ELECTRICITY MARKET DESIGN

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TOPIC 2 - Electricity market

Agenda

- Market models and functions
- Unconstrained market clearing
- Constrained market clearing

- The Italian Market Operator
  - The Electricity Spot Market
  - Day-Ahead Market

Market models and functions

3

Organized electricity markets

- Exchanged products
  - Energy for final consumption and transmission rights
  - Day-ahead market
  - Market operators: generators, consumers, retailers
  - Capacity for generation reserve, real-time balancing, congestion resolution
  - Ancillary service market
  - Market operators: generators, TSO
  - Capacity for generation adequacy
  - Capacity market (other forms of remuneration are possible)
  - Market operators: generators, consumers/TSO

4

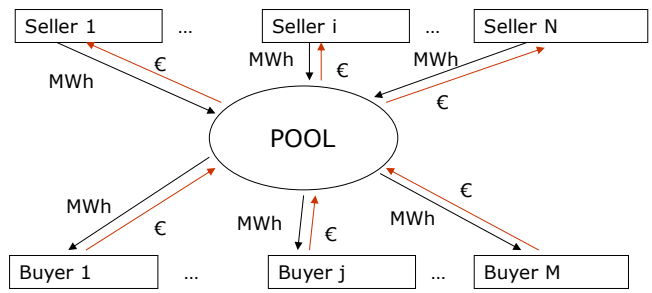
Day-ahead market

- Day-ahead market design: two extreme cases
  - Electricity pool (compulsory)
  - Bilateral or OTC (Over The Counter) market
- In real life: mix of the two

5

Electricity pool

- Day-ahead market is the only buyer for power producers and the only seller for final users



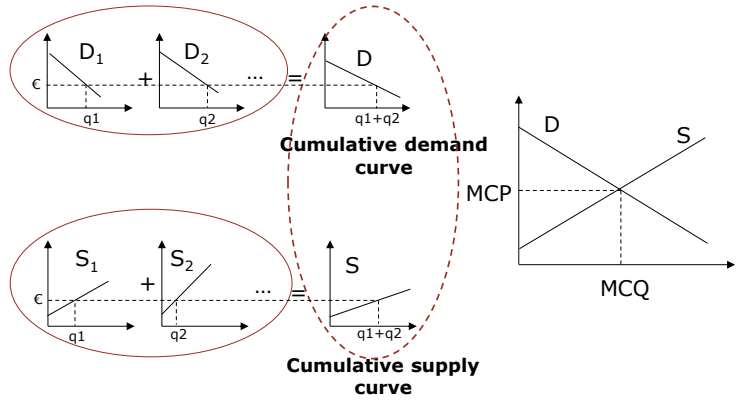
6

Electricity pool

- Sellers: generators, brokers/marketers
- Buyers: consumers, brokers/marketers, distribution and generation entities
- Market Operator (MO) is in charge of the market and uses an auction procedure to determine the prices and quantities sold (for each hour of the following day)
  - Sellers and buyers submit sealed offers and bids, describing the price and quantities at which they are willing to sell/buy energy
- The auction results determine the scheduling (unit commitment and dispatch) of the physical units and of the demand served

7

Electricity pool



8

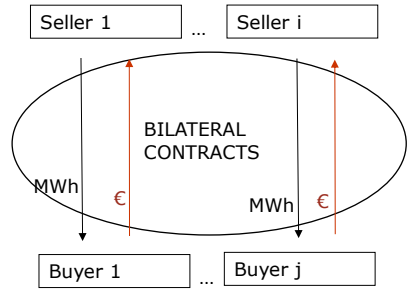
Electricity pool

- Standardized contracts (i.e. time of delivery is one hour of the following day)
- Prices and quantities: maximum transparency
- Participants: anonymous
- Payment guaranteed (on the part of the clearing house)
- Most common pricing rule: uniform price auction
  - Every seller and buyer with an accepted bid receives or pays the same price
  - Marginal System Price, price indicated in the last accepted supply bid
- Less common pricing rule: pay as bid

9

Bilateral or OTC market

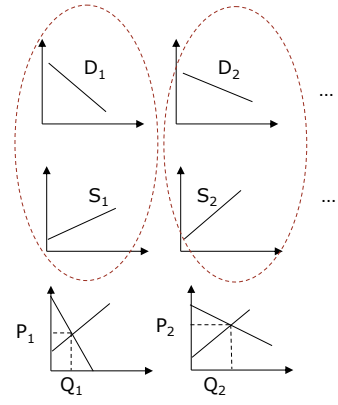
- Buyers and sellers define transactions autonomously and privately
- The TSO is notified and allows bilateral transactions, s.t. network constraints



10

Bilateral or OTC market

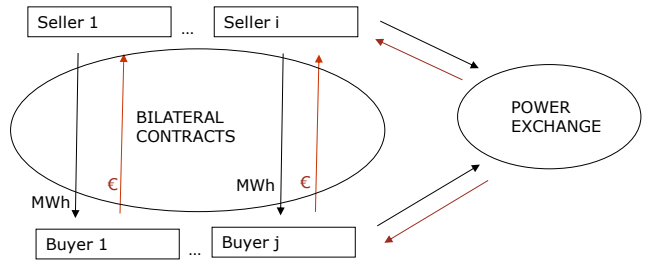
- n transaction
  - n prices P_1, P_2 …
  - n quantities Q_1, Q_2, …
- Non standardized contracts
- Stipulated years, months, day(s) ahead of delivery
- Continuous trading
- No transparency wrt other operators
- Operators are not anonymous
- Counterparty risk



11

Existing markets

- Centralized auction and bilateral trading
- The MO runs the auction taking OTC transactions as given



12

Day-ahead market clearing

Economic dispatch: unconstrained market clearing

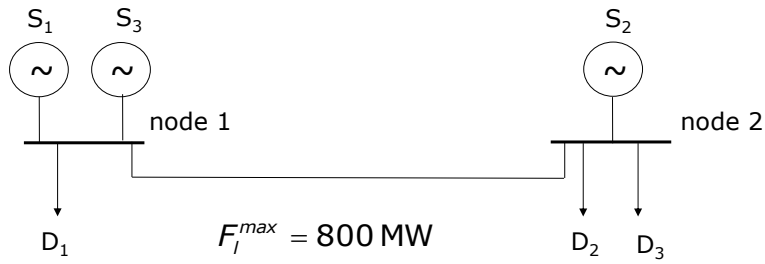
13

Day-ahead market clearing

- Hypotheses:
  - No transmission constraints
  - Perfectly competitive market:
    - Seller offers represent marginal costs of generation
    - Buyer bids represent marginal value of energy purchased
  - MO clears the market: finds price(s) and quantities (i.e. successful offers and bids)
  - Criterion: economic dispatch
    - Less costly generators first
    - Consumers with higer WTP first
  - Mathematically
    - Constrained optimization problem
  - Economic objective: welfare maximization

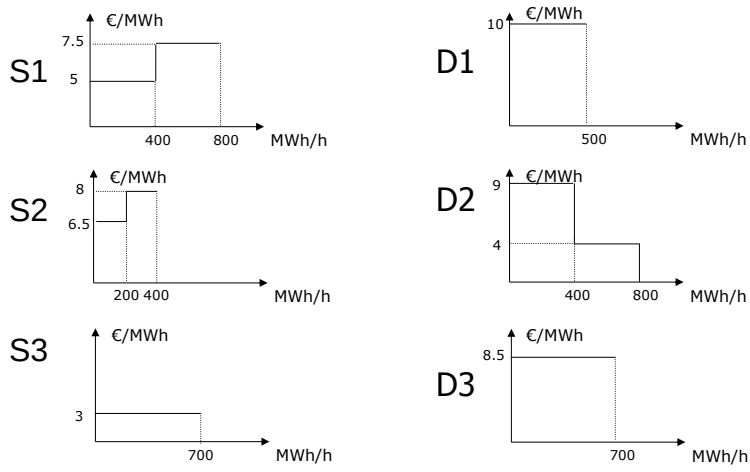
14

Two-node example



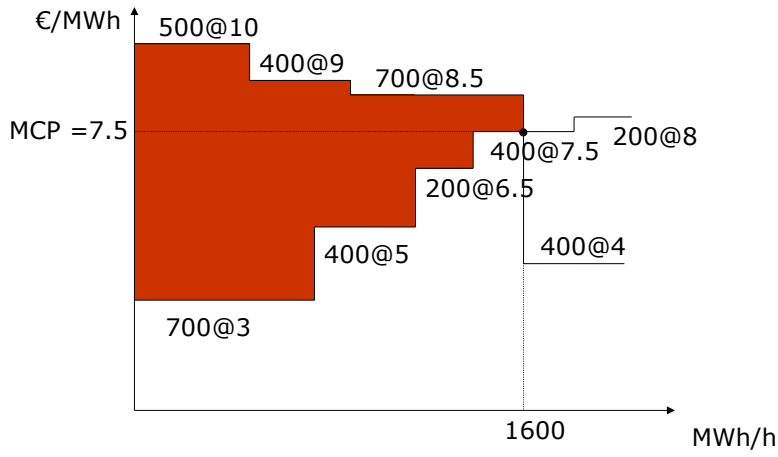
15

Two-node example



16

Two-node example



17

Two-node example

operator	Accepted quantity [MWh]	Out of merit [MWh]	Revenues [€]	Payments [€]
S1	700	100	5250	-
S2	200	200	1500	-
S3	700	0	5250	-
D1	500	0	-	3750
D2	400	400	-	3000
D3	700	0	-	5250
Total	1600	-	12000	12000

18

Optimization problem

- Unconstrained market clearing

$$\max_{P_{Sj},\,P_{Di}} \; W = \sum_{j=1}^{M} D_j(P_{Dj}) - \sum_{i=1}^{N} C_i(P_{Si})$$

$$\text{s.t.} \quad \sum_{j=1}^{M} P_{Dj} = \sum_{i=1}^{N} P_{Si} \qquad \text{Supply-Demand balance}$$

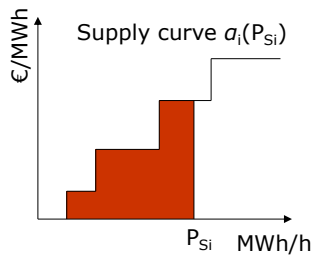
$$P_{Si}^{\min} \le P_{Si} \le P_{Si}^{\max} \quad \forall i$$

$$P_{Dj}^{\min} \le P_{Dj} \le P_{Dj}^{\max} \quad \forall j \qquad \text{Quantity constraints}$$

19

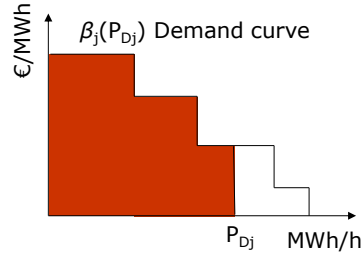
Objective function

Production cost (variable)



$$C_i(P_{Si}) = \int_0^{P_{Si}} \alpha_i(\xi)\,d\xi$$

Consumer value



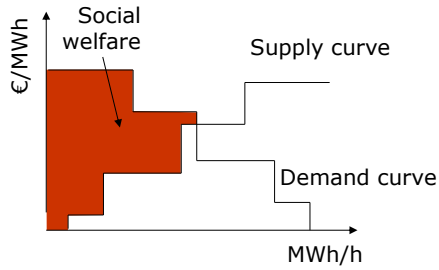
$$B_j(P_{Dj}) = \int_0^{P_{Dj}} \beta_j(\xi)\,d\xi$$

20

Objective function

- Social welfare (red area): total benefit of the buyers minus total cost of the sellers

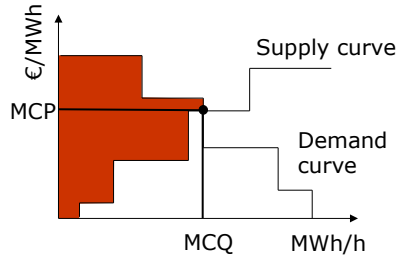
$$W = \sum_{j=1}^{M} D_j(P_{Dj}) - \sum_{i=1}^{N} C_i(P_{Si})$$



21

Market Clearing Price (MCP)

- MCP: change in social welfare for a unit change in the market clearing quantity
- Each seller receive MCP and each buyer pays MCP
- The MCP is different from the offer/bid of nearly every player



22

Producer Surplus

- For each seller *i* variable profit (surplus) is the difference between revenues (accepted quantity x MCP) and the supply curve

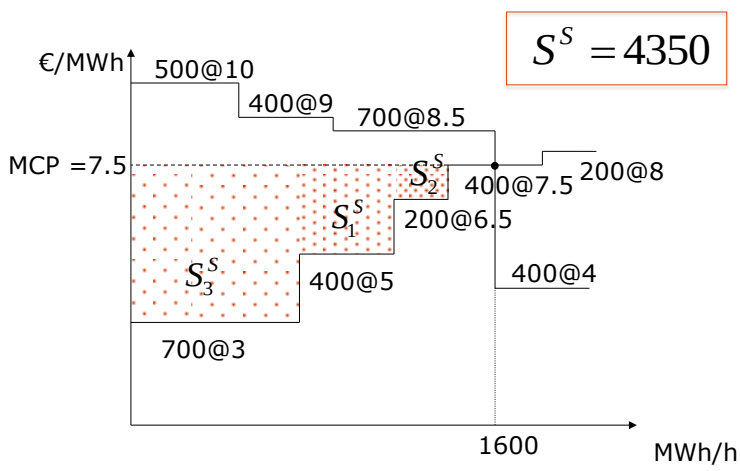
$$S_i^S = MCP \cdot P_{Si} - C_i(P_{Si}) \quad i = 1,...N$$

- Total producers' surplus:

$$S^S = \sum_{i=1}^{N} S_i^S$$

23

Producer Surplus



24

Consumer Surplus

- For each buyer j surplus measures the difference between the demand curve and the payments (accepted quantity x MCP)

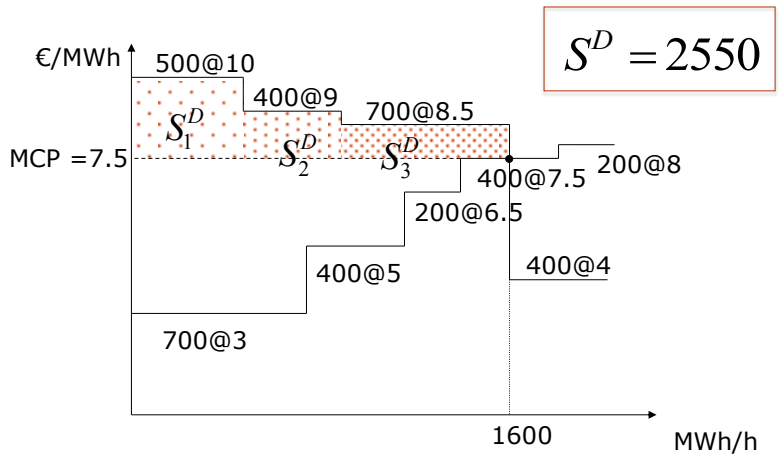
$$S_j^D = D_j(P_{Dj}) - MCP \cdot P_{Dj} \quad j = 1,...M$$

- Total consumers' surplus:

$$S^D = \sum_{j=1}^{M} S_j^D$$

25

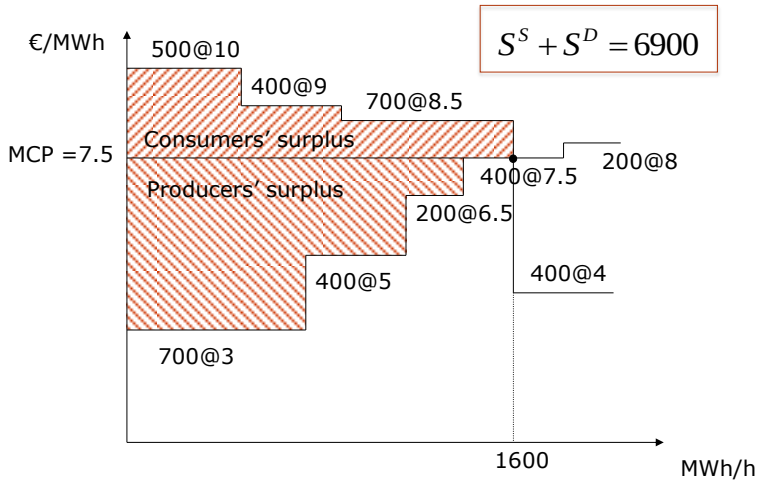
Consumer surplus



$$S^D = 2550$$

26

Social welfare



$$S^S + S^D = 6900$$

27

Fixed and variable production costs

- Last accepted bid: marginal bid
  - Covers variable costs of production
- Other accepted bids: infra-marginal bids
  - Cover variable costs of production and
  - Obtain an infra-marginal rent per MWh equal to the difference between the MCP and the marginal cost of production: i.e. cover fixed costs
- Bids out of merit: extra-marginal bids
  - No production costs
  - No revenues: cannot recover fixed costs

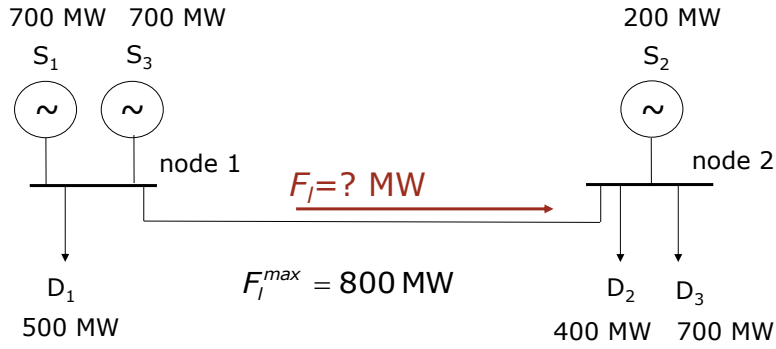
28

Day-ahead market clearing

Economic dispatch: constrained market clearing

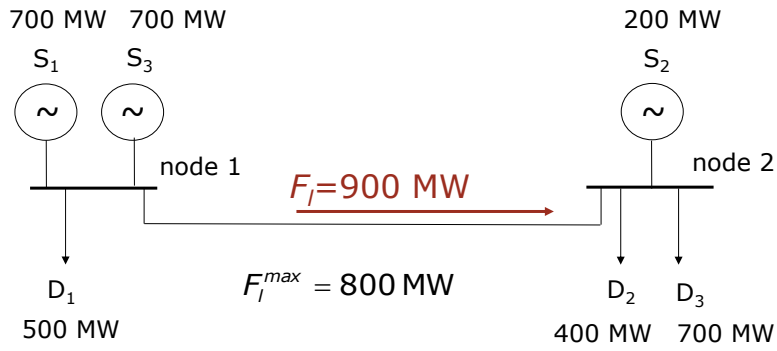
29

Two-node example



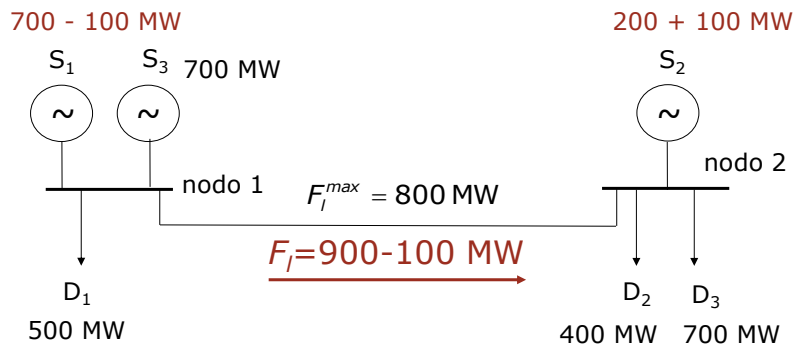
30

Two-node example



31

Two-node example



To eliminate the line overload: reduce the sale from S1 by 100 MW and instead use the higher-priced energy from S2
It is not the only solution: choose the least costly one

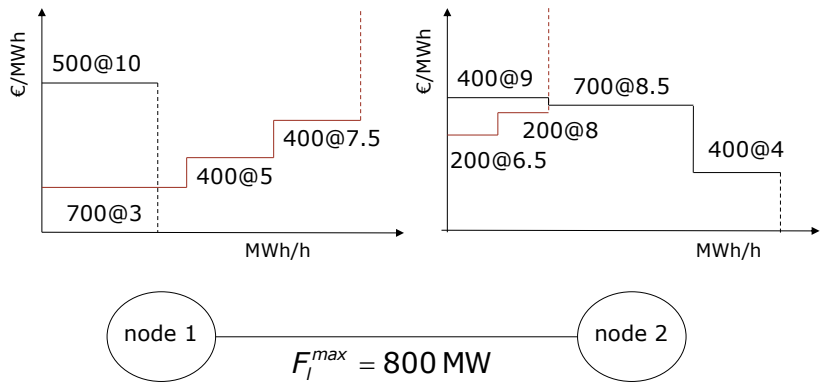
32

Two-node example

- 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 node2
  - 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)

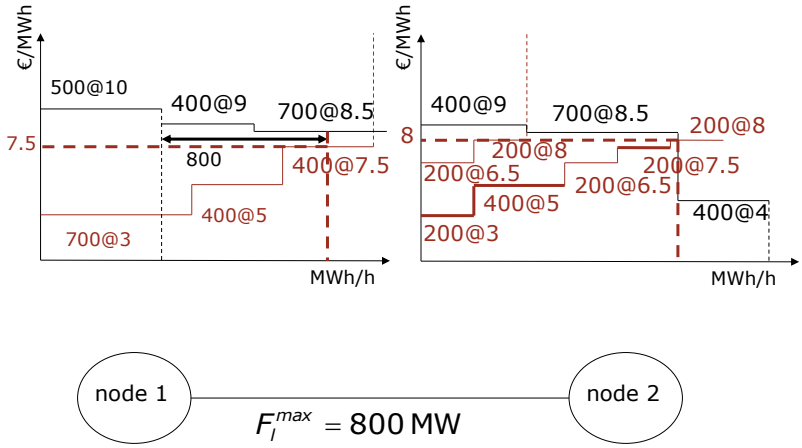
33

Two-node example



34

Two-node example



35

Two-node example

operat.	quantity [MWh]	price [€]	revenues [€]	payments [€]	variation [€]
G1	600	7.5	4500	-	-750
G2	300	8.0	2400	-	900
G3	700	7.5	5250	-	0
D1	500	7.5	-	3750	0
D2	400	8.0	-	3200	200
D3	700	8.0	-	5600	350
totale	1600	-	12150	12550	-

36

Congestions

- Congestions lead to changes:
  - from a single market equilibrium point to different, nodal equilibrium points
  - Possible curtailment in production or consumption
  - Revenues/payments for sellers and buyers
- The impact of congestions can be measured in terms of
  - Congestion rent (part of welfare)
  - Congestion cost (welfare deadweight loss)

37

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 social welfare

$$\kappa = \sum_{j=1}^{M} MCP_j \cdot P_{Bj} - \sum_{i=1}^{N} MCP_i \cdot P_{Si}$$

$$\overline{S} = \overline{S^B} + \overline{S^S} + \kappa$$

Constrained social welfare

38

Two-node example

sellers	surplus	buyers	surplus
S1	1000	*B1*	1250
S2	300	*B2*	400
S3	3150	*B3*	350
total	4450	*total*	2000
Congestion rent	12550-12150=400		
Welfare	4450+2000+400=6850		

39

Congestion rent

- For a two-node system, it is more easily calculated as:
  - Maximum interconnection flows times zonal difference in price:
  - 800 MW x (0.5 €/MWh) = 400 €
- TSO is a regulated company: two possible uses of congestion rents:
  - Transmission investments
  - Tariff reduction

40

Congestion cost

- Congestions produce a reduction in welfare
- This reduction is called deadweight loss

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

Constrained social welfare

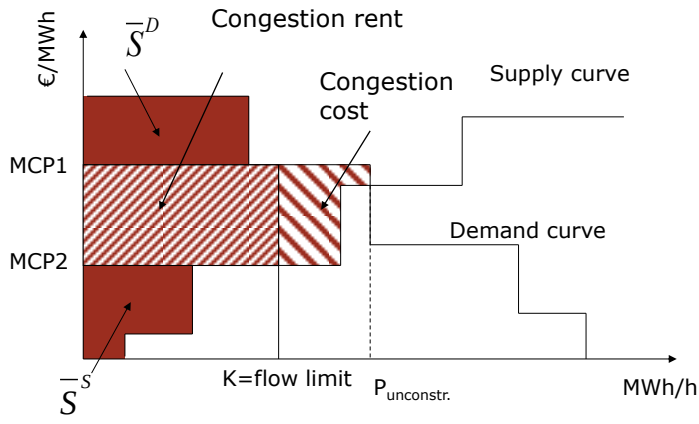
$$S = 6900$$

$$\bar{S} = 6850$$

$$\varepsilon = -(\bar{S} - S) = 50$$

41

Congestions



42

Impact of congestions

- Short-term effects
  - Redispatching
  - Multiple prices
  - Change in producer and consumer surplus
  - Congestion rents
  - Redispatch costs
- Long-term-effects: price signals
  - Price difference: siting of power plants in ndes with higher prices
  - Congestion rent: transmission expansion necessary

43

Zonal transmission model

- Also known as "market splitting"
- Allocation of "transmission rights" is done at the same time as the allocation of the "production/consumption rights" (permit to produce or consume energy)
- This allocation method is also known as an "implicit auction" for Transmission Rights (TR)
- There is another TR allocation method, known as an "explicit auction"

44

The Italian Market Operator

Gestore dei Mercati Energetici (GME)

45

Gestore dei Mercati Energetici

- GME is owned by the Ministry of Economy and Finance (this is peculiar: other MO in EU are private companies)
- GME manages
  - the "electricity market" (IPEX, Italian Power Exchange)
  - the "environmental market"
    - Green Certificates
    - Energy Efficiency Certificates
    - Emission Trading (suspended as of 2011)
    - Renewable-energy certificates of origin
  - the "gas market"

46

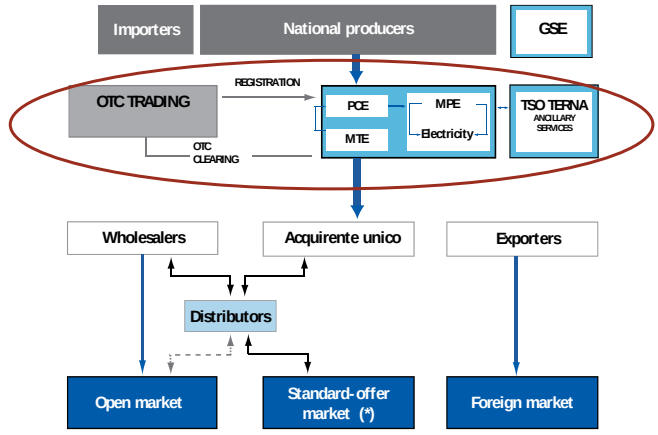
IPEX – Italian Power Exchange

- The "electricity market" (IPEX, Italian Power Exchange) includes:
  - Electricity Spot Market
  - Forward Electricity Market (with physical delivery obligation)

    and
  - Platform for registration of bilateral contracts (PCE)
  - Platform for physical delivery of financial contracts (negotiated on IDEX – the derivative market)

47

IPEX – Italian Power Exchange



48

IPEX – Italian Power Exchange

- The Italian Power Exchange (IPEX) was created with the D.lgs. n. 79/99
- It is active since April 2004 and allows demand participation since January 2005.
- Objectives:
  - Promote competition in generation and in the wholesale market
  - Favour transparency and efficiency in the dispatching activity (the latter is a natural monopoly)
  - It is a physical market: it defines injections and withdrawal to and from the transmission network, according to an economic criterion (other Power Exchanges – PX are purely commercial markets)
- IPEX is not a mandatory pool: operators can stipulate bilateral contracts (since 2007 it is compulsory to register these transactions on the PCE platform)

49

The Electricity Spot Market

50

IPEX - Spot

- The Spot Market is articulated in:
  - Day-Ahead Market (Mercato del Giorno Prima – MGP): one session between 9 and 11.30 every day
  - An Infra-Day Market (Mercato Infragiornaliero – MI): multiple sessions
  - An Ancillary Service Market (Mercato del Servizi di Dispacciamento – MSD): multiple sessions. Central counterpart is Italian TSO (Terna)
  - Since 2009 all bids are available with a seven-day delay period

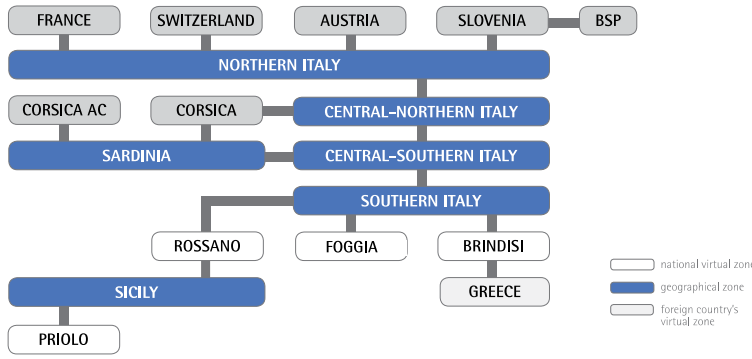
51

IPEX – Spot

	DAY-AHEAD MARKET	INTRA-DAY MARKETS	ANCILLARY SERVICE MARKET	
PRODUCT	Energy for final consumption	Energy for final consumption	Reserve and congestion management	Balancing
PARTICIPANTS	Producers and consumers	Producers and consumers	TSO Authorized generators	TSO Authorized generators
PRICING RULE	Uniform price	Uniform price	Pay as bid	Pay as bid

52

IPEX – Spot



53

IPEX – Spot

- Each geographical or virtual zone is a set of **offer points**
  - Offer points are the minimum units in respect of which hourly injection and withdrawal schedules must be defined, whether to execute bilateral contracts or as a result of the acceptance of demand bids or supply offers in the electricity Market
  - In the case of **injection** schedules, the injection offer points usually match the individual points of injection i.e. the individual generating units
  - in the case of **withdrawal** schedules, the withdrawal offer points may correspond both to individual points of withdrawal, i.e. individual consuming units, and to sets of withdrawal points

54

IPEX – Spot

- For each offer point, a **dispatching user** is identified
  - This user is answerable to the TSO both for the implementation of injection and withdrawal schedules and for the execution of balancing commands. These commands may be sent by the TSO to offer points in real time in order to maintain the security of the system
- Non-compliance with the schedules involves the payment of deviation charges (imbalance fees)

55

Day-Ahead Market

PUN and TR

Day-Ahead Market

- Objectives:
  - Trading of energy for final consumption between producers/importers and retailers/consumers: definition of price(s) and quantities
  - Withdrawal/production program for each hour of the following day
  - Allocation of transmission capacity (to market participants and to holders of bilateral contracts) for each interconnection beween zones

57

Day-Ahead Market

- DAM takes place in the morning of the day-ahead
  - gate closure: 12.00 – general results 12.55
- Preliminary information
  - Demand forecast for each hour and zone
  - Maximum flow for each hour and interconnection
- Bid format
  - Simple (price and quantity) or multiple (up to four couples of prices and quantities)
  - Other PX allow more complex bid formats

58

Day-Ahead Market

- The DAM is organized as a uniform price auction
  - All operators are rewarded or pay the marginal clearing price
- The DAM solves a welfare maximization problem s.t. transmission contraints
  - If transmission contraints are not violated the system marginal prices is unique (in all zones)
  - If at least one transmission constraint is violated the market clearing algorithm splits the markets in two (or more) zones (an exporting and an importing zone)
- Market splitting results in different zonal prices
  - The zonal price Pz is higher in the importing zone and it is lower in the exporting zone

59

Day-Ahead Market

- In the Italian DAM, accepted selling bids are remunerated at zonal prices Pz^k (k zone of injection)
- All accepted purchasing bids pay, regardless of the zone, the National Single Price (Prezzo Unico Nazionale – PUN)
  - Assuming inelastic demand, PUN for the hour i is calculated as the weighted average of zonal prices (weighted on zonal demand QA_i^k)

$$PUN_i = \frac{\sum_k Pz_i^k QA_i^k}{\sum_k QA_i^k}$$

  - This is a peculiarity of the Italian market

60

Day-Ahead Market

- The market clearing algorithm takes into account the bilateral contracts
  - as part of the supply curve at zero price and as part of the demand curve at infinite price
- These transactions use part of the transmission capacity: network constraints must be verified against all injections and withdrawals
- These transactions are part of the demand in each zone and must enter in the calculation of the PUN

61

Day-Ahead Market

- After clearing the market
- GME communicates (privately) to each operator the results for his/her bids:
  - Accepted quantities
  - Prices for those quantities
  - Totale revenues or payments
- GME publishes on its website the market results in terms of
  - Total quantities purchased and sold in each zone, for each hour and zone, and the respective prices

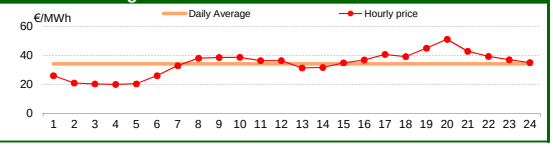
62

Day-Ahead Market

- Monday, March 14, 2016

Purchasing Price

	Average
	34.13
	38.39
	29.87
	19.99
	51.10

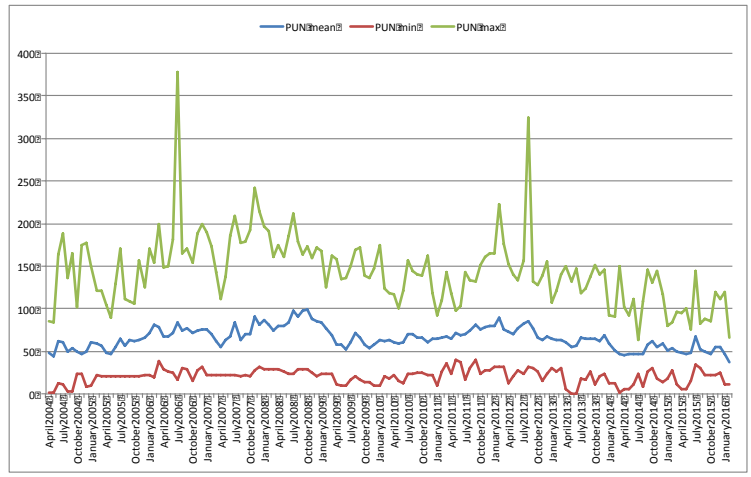


Zonal Selling Prices

	North	Central North	Central South	South	Sicilia	Sardegna
	34.37	33.75	33.75	30.69	38.53	33.75
	39.30	38.05	38.05	32.19	40.52	38.05
	29.45	29.45	29.45	29.20	36.53	29.45
	19.99	19.99	19.99	19.99	19.99	19.99
	50.89	50.89	50.89	50.89	54.39	50.89
	-0.24	0.38	0.38	3.44	-4.40	0.38

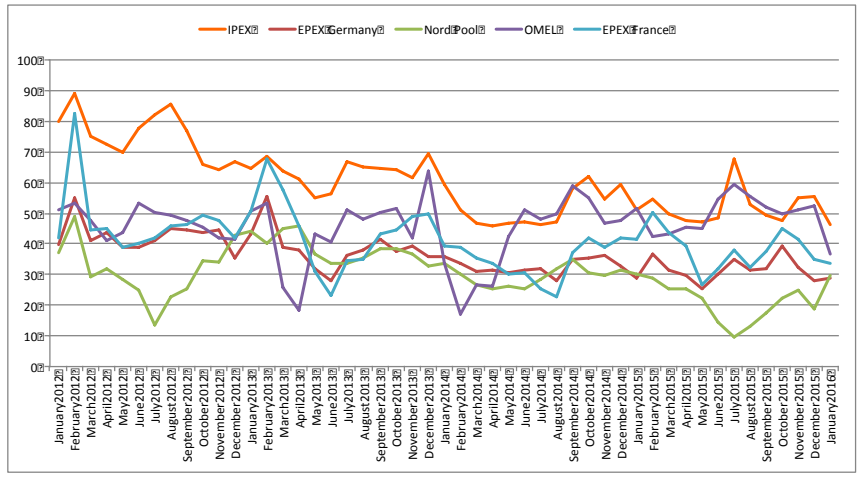
63

Day-Ahead Market



64

Day-Ahead Market



65

Day-Ahead Market

- The market splitting mechanism constitutes an "implicit auction" for the allocation of transmission rights
- If no transmission limit is violated the equilibrium price is unique:
  - The value of the TR is zero (no scarcity) and TRs are assigned to all accepted bids (including bilateral contracts)
- If at least one transmission limit is violated zonal prices are different:
  - The value of the TR is equal to the price differential (scarcity) and TRs are assigned to all accepted bids (including bilateral contracts) – not the same bids as before

66