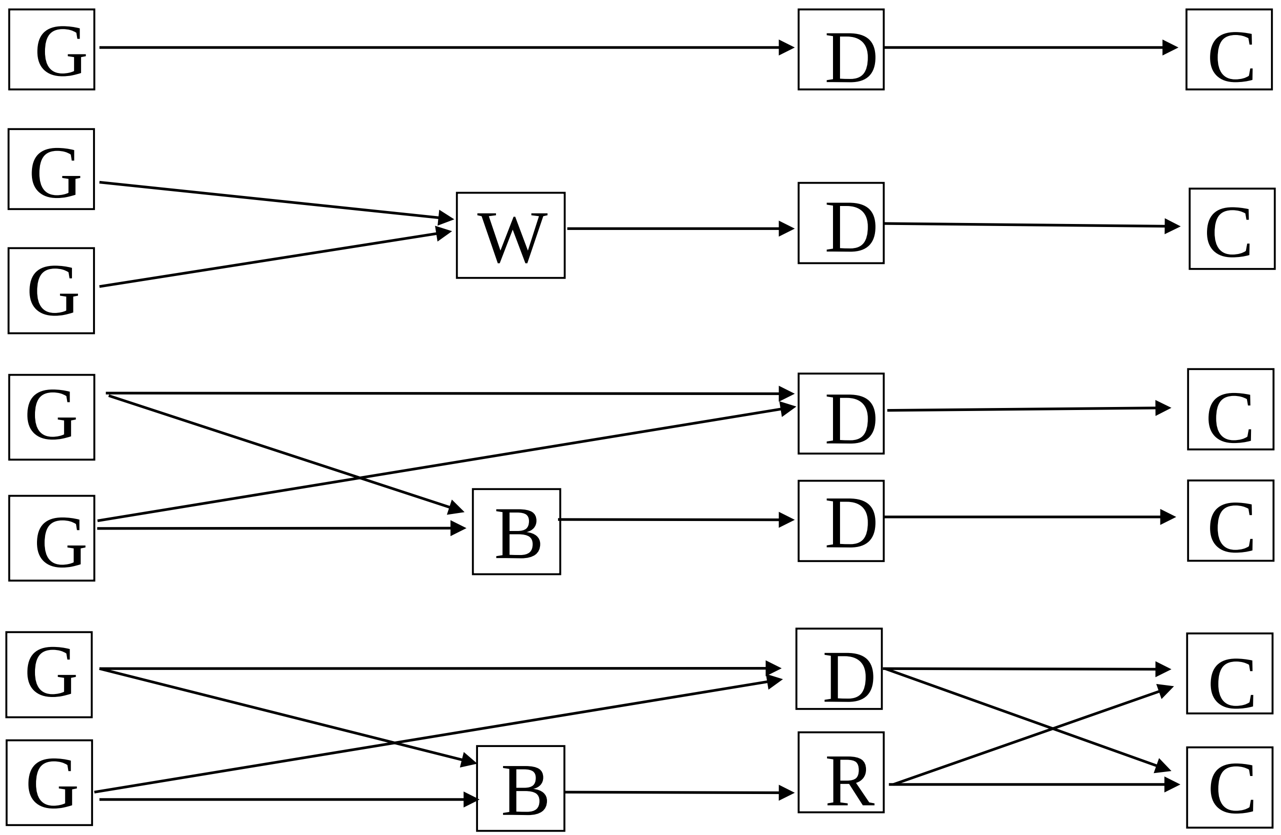
ENERGY PLANNING : MODELLING AND DECISION SUPPORT

-CONTENT-

5.1 BASIC ORGANIZATION MODELS OF ELECTRICITY MARKETS

From the Generator to the final consumer

Distco / Generators Purchasing Agent Retailer Consumer



Model 1: Monopoly

Model 2: Purchasing agency
Single buyer

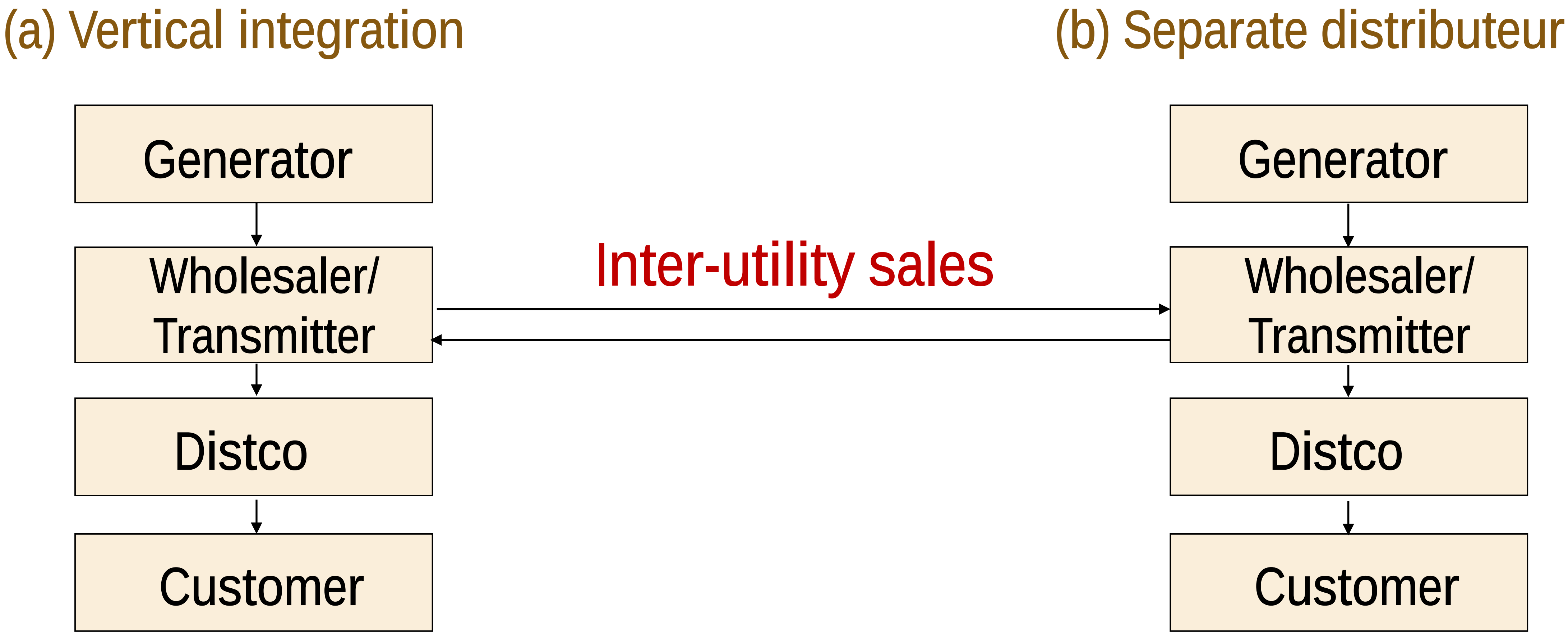
Model 3: Wholesale competition

Model 4: Retail competition

Source: Hunt and Shuttleworth

-MODEL 1: MONOPOLY-

Two variants

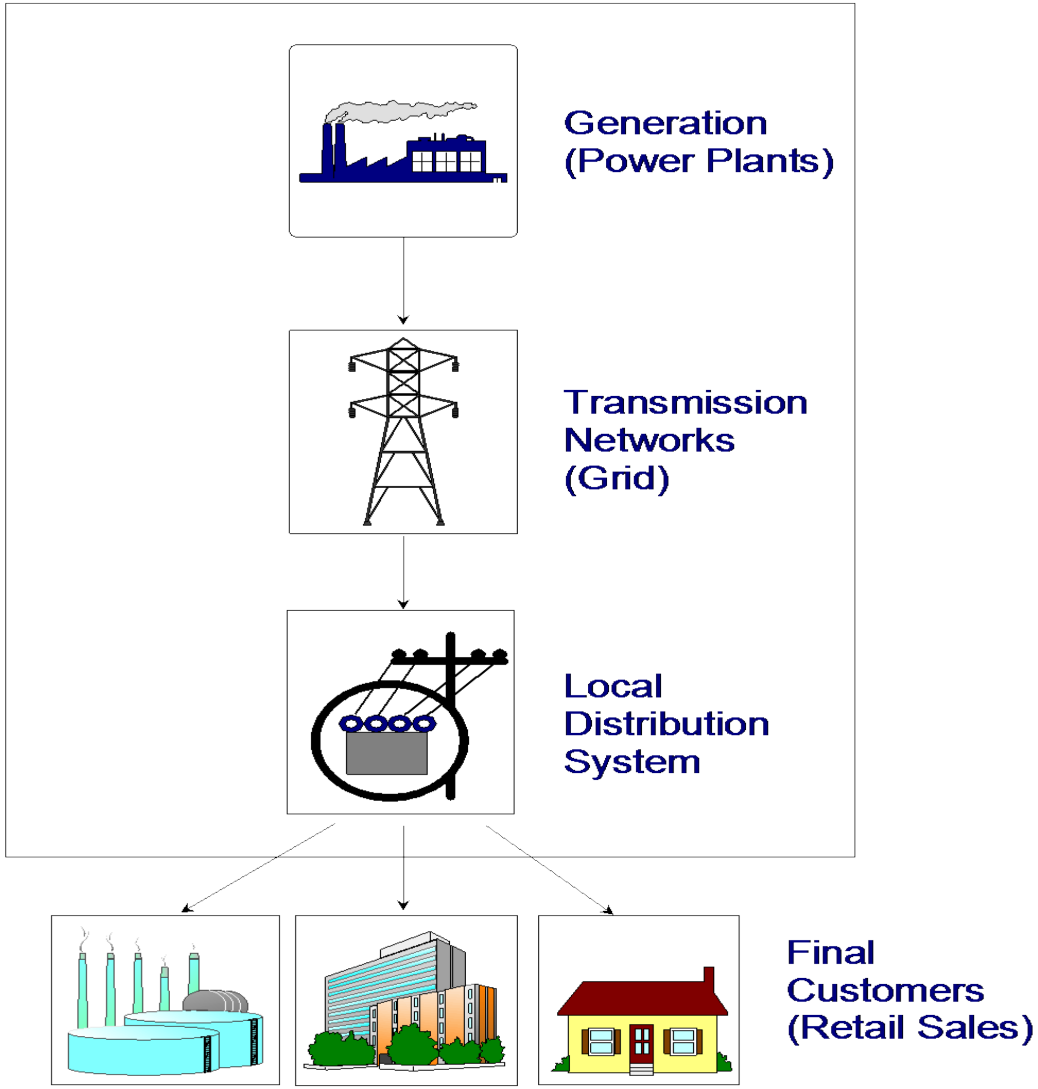


Source: Hunt and Shuttleworth

-MODEL 1: MONOPOLY-

➢ What about risks?

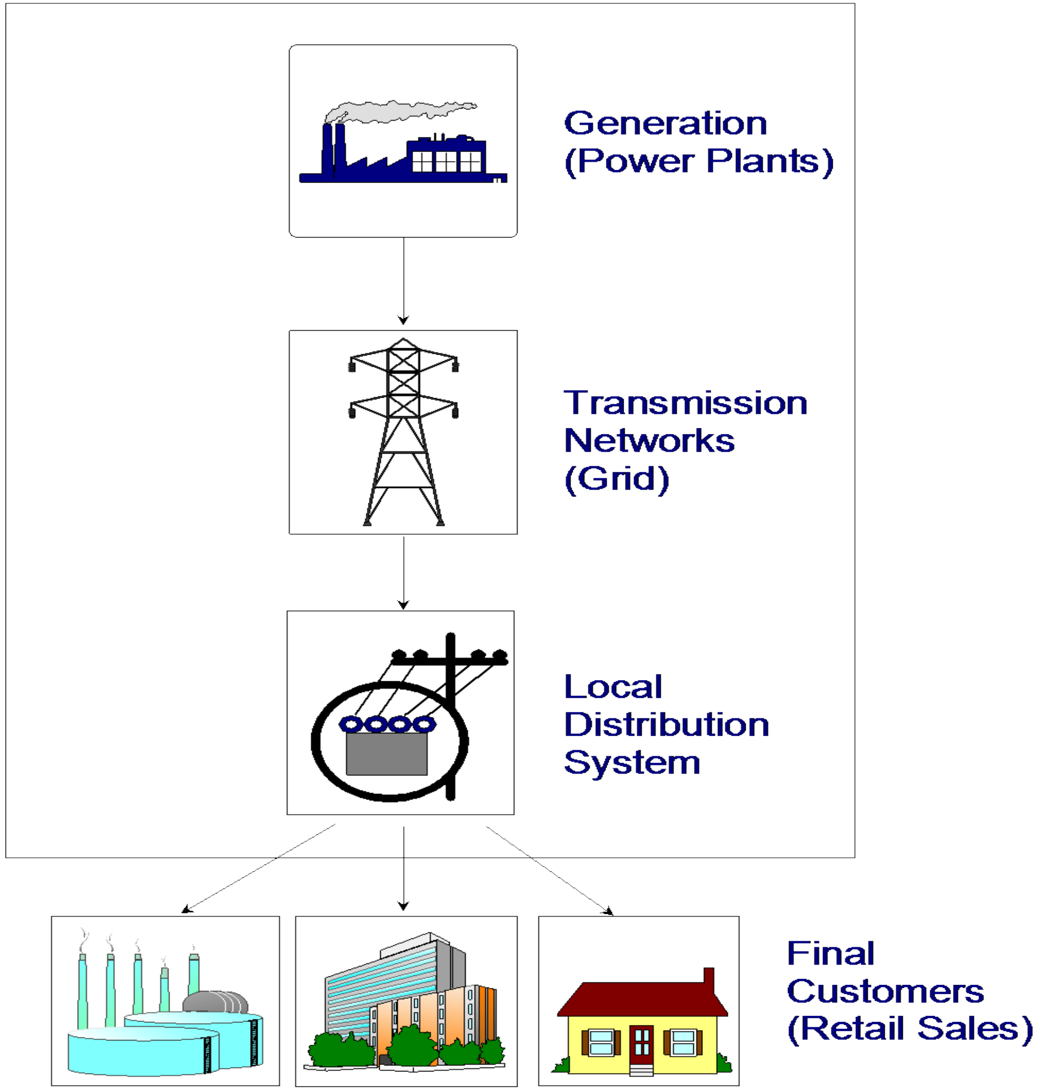
In the monopoly model, as the consumers are captive, the risks may be passed to them by the utilities unless the Regulator sets up a cap to price or permits only a partial "cost-plus" pricing (performance based regulation).



-MODEL 1: MONOPOLY-

- What about risks?

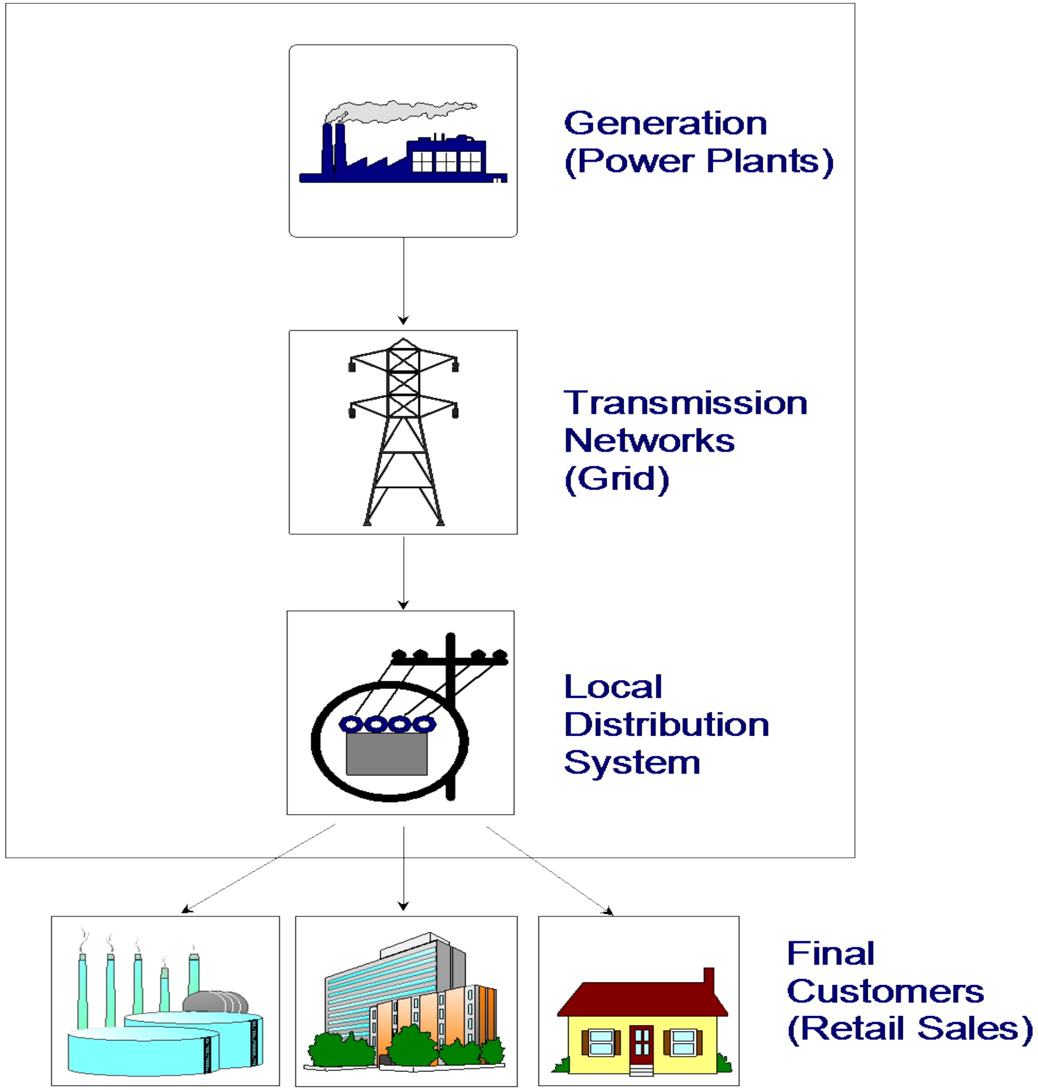
For the utility, the main sources of risks are uncertainties on the evolution of the electricity demand, fuel cost and Regulatory risks.



-MODEL 1: MONOPOLY-

- What about risks?

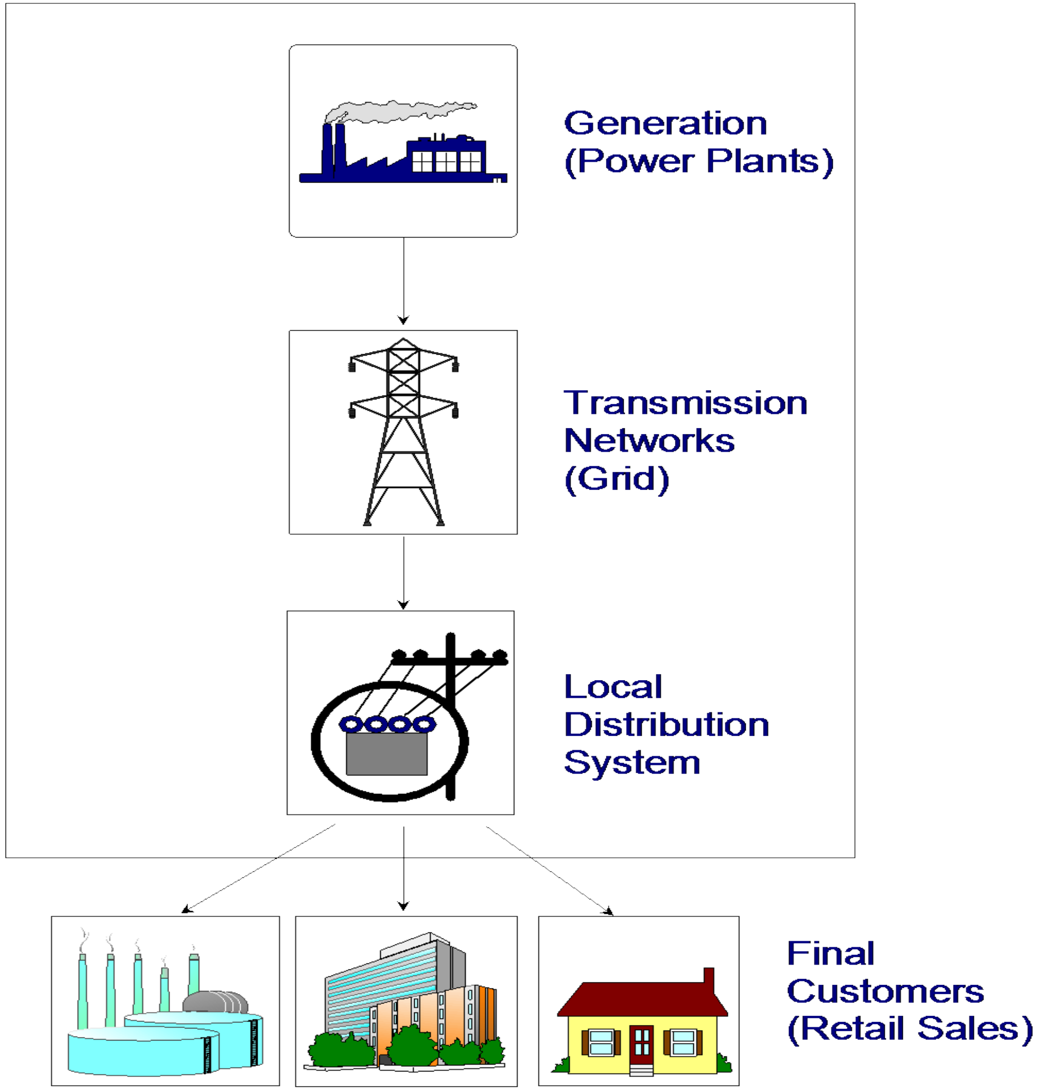
With regard to the forecast of electricity demand, the stability of the tariffs protects the utilities in case of lower demand trend. In a competitive market, lower demand trend would imply decrease of the prices along with lower utilization factor of the electricity installed capacity.



-MODEL 1: MONOPOLY-

- What about risks?

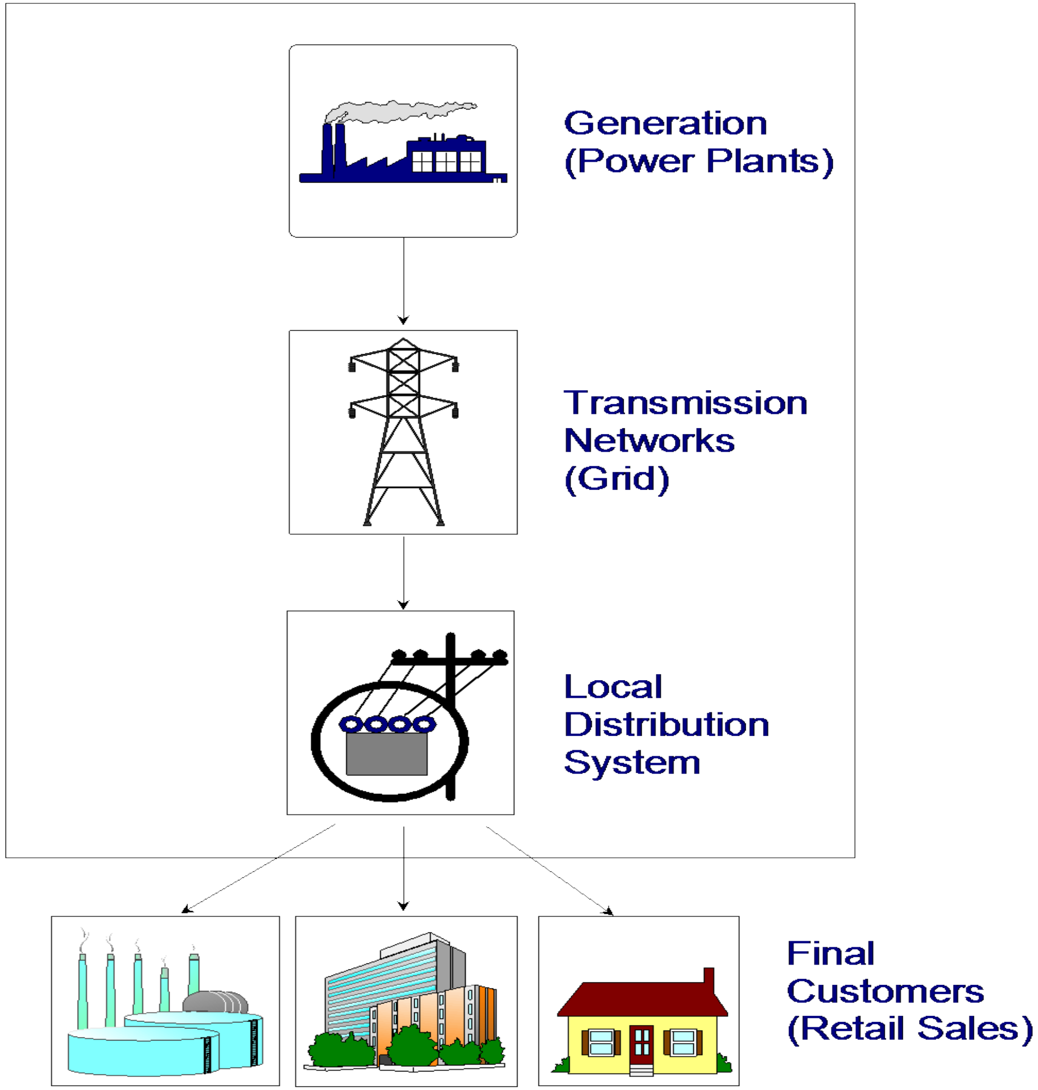
In case of interconnection an over-capacity in a country may be partially compensated by an increase of electricity export in other countries. However, the export price will depend on the demand/supply adequacy over the whole interconnected area.



-MODEL 1: MONOPOLY-

- What about risks?

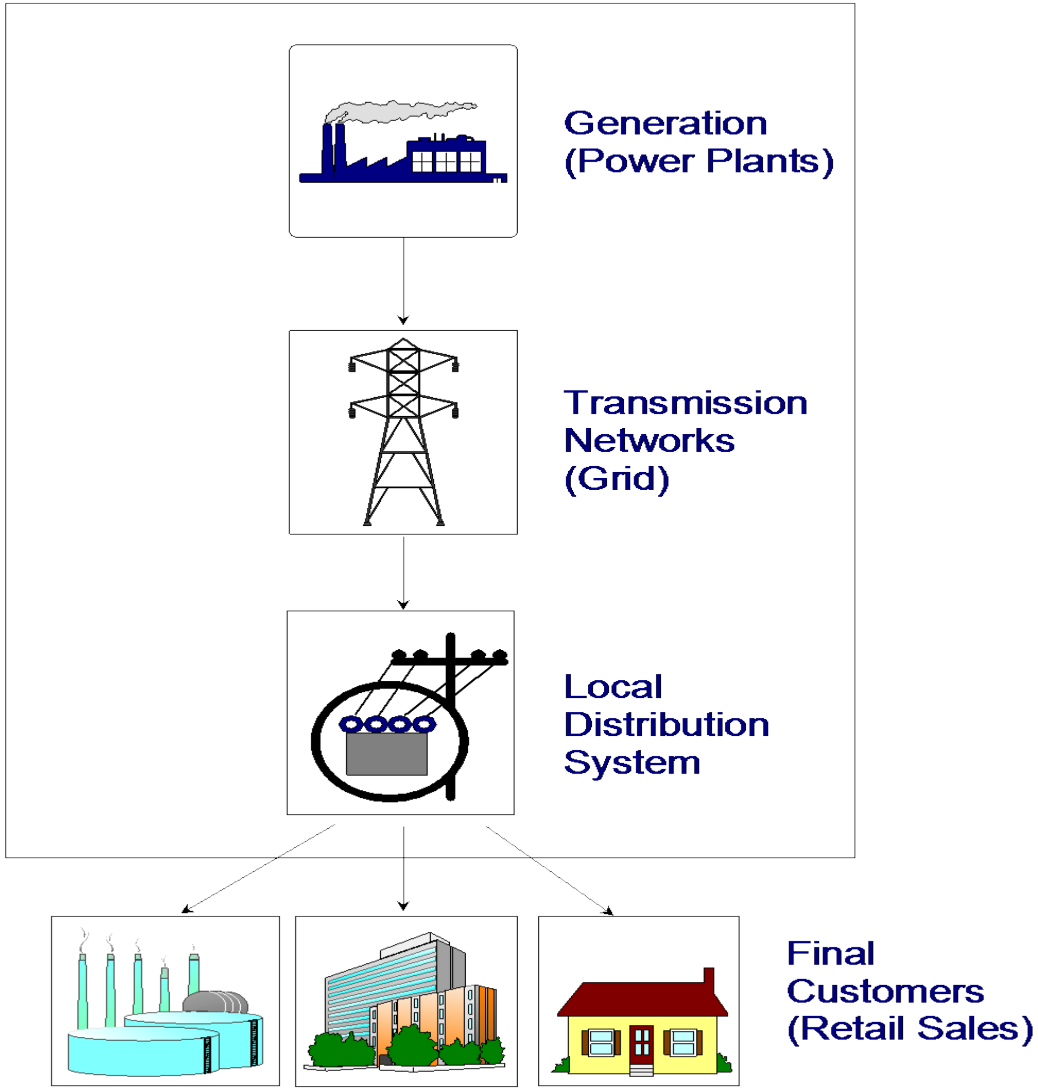
In case of surge of electricity demand due to extreme weather conditions in a country for instance, efficient interconnection allows electricity power imports if the country's reserve margin is not sufficient: An efficient cross-boarder electrical regulator must plan for long term the reserve margin of each member country and of the pool as a whole.



-MODEL 1: MONOPOLY-

- What about risks?

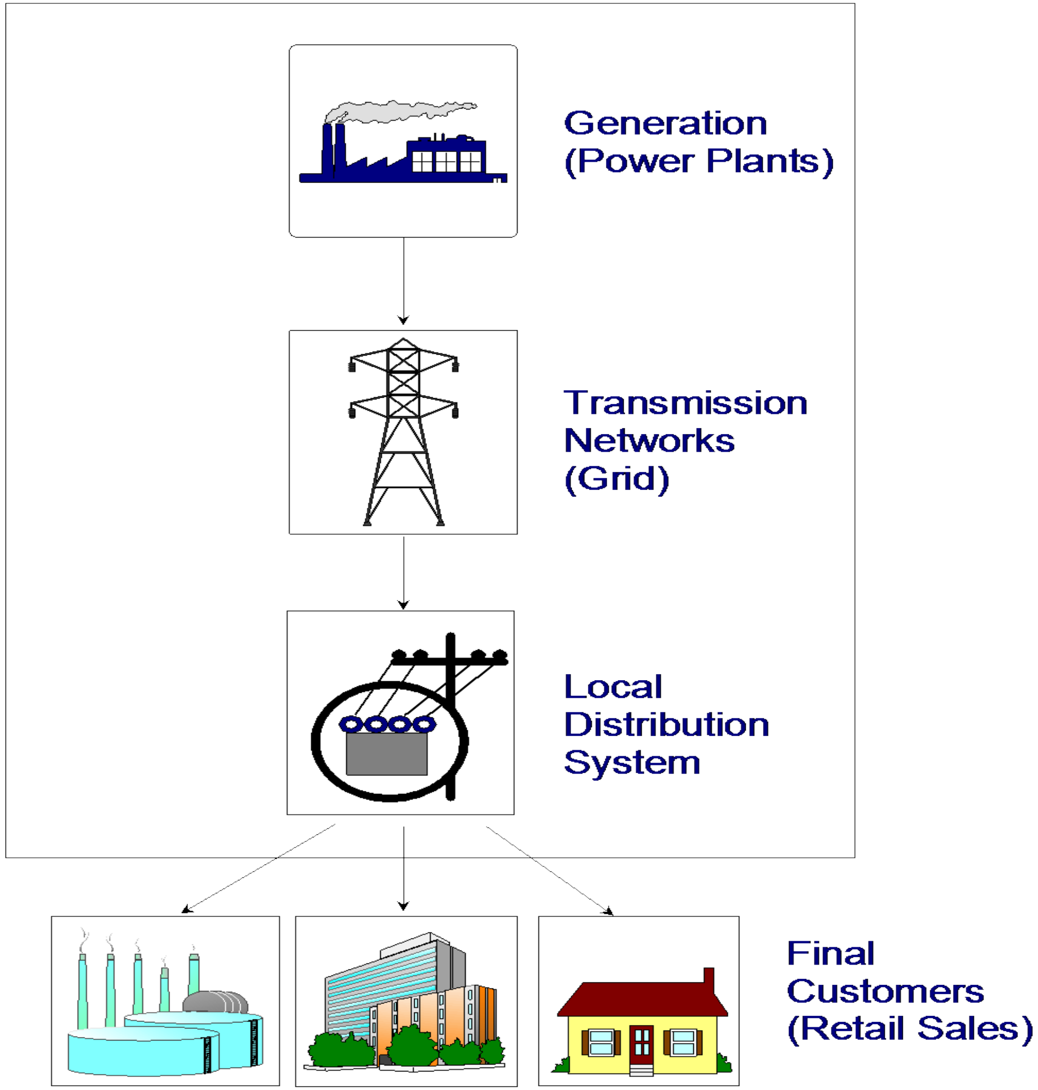
Efficient regulatory systems allow passing any increase of fuel prices to the consumers through the tariffs. Otherwise, the cash flow of utilities may decrease sharply leading to difficult fuel provision. Several developing countries encountered that situation in 2008 when the soaring joint fuel and food prices did not enable governments to accept adjustment of electricity prices.



-MODEL 1: MONOPOLY-

- What about risks?

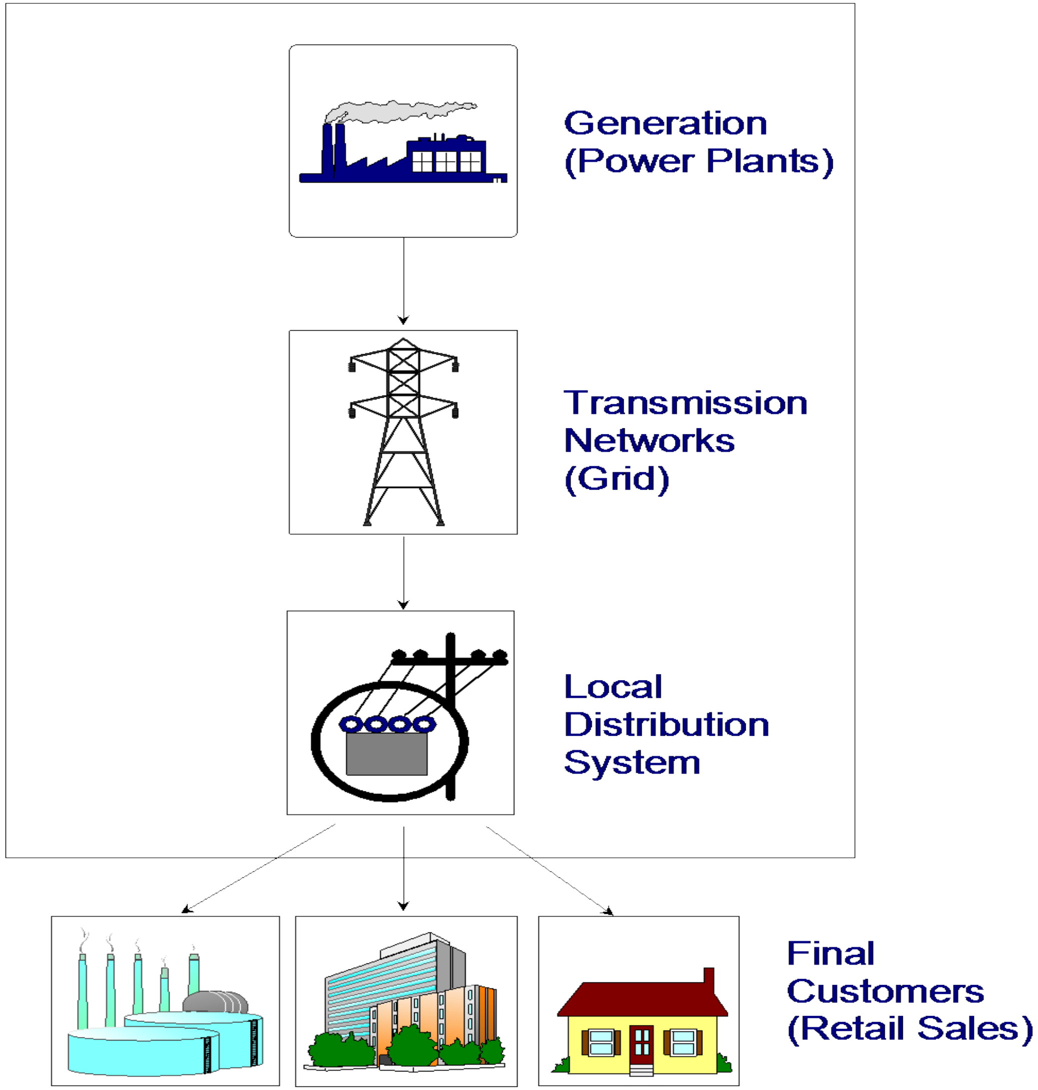
Regulatory risks concern uncertainties related to regulated tariffs and transition towards restructuring (e.g. stranded costs). The main risks in both cases are regulation unpredictability and inefficiency. In order to mitigate these risks, several utilities during the 1990s started diversifying their scopes trying to gain in economy of scope, extending their core competencies to load management and rational use of electricity.



-MODEL 1: MONOPOLY-

- What about risks?

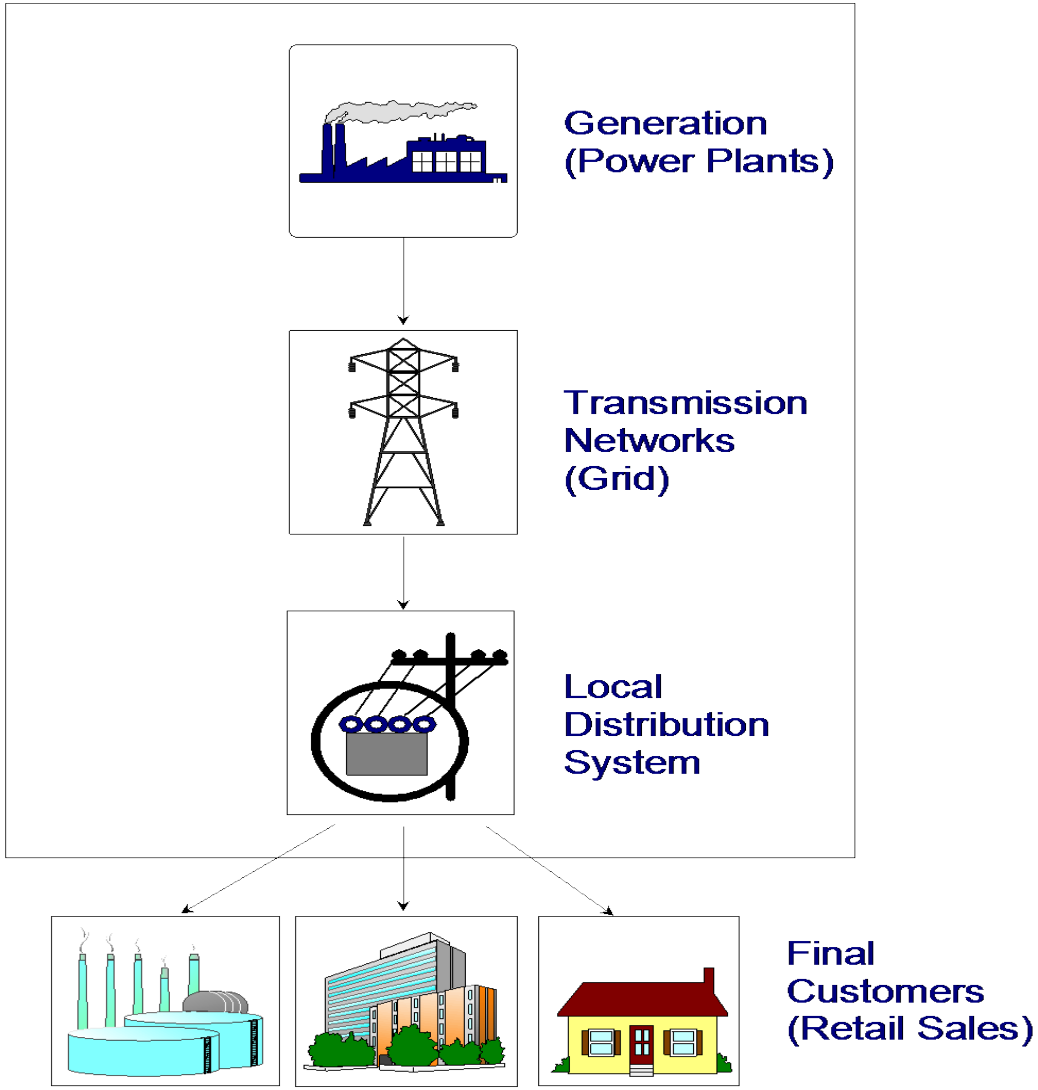
Finally regulatory failure and mismanagement in several monopolistic electricity markets especially in developing countries lead to reforms imposed by the international multilateral funding institutions such as the group of the World Bank.



-MODEL 1: MONOPOLY-

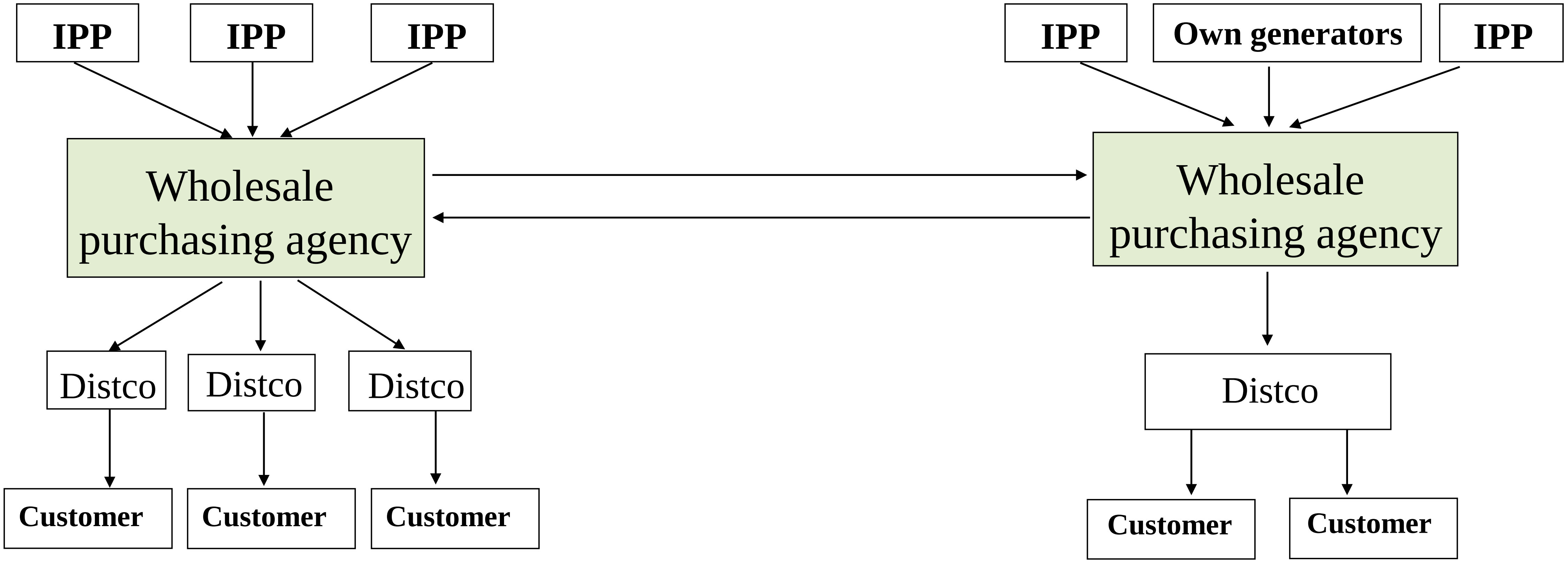
- What about risks?

These reforms include: corporation or commercialisation of the public owned utilities, enactment of energy law, establishment of an independent regulatory authority, private investment in greenfield sites, privatisation (Jamasb et al., 2005)



-MODEL 2: WHOLESALE PURCHASING AGENCY-

Two variants

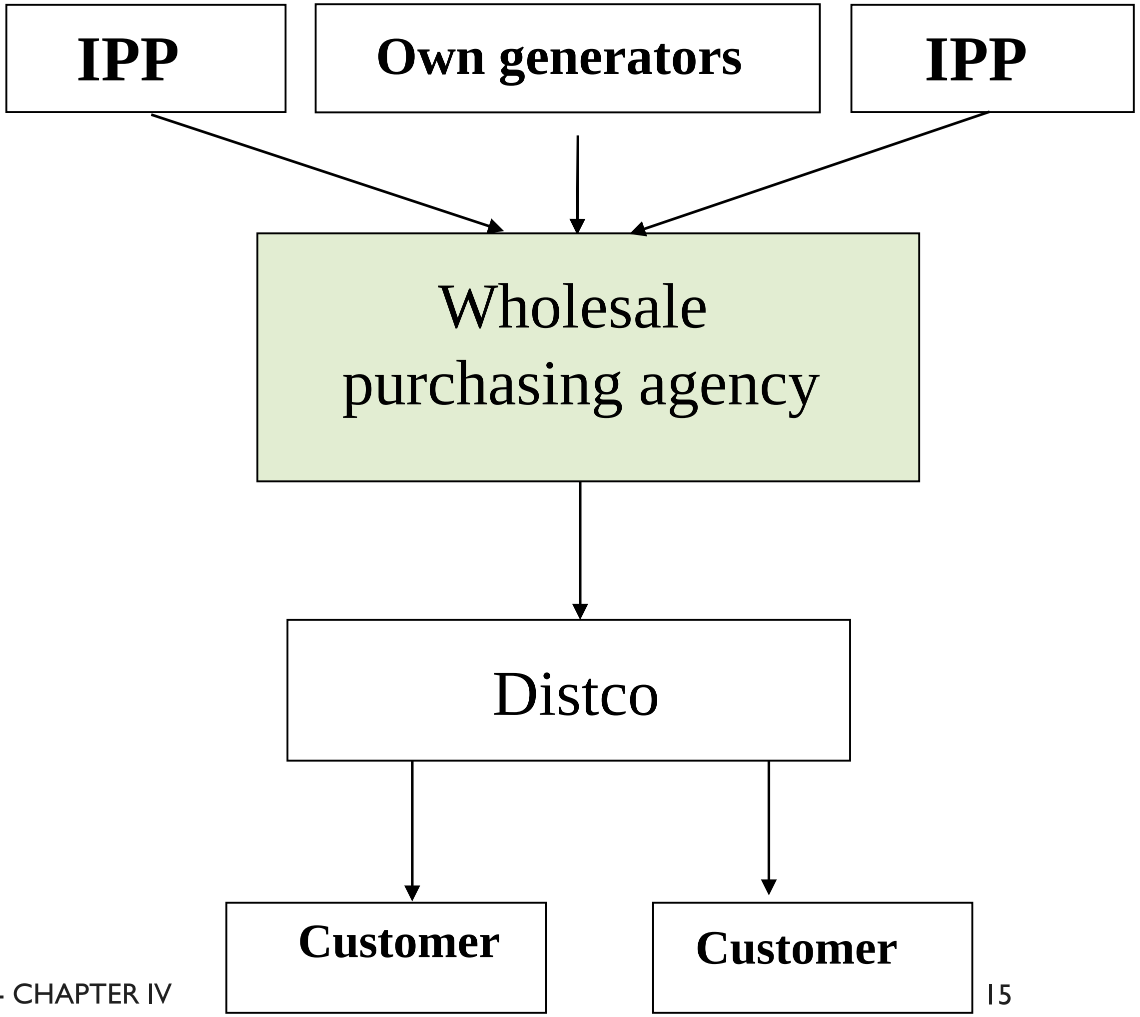


Source: Hunt and Shuttleworth

-MODEL 2: WHOLESALE PURCHASING AGENCY-

➢ What about risks?

The Independent Power Producers have a contract with the purchasing agency that commits the latter to purchase the electricity produced by the former. That contract (Power Purchase Agreement –PPA) includes a fixed component covering the fixed cost and an energy payment indexed on the fuel cost. An unavailability penalty may be included as well.

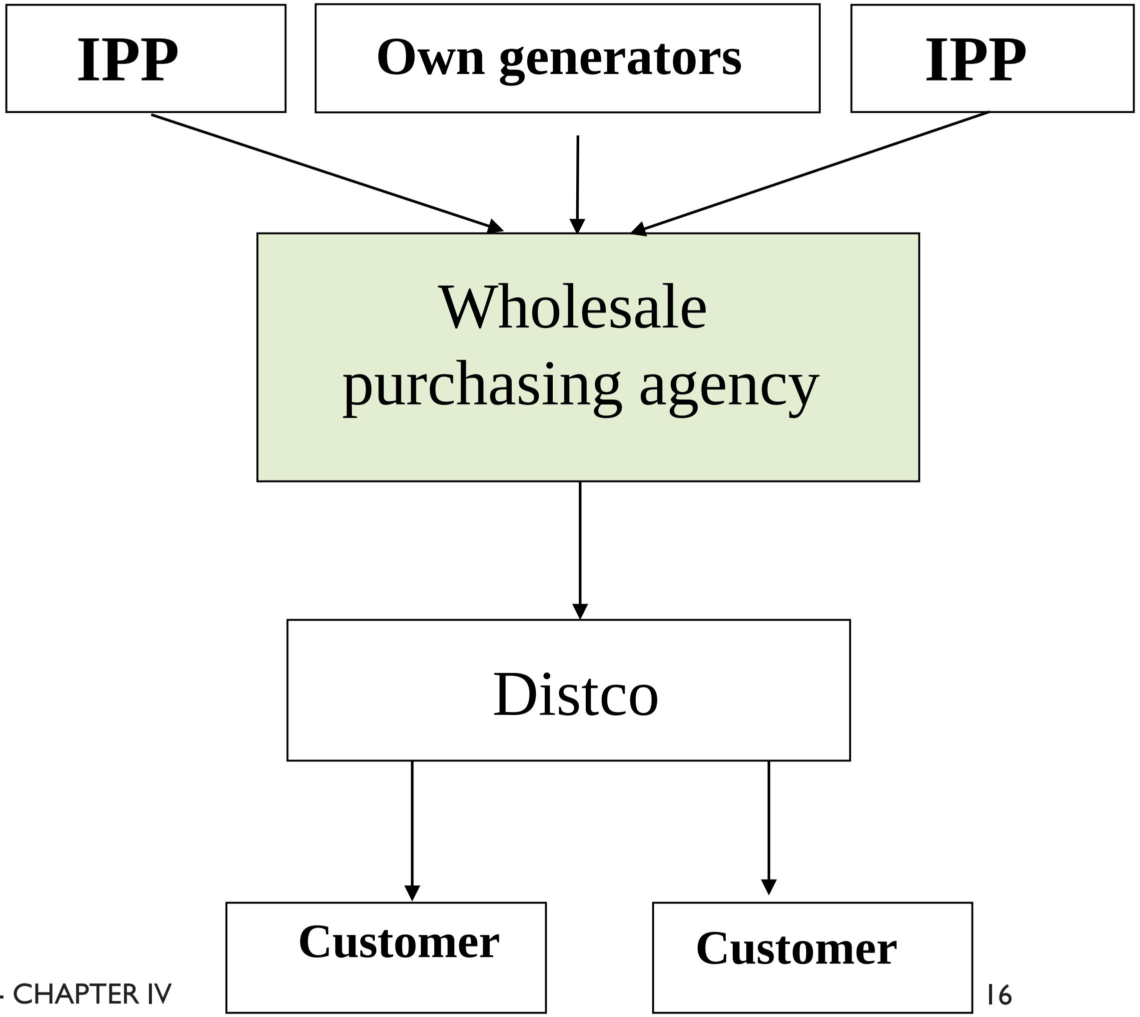


Source: Hunt and Shuttleworth

-MODEL 2: WHOLESALE PURCHASING AGENCY-

- What about risks?

The risks related to demand forecasting and fuel prices are transmitted to the customers through the single buyer and the distribution company.

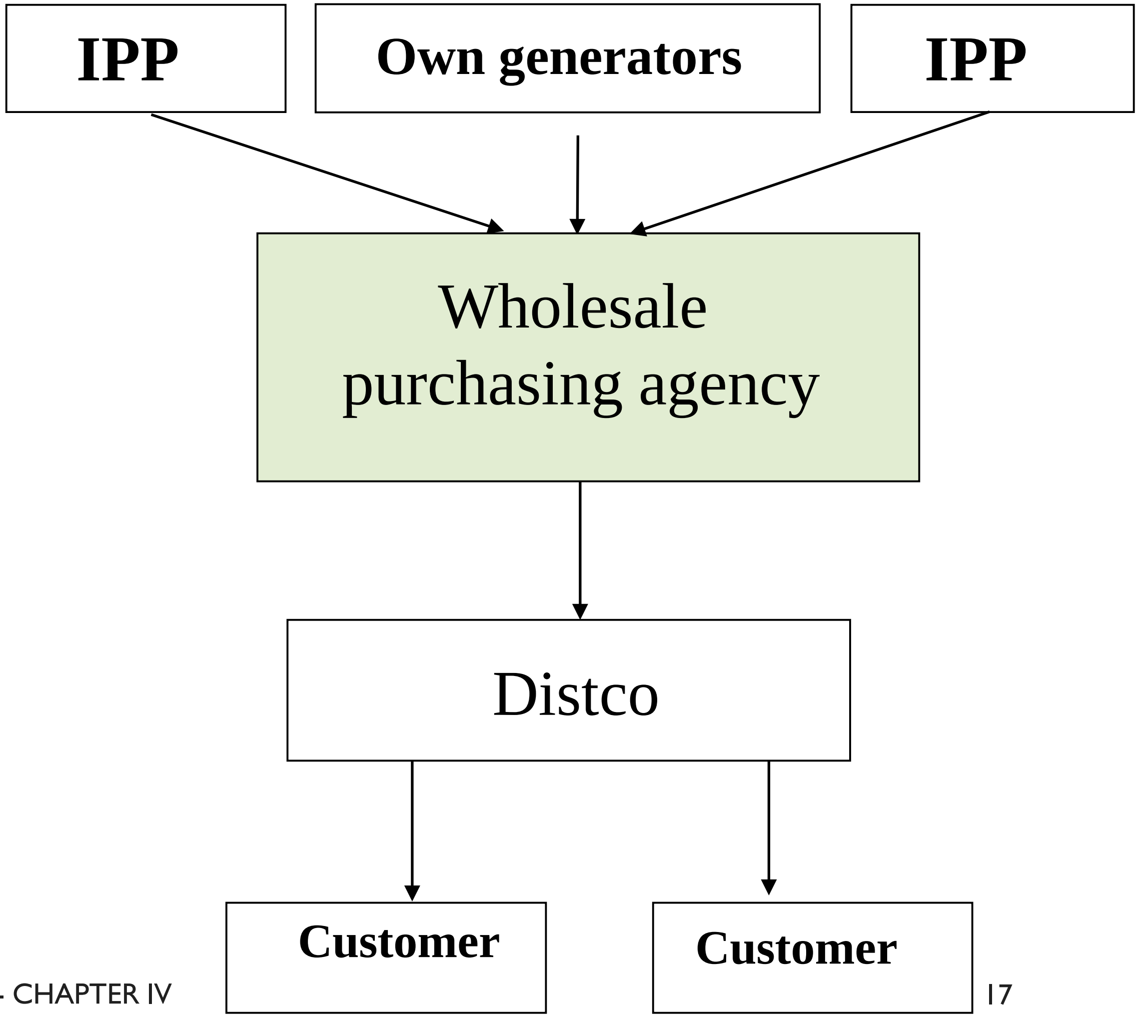


Source: Hunt and Shuttleworth

-MODEL 2: WHOLESALE PURCHASING AGENCY-

- What about risks?

There is almost no competition as the context is often characterised by a lack of investment.
Thus the contracting is often lacking fairness, which may result in high electricity rates to the final consumers. The single buyer model should not be considered as a competitive market model. It is rather a transition from a monopolistic model to a wholesale competition.

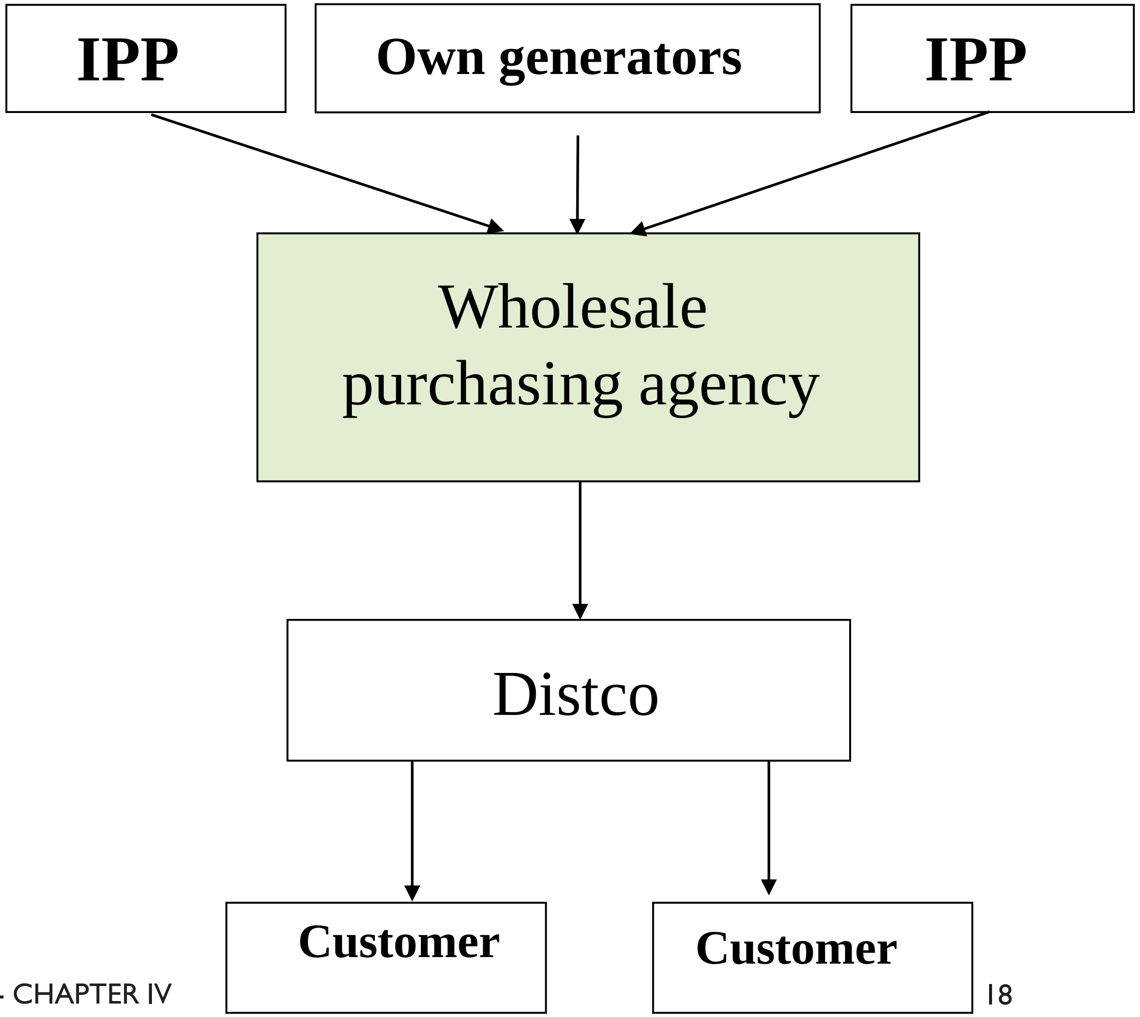


Source: Hunt and Shuttleworth

-MODEL 2: WHOLESALE PURCHASING AGENCY-

- What about risks?

Concerning the ownership of the assets, several models exist: the BOT – Build Operate and Transfer; the BOOT – Build Own Operate and Transfer; the BOO – Build Own and Operate.

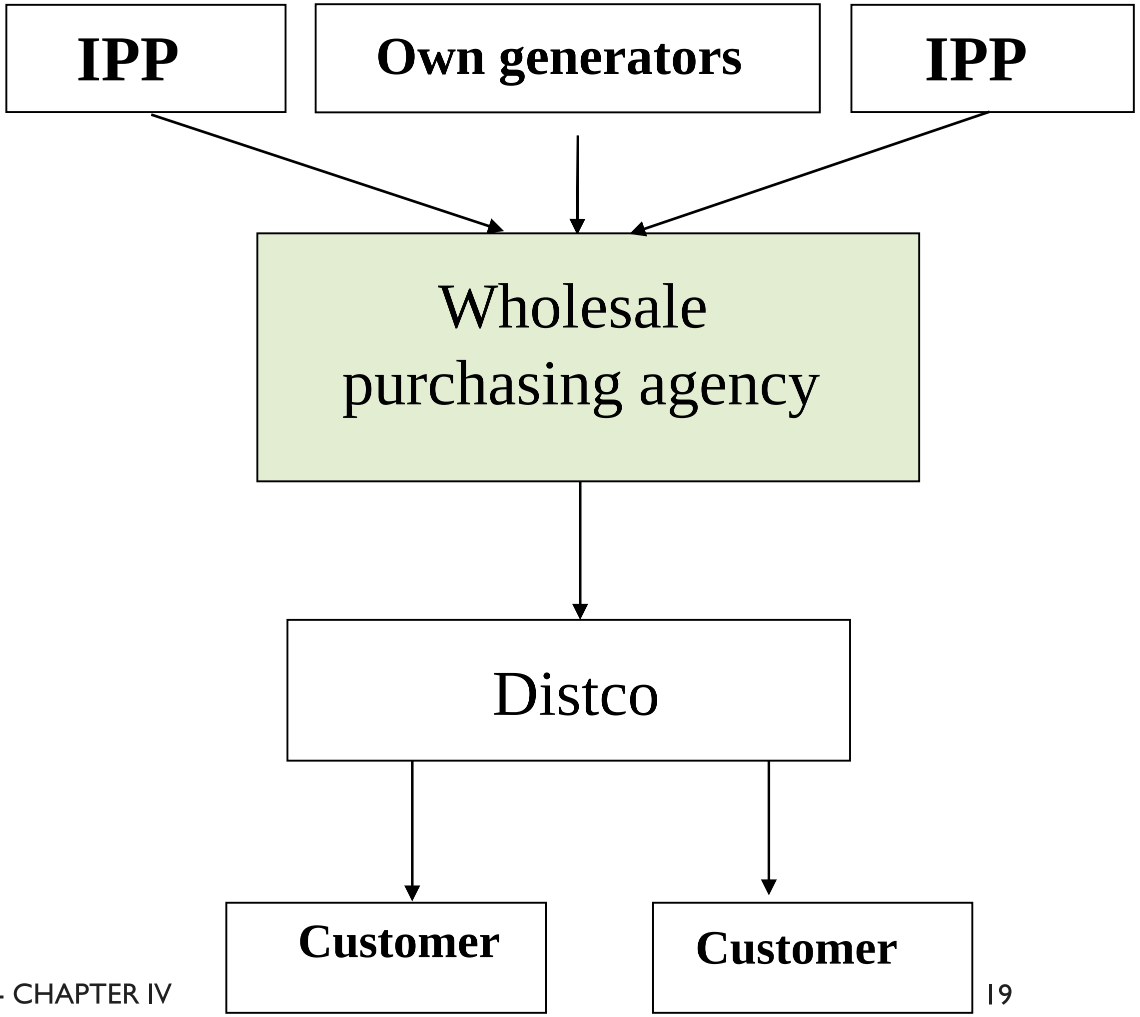


Source: Hunt and Shuttleworth

-MODEL 2: WHOLESALE PURCHASING AGENCY-

- What about risks?

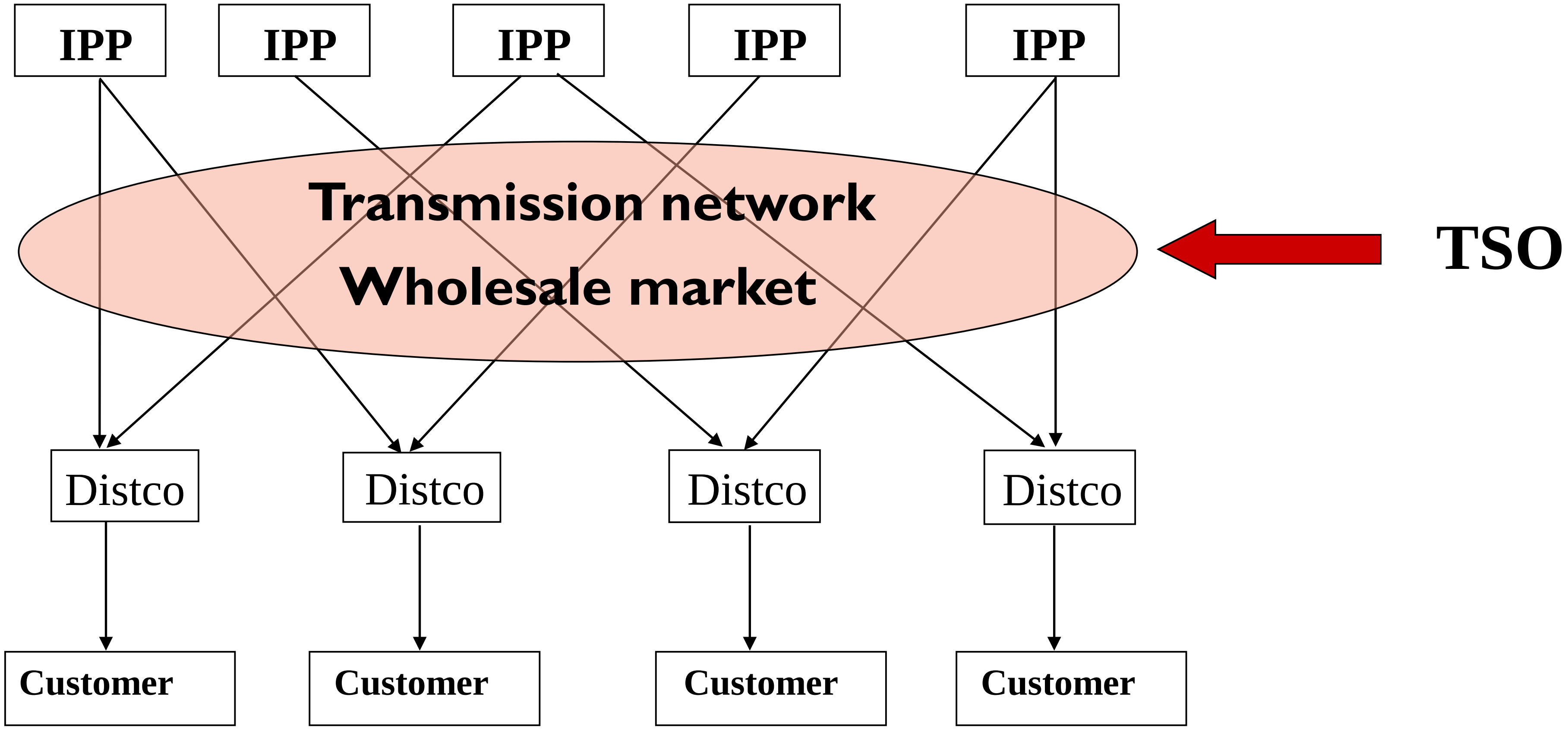
As it is the case of the monopolistic model, existence of an efficient interconnection is a way to hedge the quantity risks



Source: Hunt and Shuttleworth

-MODEL 3: THE WHOLESALE COMPETITION-

Requirement of a Third Party Access to the Transmission network



Source: Hunt and Shuttleworth

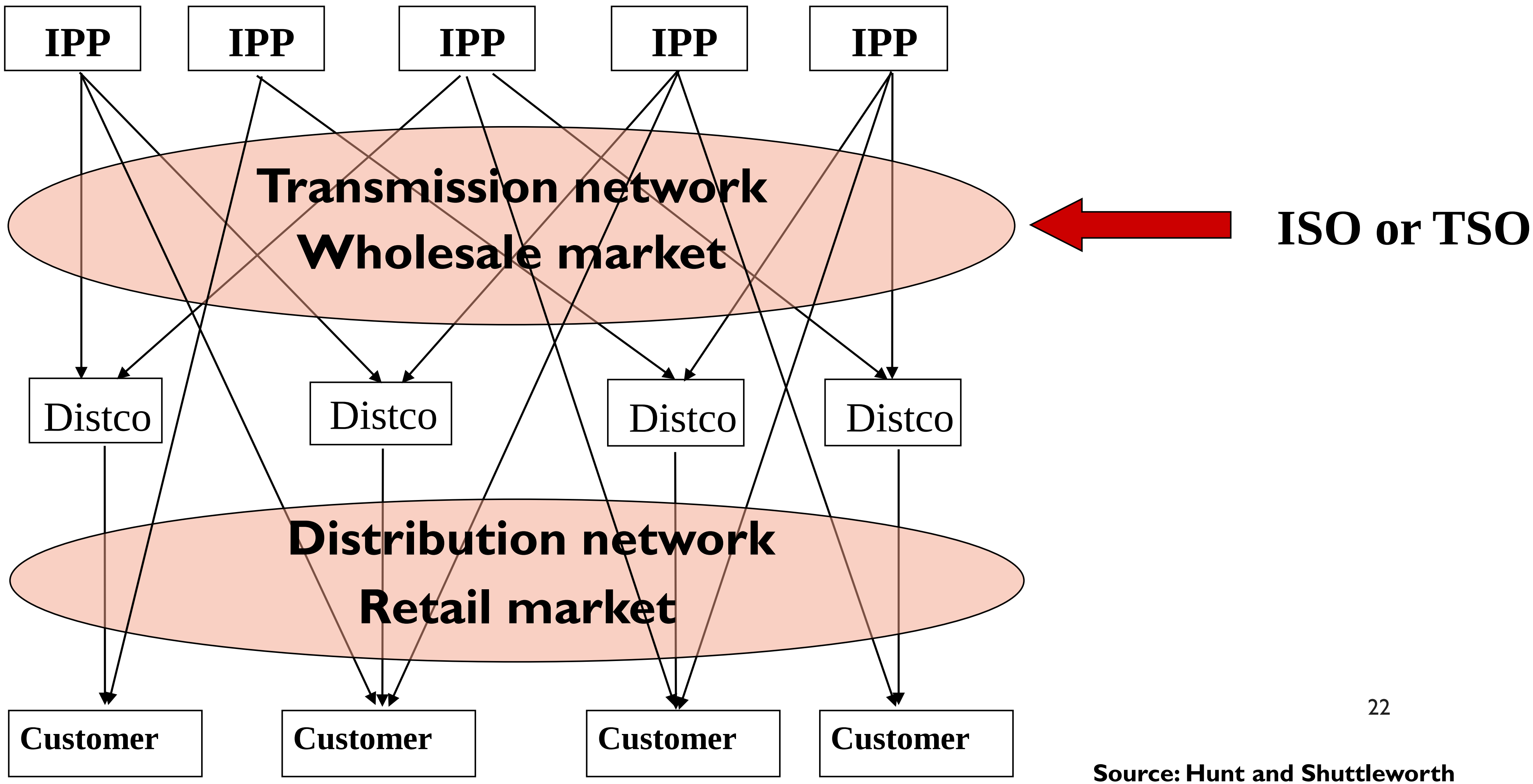
-MODEL 3: THE WHOLESALE COMPETITION-

Main Characteristics

- Independent Dispatching (Transmission system operator – TSO)
- An organized Day-Ahead market coordinated by a market operator MO (every hour or 30 mins)
- Non-discriminatory access and pricing of the transmission service
- The organized market is complemented by bilateral contracts (over the counter transaction – OTC)

-MODEL 4: RETAIL COMPETITION -

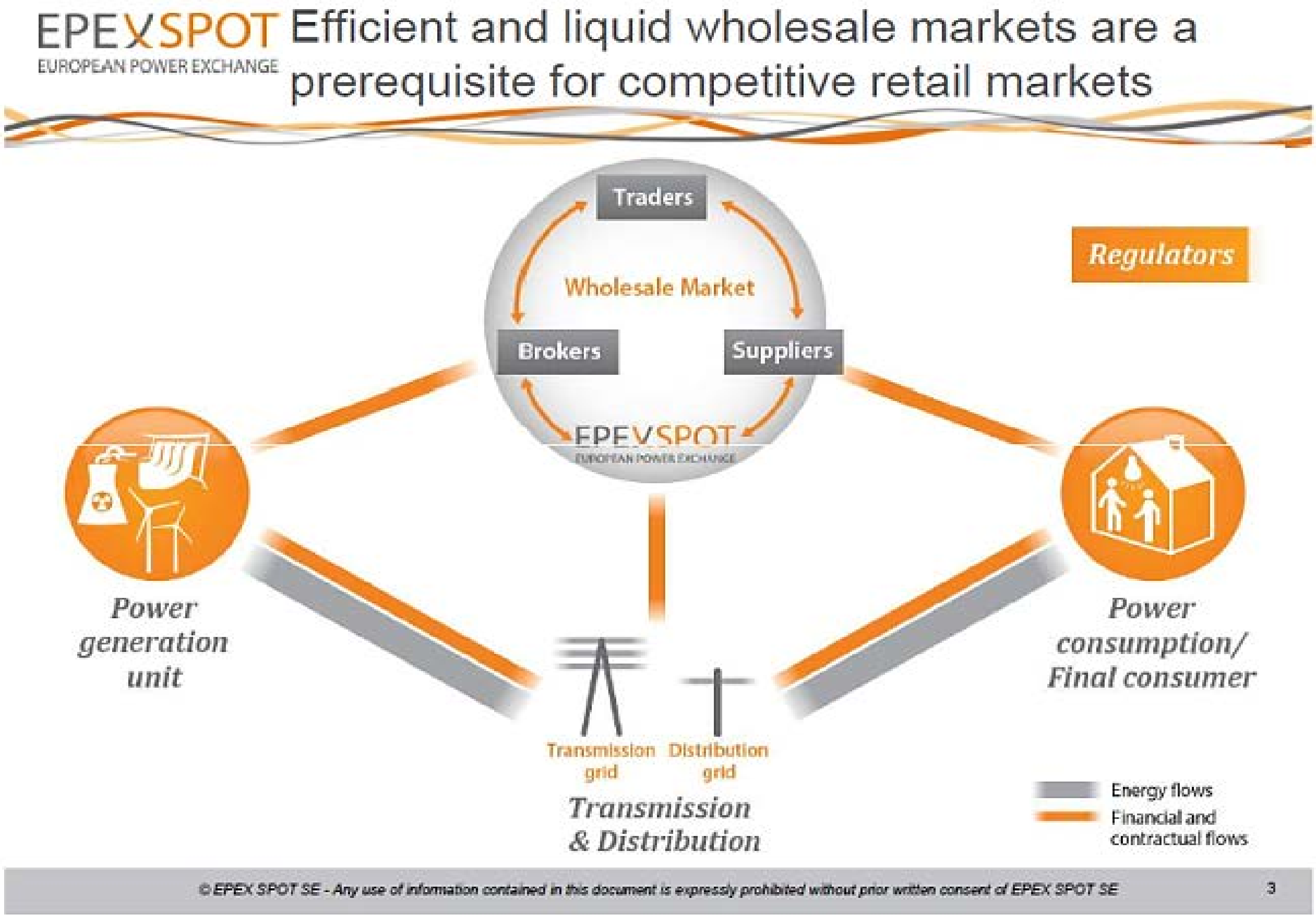
Required Non Discriminatory Access to the Transmission and Distribution Networks



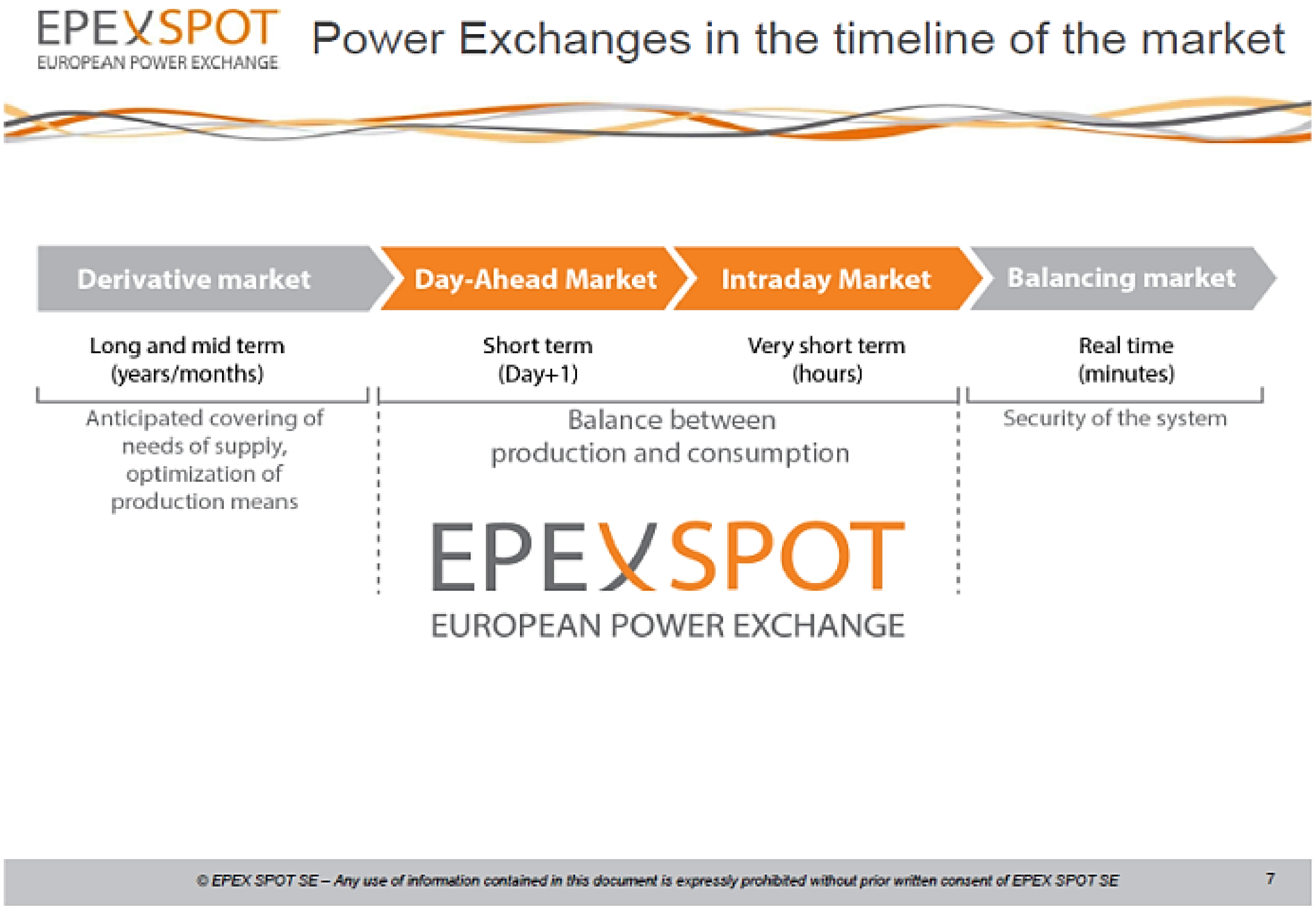
Source: Hunt and Shuttleworth

5.2 AN EXAMPLE OF ORGANIZED MARKET IN CONTINENTAL EUROPE

– EPEX–



– EPEX–


EPEX SPOT
EUROPEAN POWER EXCHANGE
Power Exchanges in the timeline of the market
Derivative market
Day-Ahead Market
Intraday Market
Balancing market
Long and mid term
(years/months)
Short term
(Day+1)
Very short term
(hours)
Real time
(minutes)
Anticipated covering of needs of supply, optimization of production means
Balance between production and consumption
Security of the system
EPEX SPOT
EUROPEAN POWER EXCHANGE
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7

– EPEX–

EPEXSPOT
EUROPEAN POWER EXCHANGE

Corporate facts

EPEXSPOT
EUROPEAN POWER EXCHANGE

205 members

339 TWh traded in 2012

Based in Paris

Created in 2008

60 employees
with 14 nationalities

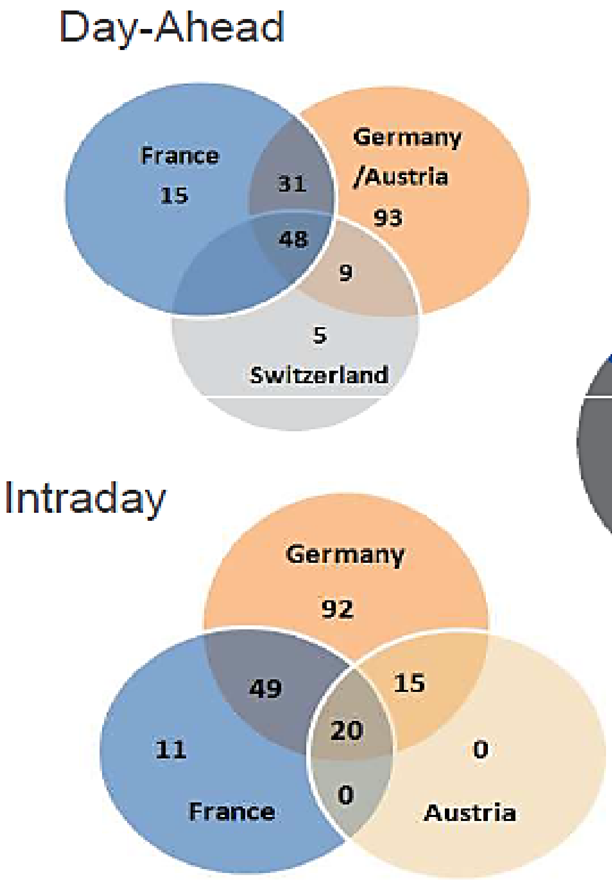
Branch in Leipzig

A European success so far…

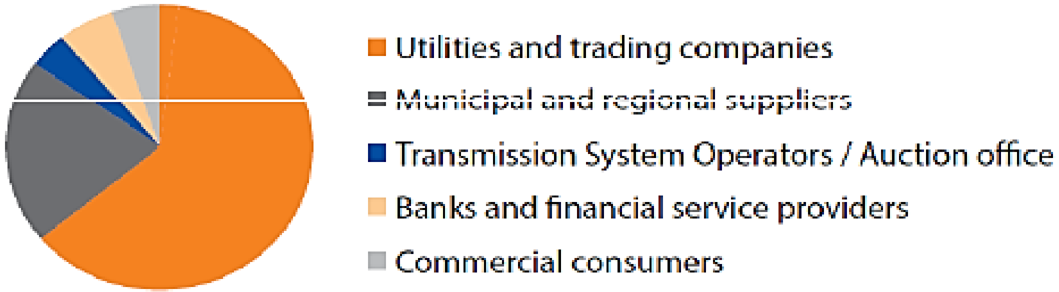
– EPEX–

EPEX SPOT
EUROPEAN POWER EXCHANGE

Who are buyers and sellers on EPEX SPOT?



In total, EPEX SPOT holds **207 Members** (Day-Ahead & Intraday) as of 21 May 2013.



– EPEX–

EPEX SPOT — A Power Exchange at the Heart of Europe

EUROPEAN POWER EXCHANGE

EPEX SPOT's market areas are covering an area of **1,200 TWh** of yearly power consumption which is **40%** of the European Integrated Electricity Market.

EPEX SPOT Markets

- **France**
- **Germany/Austria**
- **Switzerland**

+ Hungarian Day-Ahead Market on behalf of the Hungarian Power Exchange HUPX

+ CZ-SK-HU Market Coupling operations on behalf of OTE, OKTE and HUPX

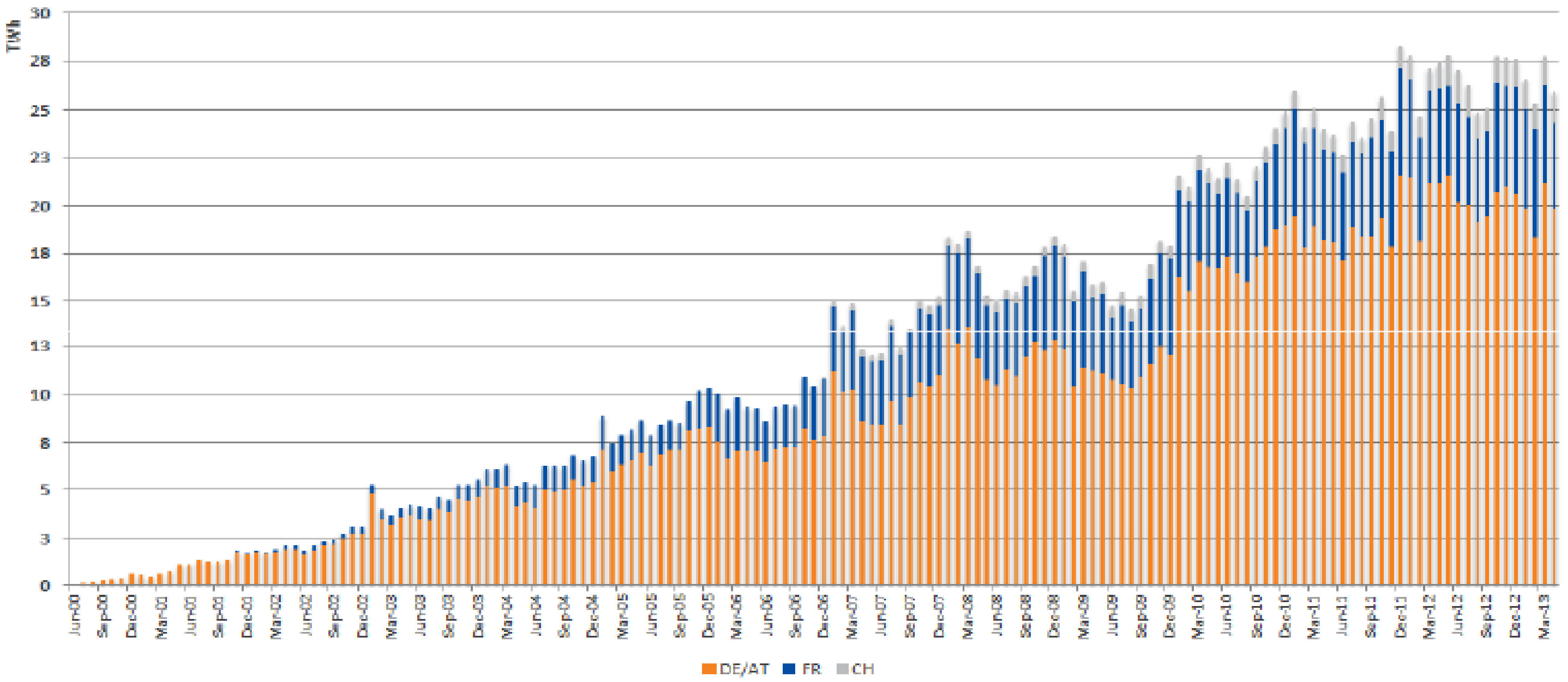
19 interconnectors with own and neighbouring markets

➢ A natural incentive to integrate the European power markets, facilitated by harmonised trading systems

– EPEX–

EPEXSPOT
EUROPEAN POWER EXCHANGE

Day-Ahead volumes on all 3 hubs since 2000



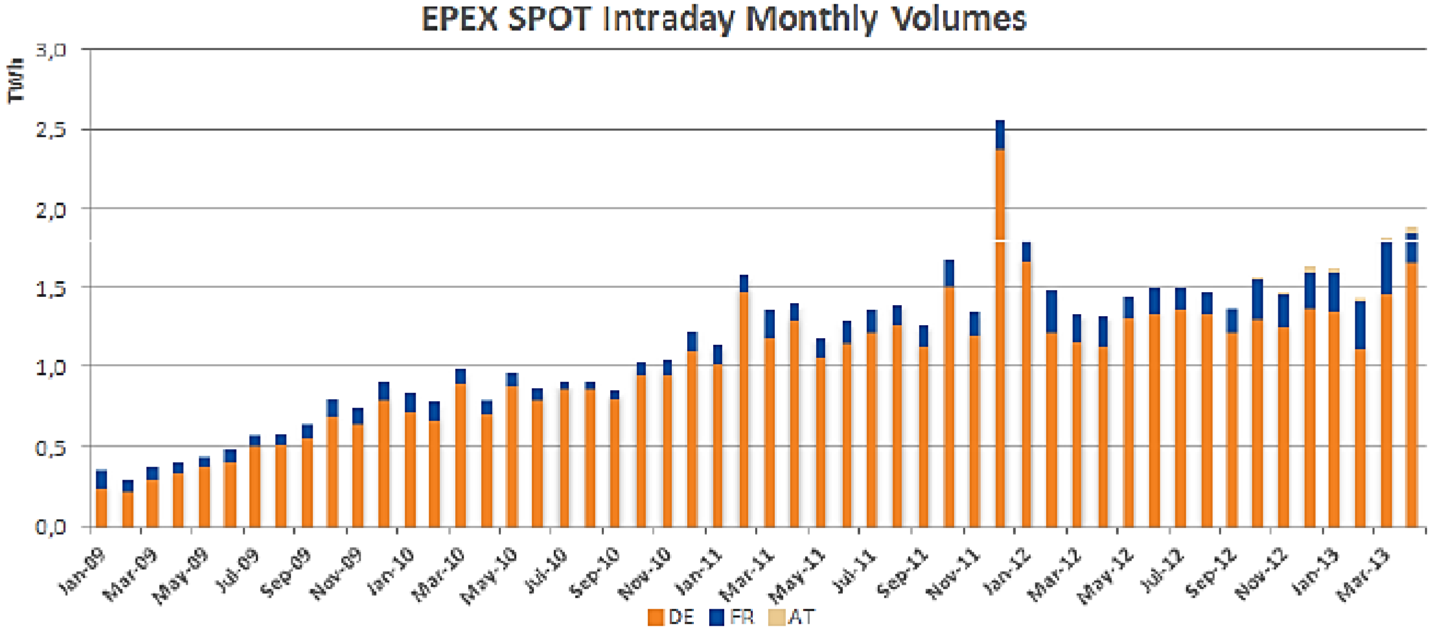
2001: Establishment of Powernext SA
7/2002: Merger of Energy Exchanges Frankfurt-Leipzig
9/2006: Switzerland becomes a new market
9/2008: Creation of EPEX SPOT SE
1/2009: Transfer of Powernext Power Spot into EPEX SPOT SE
9/2009: Transfer of EEX Power Spot into EPEX SPOT SE

– EPEX–

EPEXSPOT
EUROPEAN POWER EXCHANGE

Intraday volumes

- Intraday markets are still very active both locally and cross-border
- Cross-border trades represented on average 13% of total traded volume



5.3 LIQUIDITY RISK AND PRICE RISK

➢ What is liquidity risk ?

- According to the Department of Energy and Climate Change of Great Britain (DECC,2013), the lack of Liquidity «is an important failure of a well-functioning market»

- DECC defines liquidity as «the ability to quickly buy or sell a desired commodity or financial instrument without causing a significant change in its price and without incurring significant transaction costs.»

➢ What is liquidity risk ?

- An important indicator of liquidity is the number of sellers and buyers who are available to take part of market transactions at any given time.

- When the market does not have enough incentives, the agents prefer bilateral transactions.

Consequences of a non liquid market:

- Difficulty for new entries in the competitive segments of the market (generation and retail)
- Possible market manipulations such as collusion, or influence on market price by marginal generators
- Suspicious market prices and inhability to give good signals to investors

- How to manage liquidity risk?

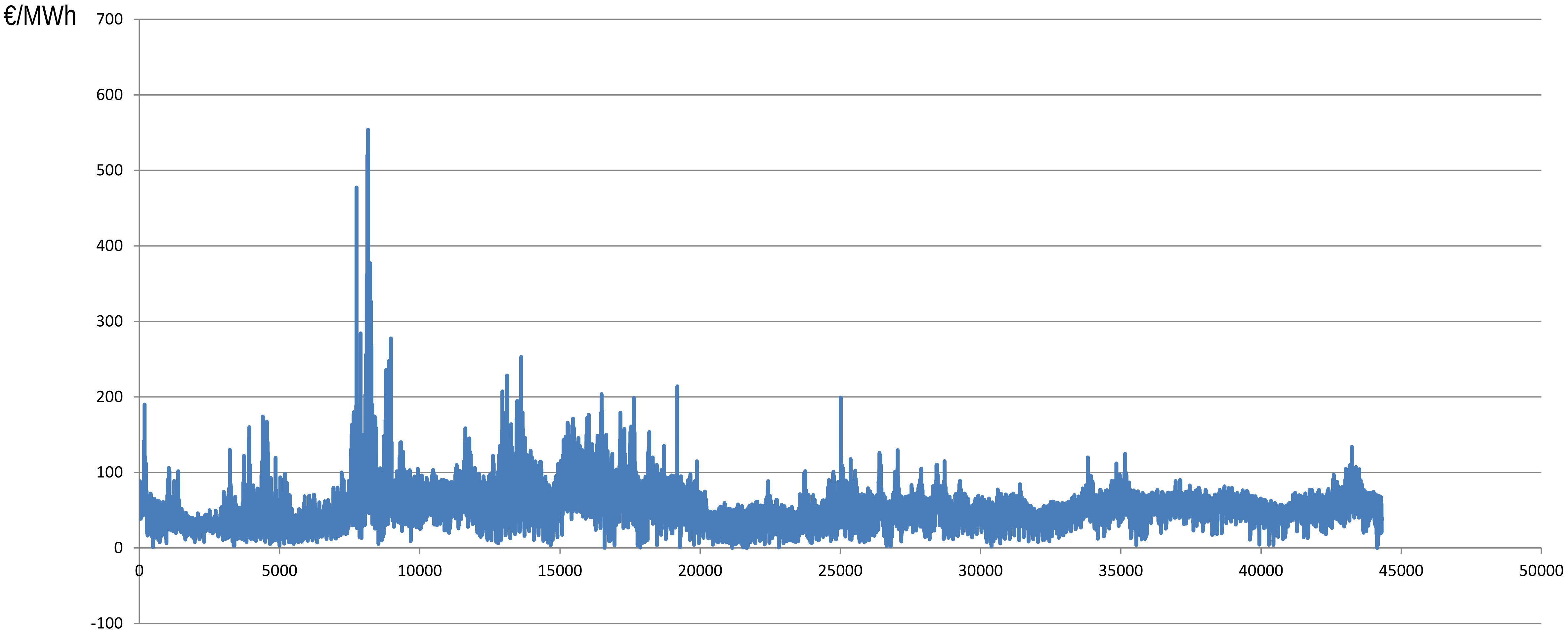
By regulating interventions:

- Give public incentives for participation to the auctions
- Make the participation to the auctions mandatory
- Restrict the bilateral contracts out of the organised market

➢ What is price risk ?

- Price risk is the most important risk in the wholesale competition
- It stems from the high volatility of the spot prices and from the potential losses from prices spikes

Illustration of the variability of spot prices



Characteristics of spot prices:

- Price spikes
- High volatilities
- Seasonality
- Serial correlation
- Mean reverting
- Possibility of negative prices

Few short and medium forecasting methods of prices:

- Time series (e.g. ARIMA, ARCH, GARCH)
- Time series taking into account seasonal effects (SARIMA)
- Times series with exogenous variables such weather conditions, load (ARIMAX)
- Mean reverting model
- Jump-Diffusion models
- Neural Networks
- Multi-agents

5.4 MANAGING PRICE RISK AT SHORT AND MEDIUM TERMS

- High variability of spot prices means opportunities for high benefits as well as for high losses
- Possibilities to hedge the losses by efficiently managing the risk
- At short and medium term, risks can be managed using a well balanced portfolio of contracts
- These include spot as well as bilateral and derivatives

Forward contract

A forward contract binds a buyer and a seller of Electricity.

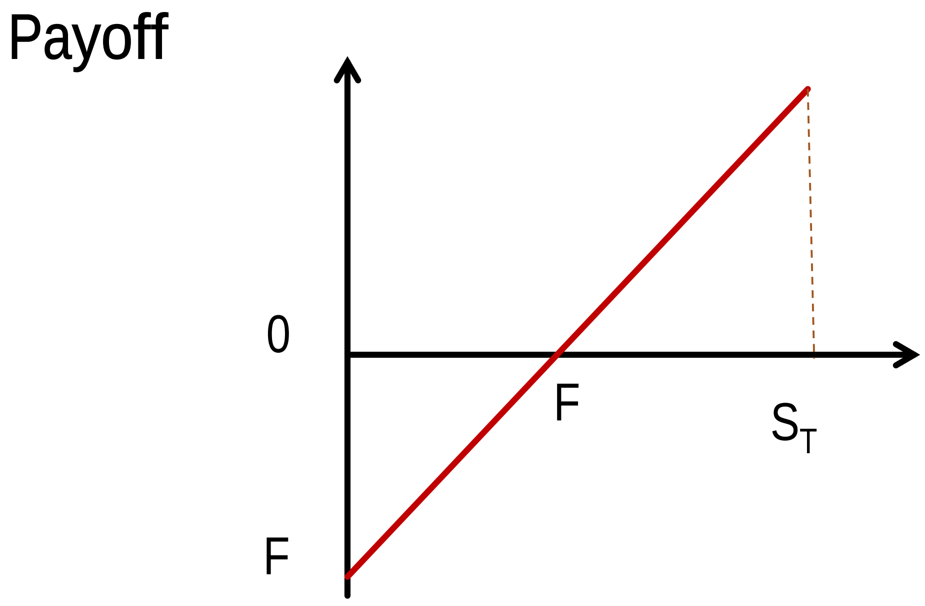
They are committed to buy (sell) a given amount of Electricity at a certain time T in the future (the maturity time) at a pre-specified price : the Forward price F.

Let S_T be the spot price at the time T, the payoff is:

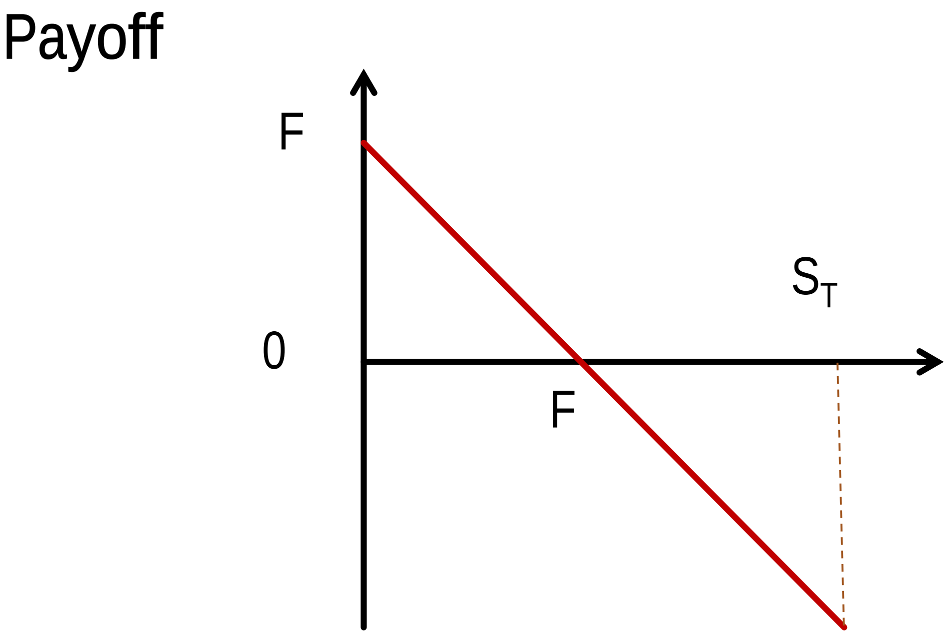
$$\text{Payoff} = S_T - F$$

Forward contract

The Electricity buyer:



The Electricity seller:



Futures contract

Futures contracts are comparable to forward contract with the following differences:

- Futures are traded in organized markets and are standardized while forward contracts are customized and traded bilaterally.

- Futures are financial instrument (derivatives) and may not imply physical transaction of electricity,but rather a financial transaction.

Forward and Futures contracts

Let a buyer A and seller B enter a forward contract of 1000 MWh to be delivered by B in six months at 50 € / MWh.

After six months, the spot price was 55 € / MWh, what are the payoffs of A and B? Why?

If the contract was futures, how much A would have earned (lossed)?

Option contracts

Electricity call (buyer) or put (seller) options offers the purchasers the right not the obligation to buy or sell a fixed amount of underlying electricity at a pre-specified price K (the strike price) by an expiration time T.

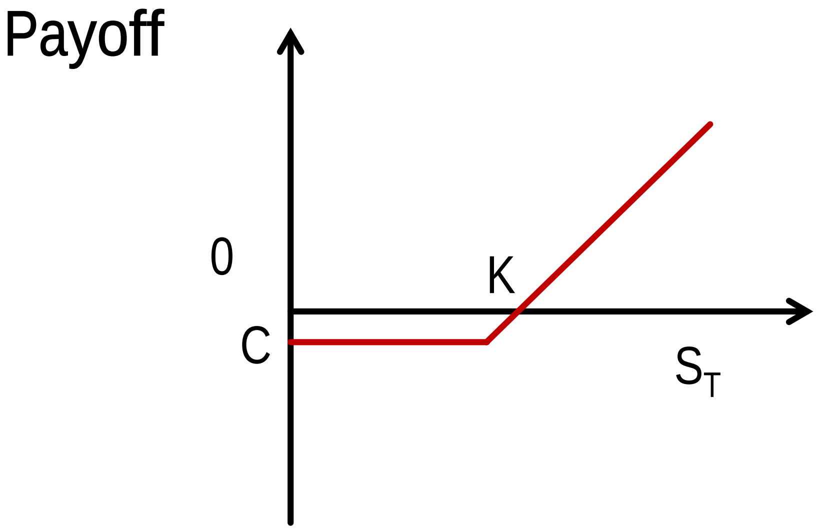
Let S_T be the spot price at the time T, the payoff of the call is:

$$\text{Payoff} = \max(ST - K - c, -c)$$

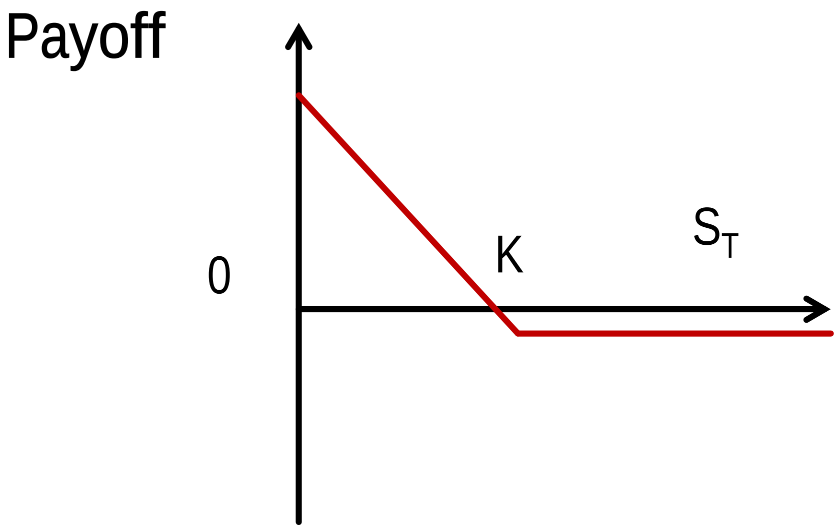
Where c is the transaction cost of the option contract

Option contracts

The Electricity buyer: Call option



The Electricity seller: Put option



Option contracts

A rational buyer will exercize his call option if the spot price is higher than the sum of the strike price and the transaction cost:

$$S_T \geq K+c$$

A rational seller will exercize his Put option if the sum of the strike price K and the transaction cost is higher than the spot price:

$$K+c \geq S_T$$

5.5 MANAGING PRICE RISK AT LONG TERM

- At long term only the design of a well balanced portfolio of assets enables managing efficiently Price risk
- That gives greater importance to modern Portfolio theory
- But concerns rise about the definition of the risk itself

PORTFOLIO THEORY

The aim of the Portfolio theory is to derive the relation between risk and return.

It was mainly applied to the financial market and establishes how rational investors must optimize the return of their portfolio for a given risk level (Markowitz, 1952).

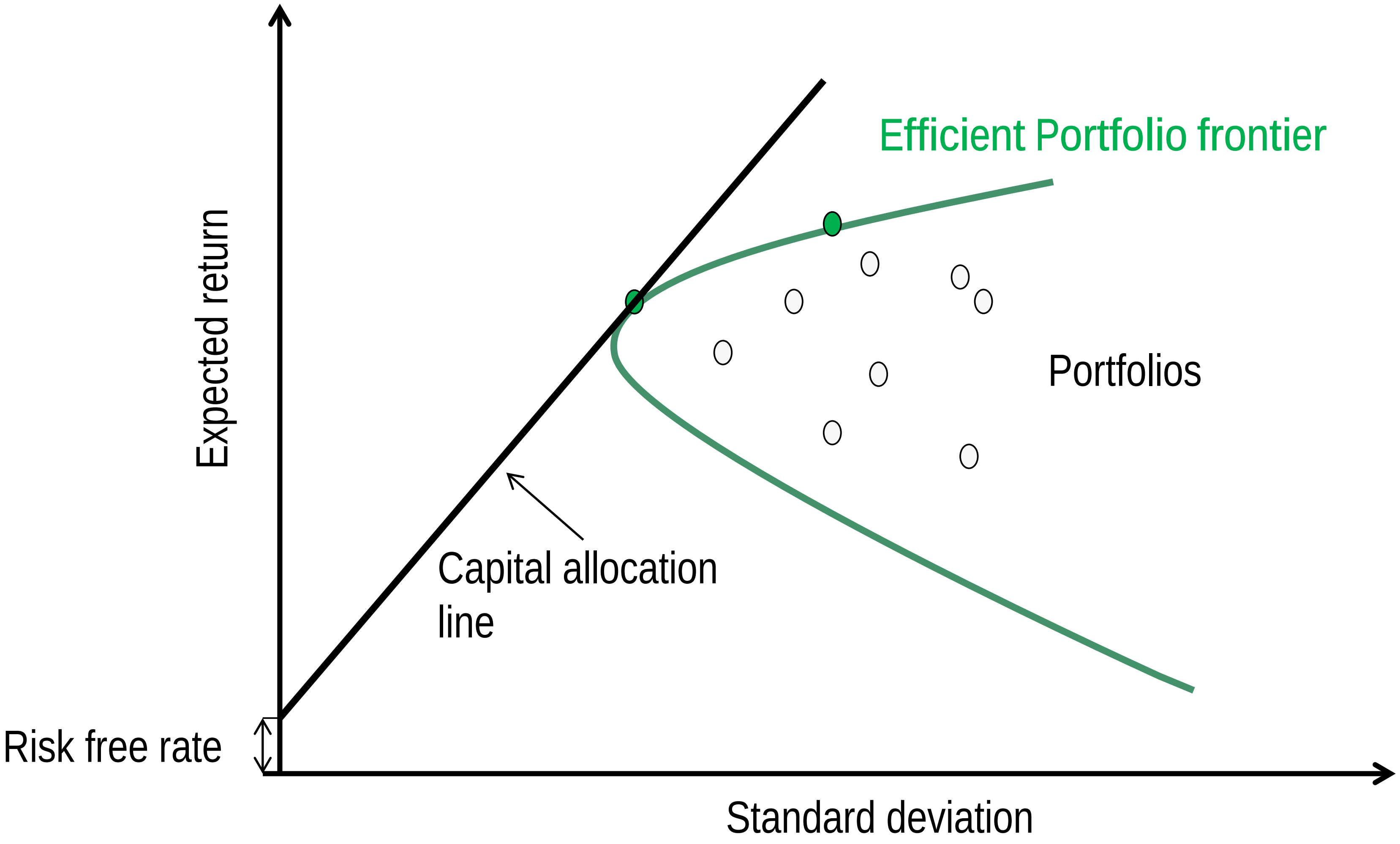
The Modern Portfolio Theory of Markowitz is applied in energy Planning to derive diversification vs. Cost of security of energy supply (Awerbuch and Berger, 2003).

MEAN-VARIANCE OPTIMIZATION (MVO)

In Markowitz's modern portfolio theory (MPT), the risk is modeled by the variance of the return.

Within the MPT, a mean-variance quantitative method is used to estimate an efficient frontier where are located the optimal portfolios.

EFFICIENT PORTFOLIO FRONTIER



APPLICATION OF PORTFOLIO OPTIMIZATION TO THE PLANNING OF ELECTRICAL GENERATING SYSTEMS

MPT was used in several studies to compare different Electrical Generating System matrixes in long term:

- Jansen et al. (2006) applied MPT to analyse the Dutch Electricity Generating mix in 2030; they compared a Reference case and two «renewables cases».

- Huang and Wu (2008) performed a portfolio risk analysis on the electricity supply planning with Taiwan as a case study

-Madlener et al. (2010) used MPT to optimize the E.ON's Power Generating system

CRITICISMS OF MEAN-VARIANCE OPTIMIZATION (MVO)

The main criticism of MVO is the expression of risk in terms of variance

- A Post-Modern Portfolio Theory (PMPT) was proposed (Swisher et al., 2005)
- PMPT uses downside probability instead of standard deviation to model risk
- Schmutz and Gnansounou (2004) developed a fuzzy and multiple criteria comparison of portfolios based on various indicators of generalized risks (failure, success and mean) with their associated fuzzy measures

5.6 ELECTRICAL GENERATING SYSTEM PLANNING IN A MARKET ENVIRONMENT

- In the context of a competitive market, it is assumed that the key factor of investment in the generating system is to maximize the profit
- However, that statement may be discussable as the final goal of an efficient electrical generating system is not to maximize the benefit of some market players while reducing the security of supply Electrical power to the consumers
- Thus, the first statement (i.e. maximization of profit) restricts the issue of electricity trade to profit making
- Competitive market is not an end in itself but a means

A few relevant and theoretical questions may be raised in regards to the liberalization of the electricity supply industry (LESI) and the security of electricity supply (SES)

- Is the LESI compatible with a high SES?
- How should the competitive market be designed in order to make the LESI compatible with a high SES?
- Is the strategic planning relevant in the framework of a competitive market?
- How to model the Electricity supply Industry in the case of a competitive market?
- How to model the strategic planning of Electricity Generating system in a competitive market?

Is the liberalization of the Electricity supply Industry compatible with the Security of Electricity Supply?

- There are several models of competitive electricity markets
- The SES means that Electricity demand and supply achieve a well balanced adequacy in long term
- This condition is not fatal
- Which means that the compatibility between LESI and SES depends on how the market is designed

How should the competitive market be designed in order to make the LESI compatible with a high SES?

- Regulation must adequately address market failures
- Market failure in the case of Electricity is the relation between the «Boom and bust» phenomenon, market price and investment
- Another market failure is the design of the reserve margin

Is the strategic planning relevant in the framework of a competitive market?

- In the framework of a LESI, the strategic planning moves from the whole generating system to the Corporate level
- However the issue of the security of Electricity Supply makes still relevant a strategic planning at a global level
- Environmental and energy policy are other reasons of a renewal of strategic planning at global level
- However that planning should be indicative, not prescriptive

How to model the Electricity supply Industry in the case of a competitive market?

- The Electricity Supply Industry (ESI) should be explicitely represented
- The interaction between the components of the ESI should be represented
- A new paradigm of Electrical generating system planning
- A bottom-up but integrative approach based on artificial intelligence (AI)

How to model the Electricity supply Industry in the case of a competitive market?

- Agent-based modeling
- Basic agents
- Synthetic agents

Each actor is considered as an agent, which can be defined as a software module designed to achieve specific tasks in an autonomous way, possibly with a certain level of "intelligence" including the capability of reasoning about its environment, inferring new knowledge about the current knowledge stored in its knowledge base, learning from its past experience or from examples and patterns coming from a given expertise domain.

Approach proposed by Gnansounou et al. (2004, 2007a, 2007b)

How to model the Electricity supply Industry in the case of a competitive market?

Two kinds of agents are designed by Gnansounou et al.

Basic agents:

A *basic agent* is an elementary agent defined by a set of static and dynamic attributes as well as some specific capabilities. Each agent has his goals and actions. He has to formulate and adjust the strategies and to perform the actions.

Set of basic agents:

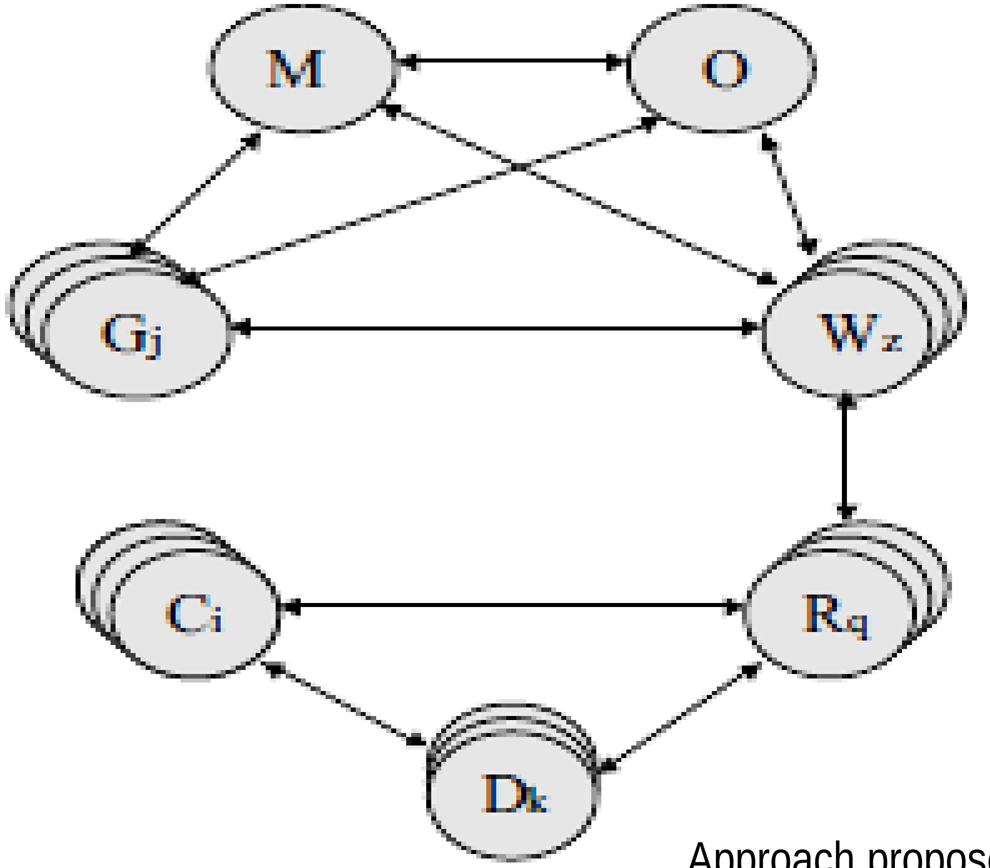
consumer (C), generator (G), system operator (O), distributors (D), the market operator(M), wholesalers (W), retailer (R), and regulator (T).

Synthetic agents:

A synthetic agent is composed of basic agents and coordinates the actions of its components related to a specified goal and accordingly to some strategies.

How to model the Electricity supply Industry in the case of a competitive market?

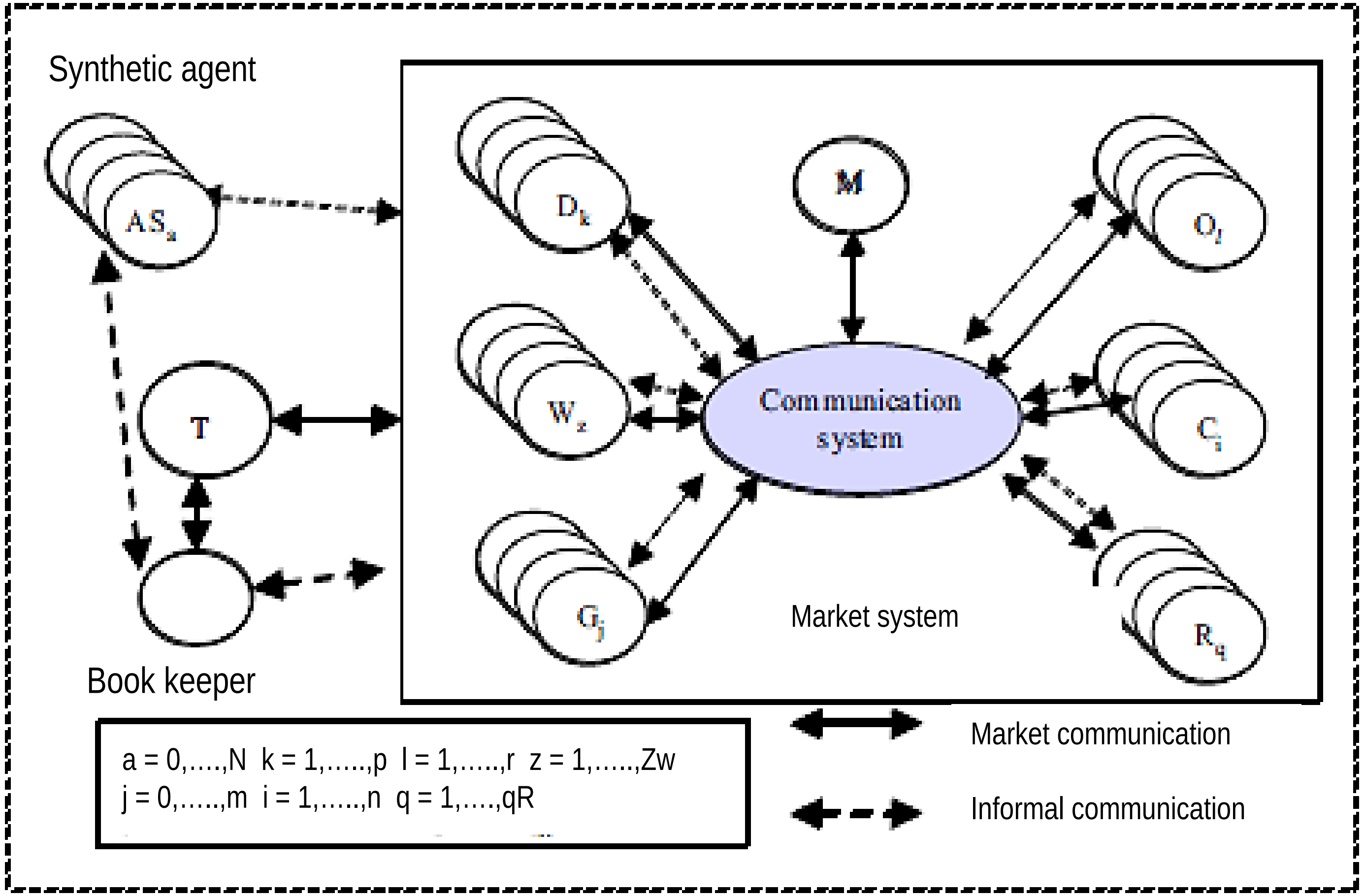
Specific ESI



Approach proposed by Gnansounou et al. (2004, 2007a, 2007b)

How to model the Electricity supply Industry in the case of a competitive market?

Multi-agent system



Approach proposed by Gnansounou et al. (2004, 2007a, 2007b)

How to model the strategic planning of Electricity Generating system in a competitive market?

The market settlement is supposed to be an auction with a uniform price where the generator agents compete to obtain as much profit as possible through supplying electricity to the consumers. The generator agents submit the price and quantity bids to the market operator for each intra-week period d of week *w* and year *y*.

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The Market Clearing Price (MCP) is calculated as follows:

$$\mathrm{MCP}_{s,v} = \mathrm{SMP}_{s,v} * \left(1 - \mathrm{LOLP}_{s,v}\right) + \mathrm{LOLP}_{s,v} * \mathrm{VOLL}$$

CA(k) : Operating capacity of power plant k.
Loads,v : Electricity load in intra-week period v of week s
VOLL: Value of the lost load

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The payoff objective of each week of a generator agent Gi who operates $k = 1,\ldots,K$ power plants is:

$$\text{Max}\ \pi_s(G_i) = \sum_{k=1}^{Ki} \sum_{v=1}^{V} (MCP_{s,v} * q_{s,v}(k) - c_{s,v}(k))$$

$\pi_s(Gi)$: profit of generator agent Gi during week s.
$q_{s,v}$: selling quantity of plant k at each intra-week period v in week s.
$c_{s,v}$: production cost of plant k at each intra-week period v in week s.

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Agent A's planning is an optimization problem with dynamic programming as follows:

$$\text{Max PB}_j = \sum_{y=0}^{Y} (\pi_{j,y} - I_{j,y} + S_{j,y} - F_{j,y} - O_{j,y}) * \frac{1}{(1+r)^y}$$

$F_{j,y}$: fuel cost of agent A with plan j at y

$O_{j,y}$: O&M cost of agent A with plan j at y

r: discount rate

$$\text{s.t. } Z_{j,y} = Z_{j,y-1} - X_{j,y} + E_{j,y} + U_{j,y}$$

$$I_{j,y} \leq I_{l,y}$$

$U_{j,y}$ is admissible if and only if $\exists U_{j,y-1}$ /

$$U_{j,y} \geq U_{j,y-1}$$

j: index of plans, j = 1,2,…. jA
y: index of years, y=1,2,….Y
PBj: present net benefit of agent A with plan j
$\pi_{j,y}$: benefit of agent A with plan j at y
$I_{j,y}$: investment of agent A with plan j at y
$I_{l,y}$: investment limitation of agent A at y
$S_{j,y}$: salvage value of agent A with plan j for investments

$Z_{j,y}$: vector of all generating units of agent A with plan j at year y
$E_{j,y}$: vector of committed addition of generating units of agent A with plan j at year y
$X_{j,y}$: vector of committed retirement of generating units of agent A with plan j at year y
$U_{j,y}$: configuration of expansion (i.e combination of numbers of candidate generating units) at year y according to the plan j

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Three main issues:

- Bidding strategies of the generators when modelling the price series
- Consistency between the modelling of the price series and the strategic planning of the electrical generating system of a given generator
- Consistency between the strategic planning of the electrical generating system of a given generator and the one of its competitors

References:

- Awerbuch, S., Berger, M., 2003. Applying portfolio theory to EU electricity planning and policy-making. IEA/EET Working Paper EET/2003/03. International Energy Agency (IEA) Paris.

- Gnansounou et al., 2004. Market Oriented Planning of Power Generation Expansion using Agent-based Model, IEEE

- Gnansounou et al. 2007a. Toward a multi-agent architecture for market oriented planning in Electricity supply industry. International Journal of Power and Energy Systems, Vol. 27, No. 1, 2007.

- Gnansounou et al. 2007b. A multi-agent approach for planning activities in decentralized electricity markets. Knowledge-Based Systems 20 (2007) 406–418

- Huang, Y.-H., Wu, J.-H., 2008. A portfolio risk analysis on electricity supply planning. Energy Policy 36 , 627-641.

- Hunt, S., and Shuttleworth, G., 1996. Competition and Choice in Electricity. Book, John Wiley & Sons (Chichester, U.K. and New York).

- Jansen, J.C., Beurskens, L.W.M., van Tilburg, X., 2006. Application of portfolio analysis to the Dutch generating mix. ECN. Project number 77677.01.02.

- Madlener, R., Glensk, B., Westner, G. 2010. Optimization of E.ON's Power Generation with a Special Focus on Renewables. Volume 2, Issue. E.ON Energy research Center.

- Markowitz, H.M., 1952. portfolio selection. Journal of finance 7 (1), 77-91.

- Schmutz, A., Gnansounou, E. , 2004. Appraisal of Portfolio of assets in Electricity Market: Risk Measures under Vagueness and Flexibility. Zeitschrift für Energiewirtshaft vol.29, num. 2, p. 147-156

- Swisher, P., Kasten, G., W., 2005. Post-Modern Portfolio Theory. FPA Journal, September issues.

- DECC, 2013, Energy Bill 2012 Impact Assessment Liquidity Measures. Department of Energy and Climate Change of Great Britain.