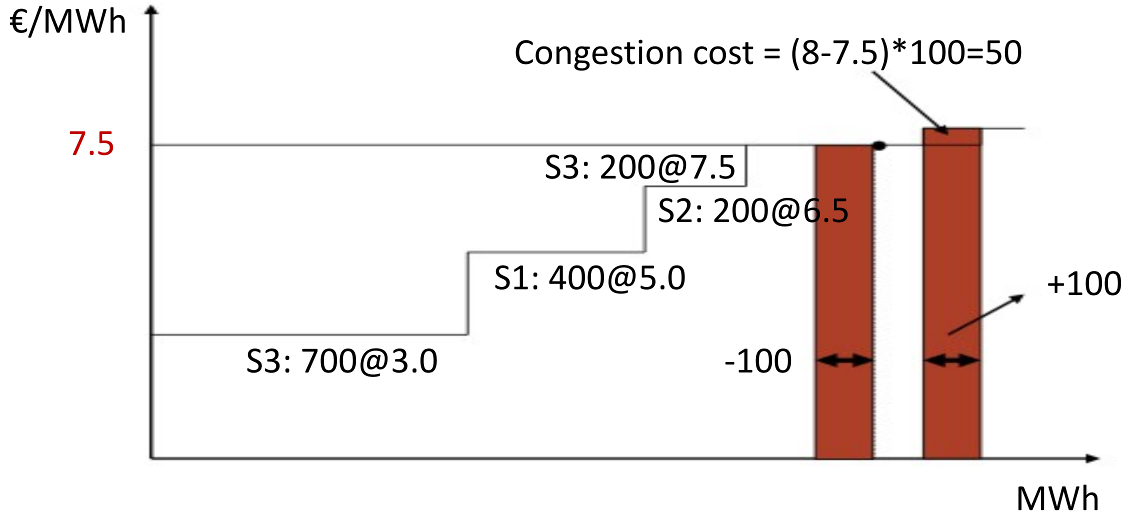
- Congestions produce a reduction in total surplus
- This reduction is called **deadweight loss**

$$\varepsilon = -(\bar{S} - S)$$

ε =-(6850-6900)=50

Congestion cost:

- The efficiency loss represent the redispatch costs: the costs incurred because of the use of out-of-merit units to avoid violation of the network constraints



Constrained SMP mechanism: congestion costs

Short term effects

- Change in merit order wrt unconstrained equilibrium
- Multiple prices
- Change in producer and consumer surplus
- Congestion rents
- Redispatch costs

Long term effects:

- Price difference: siting of power plants in nodes with higher prices
- Congestion rent: transmission expansion necessary

Constrained SMP mechanism: exercise

- The electricity market in Country A consist of 2 zones: North and South
- Myplants owns 2 power plants and competes with other power plants
- Myplants must define the optimal bidding knowing the competitors' bid strategies and level of market demand (and constraint) in each hour

	Hour 1	**Hour 2**
North zone - demand (MW)	60	80
South zone - demand (MW)	70	90
Total demand MW	**130**	**170**
Transmisison capacity MW	80	80
bid granularity €/MWh	0.1	0.1

Competitors	**Capacity (MW)**	**bid €/MWh**	**Zone**
plant 1 hydro	40	4	North
plant 2 CCGT	60	8	North
plant 3 peakloader	20	9	South
plant 4 peakloader	30	12	South
Total Competitors' Capacity	150		

Myplants	**Capacity (MW)**	**variable costs €/MWh**	**zone**
myCCGT	80	7.5	North
mypeakloader	40	9	South
Total Myplants' Capacity	**120**		

Constrained SMP mechanism: exercise

10:00

Aim: calculate the optimal bids for Myplants in hours 1 assuming that:

- **Myplants maximize its profit**
- **Myplants doesn't bid below its variable costs**
- **Competitors plants have priority of dispatch wrt Myplants**

Hint:

- Build the supply curve based on bid and variable costs level
- Verify grid constraint condition
- Set the bid for Myplants to maximize its' profit

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Myplants	Capacity (MW)	variable costs €/MWh	zone
myCCGT	80	7.5	North
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Total Myplants' Capacity	**120**		

Constrained SMP mechanism: solution – hour 1

Zone	Hour 1	Zone	MW - capacity	Cumulative max production	Cumulative production	Variable costs	Bid	Dispatched (Yes/no)
North	plant 1 hydro	North	40	40	40		4	Yes
North	plant 2 CCGT	North	80	120	120		8	Yes
North	**myCCGT**	**North**	**60**	**180**	**130**	**7.5**	**8.4**	**Yes**
South	plant 3 peakloader	South	20	200	0		8.5	No
South	mypeakloader	South	30	230	0	9	0	No
South	plant 4 peakloader	South	30	260	0		12	No

- myCCGT plant can bid at competitors' bid-ε price: 9-0.1=8.9 €/MWh. This bid is higher than the variable costs of CCGT plant
- Mypeakloader has higher variable cost wrt equilibrium SMP: rationale strategy is not bidding
- Profit for Myplants company: 8.4€/MWh*(130-120)=84 €

Constrained SMP mechanism: exercise

10:00

Aim: calculate the optimal bids for Myplants in hours 2 assuming that:

- **Myplants maximize its profit**
- **Myplants doesn't bid below its variable costs**
- **Competitors' plants have priority of dispatch wrt Myplants**

Hint:

- Build the supply curve based on bid and variable costs level
- Verify grid constraint condition
- Set the bid for Myplants to maximize its' profit

	Hour 1	Hour 2
North zone - demand (MW)	60	80
South zone - demand (MW)	70	120
Total demand MW	**130**	**200**
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Competitors	Capacity (MW)	bid €/MWh	Zone
plant 1 hydro	40	4	North
plant 2 CCGT	60	8	North
plant 3 peakloader	20	8.5	South
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Total Competitors' Capacity	150		

Myplants	Capacity (MW)	variable costs €/MWh	zone
myCCGT	80	7.5	North
mypeakloader	40	9	South
Total Myplants' Capacity	**120**		

Constrained SMP mechanism: solution – hour 2

Zone	Hour 2	MW - capacity	Cumulative max production	Cumulative production	Variable costs	Bid	Dispatched (Yes/no)
North	plant 1 hydro	40	40	40		4	Yes
North	plant 2 CCGT	60	100	100		8	Yes
North	myCCGT	80	180	180	7.5	8.4	Yes
South	plant 3 peakloader	20	200	200		8.5	Yes
South	mypeakloader	40	240	0	9	0	No
South	plant 4 peakloader	30	270	0		12	No

- North-South flows: demand – south plant dispatched = 120-20=100 -> **violation grid constraints**
- The unconstrained dispatch is not feasible
- We must find the optimal dispatch wrt 2 single market zones

Constrained SMP mechanism: solution – hour 2

Zone	Hour 2	MW - capacity	Cumulative max production	Cumulative production	Variable costs	Bid	Dispatched (Yes/no)
North	plant 1 hydro	40	40	40		4	Yes
North	**myCCGT**	**80**	**120**	**120**	**7.5**	**7.9**	**Yes**
North	plant 2 CCGT	60	180	160		8	Yes

Zone	Hour 2	MW - capacity	Cumulative max production	Cumulative production	Variable costs	Bid	Dispatched (Yes/no)
South	plant 3 peakloader	20	20	20		9	Yes
South	**mypeakloader**	**40**	**60**	**40**	**9**	**11.9**	**Yes**
South	plant 4 peakloader	30	90	0		12	No

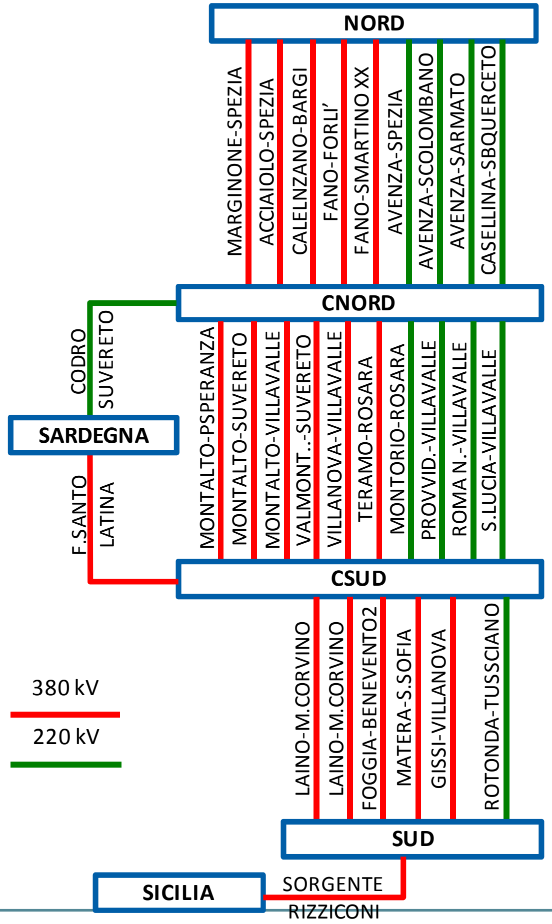
Profit

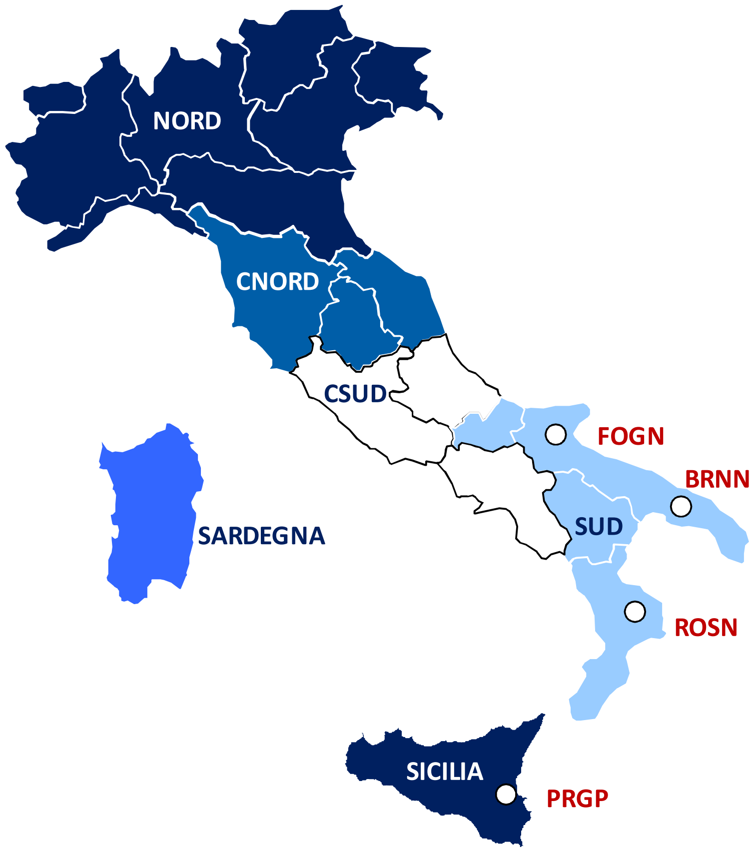
- (7.9-7.5)*80
- (11.9-9)*20
- Profit: 90 €

- myCCGT plant can bid at competitors' bid-ε price: 8-0.1=7.9 €/MWh. This bid is higher than the variable costs of CCGT plant
- Mypeakloader plant can bid at competitors' bid-ε price: 12-0.1=11.9 €/MWh. This bid is higher than the variable costs of CCGT plant

Italian DAM

Italian asymmetric zonal mechanism





Criteria for the definition of market zones:
- Constrained inter-zone transmission capacity
- No intra-zonal congestion
- The location of injection and withdrawal points within a zone does not affect transport capacity between zones

The market is currently divided in 6 zones. This configuration may change according to changes in congestions

There are also limited production sites

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Italian asymmetric zonal mechanism

Day-ahead market (MGP) works as a non discriminatory auction, where all operators bidding to sell electricity are paid the **system marginal price**

GME ranks bids for selling and buying electricity based on a **economic merit order** criterium

bilateral agreements are considered as zero-price bids – for quantities sold – and undetermined-price bids – for quantities purchased.

The pricing algorithm includes consideration of maximum transport capacity among market zones, the latter identified by the TSO (Terna)

No violation of interzonal transmission limits

single price emerges on the market

Violation of interzonal transmission limits

Market splitting in zones:

1. Aggregation of Demand and supply curve at zonal level
2. different price applies to each zone; price differences reflect different congestion costs

Different prices between supply/demand side:

1. Supplier obtains zonal price
2. ange pay a national purchase price (PUN), which does not vary among zones (equal to a weighted average of zonal prices)

Physical constraints in the grid prevent efficient pricing in the market

Italian asymmetric zonal mechanism

Price differences among market zones represent an indication of the efficiency gain resulting from an upgrade of inter-zone transmission capacity. In other words, price differences represent the **value of transmission capacity**

- Producers injecting electricity in “exporting” zones **contribute to increase network congestions**
- Then they implicitly **pay the cost of transmission capacity**
- They receive a **lower electricity price** (and thus a lower revenue)

- Producers injecting electricity in “importing” zones **contribute to lower network congestions**
- Then they implicitly r**eceive the cost of transmission capacity**
- They receive a payment for transmission capacity through a **higher electricity price** (and thus a higher revenue)

Zonal pricing provides an incentive to localize investments in new capacity where prices are higher due to scarce or inefficient production capacity

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Italian asymmetric zonal mechanism: additional costs for bilateral agreements

In the day-head market (MGP), operators “implicitly” pay or receive a price for using available inter-zone transport capacity

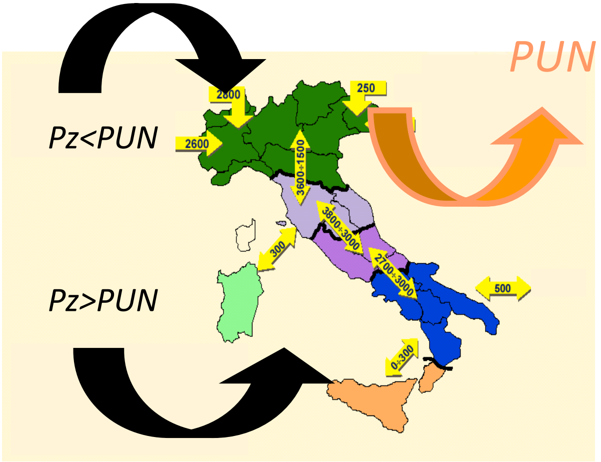
For bilateral agreements, operators pay or receive a similar price – namely the CCT – which is equal to the value of the available transport capacity plus a component for preventing arbitrage between exchange and OTC transactions

$$CCT = PUN\text{-}P_{injection\ zone}$$

if PUN > $P_{injection\ zone}$ (exporting zone), the operator that signs the bilateral agreement owes the CCT to GME

if PUN < $P_{injection\ zone}$ (importing zone), the operator that signs the bilateral agreement receives the CCT from GME

CCT components:
- Congestion cost (price of withdrawal zone minus price of injection zone)
- Non-arbitrage component (PUN minus price of withdrawal zone)



As a result of the PUN mechanism, CCT is also due by those operators who inject and withdraw electricity in the same market zone

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