First ELECON Workshop
Towards Efficient European and Brazilian Electricity Markets

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ELECTRICITY CONSUMPTION ANALYSIS & ENERGY EFFICIENCY

Simulation of Electricity Markets

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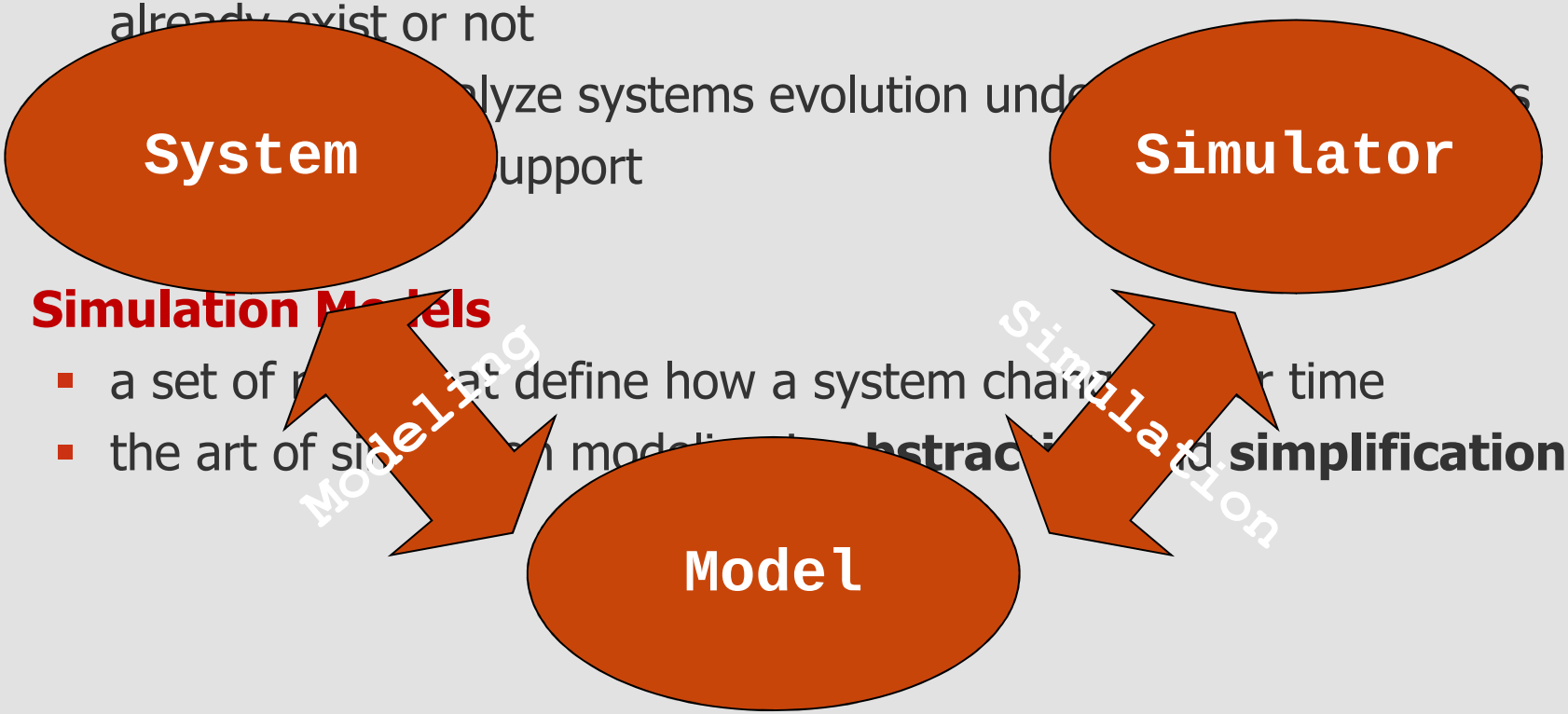
Outline

- Simulation
- Electricity Markets
- Multi-Agent Simulators for Electricity Markets
- MASCEM
- Scenarios Generator

Simulation

- **Simulation**
  - important tool to gain knowledge about systems, whether they already exist or not
  - lyze systems evolution unde s
  - upport



- **Simulation M els**
  - a set of r at define how a system chan r time
  - the art of si n mode **bstrac d simplification**

Multi-Agent Simulation

- **Multi-Agent Simulation**
  - multi-agent system is used as a model that describes simulated actors and their decision processes
  - systems behavior emerges as a result of the actions of the agents, and their interactions with other agents and the environment
- **Agents**
  - characterized by independence and autonomy that have the ability to plan and to establish their actions ahead of time, to develop appropriated problem's solving strategies, to communicate, or to share resources
  - agents have the possibility to follow events as they occur in the environment and to learn from past experiences

Multi-Agent Simulation

- **Agents**
  - Autonomy: agents operate without others having direct control of their actions and internal state;
  - Social ability: agents interact with other agents (and possibly humans) through some kind of language (message passing, …);
  - Reactivity: agents are able to perceive their environment (which may be the physical world, a virtual world of electronic networks, or a simulated world in-cluding other agents) and respond to it;
  - Goal-oriented: an agent does not simply act in response to the environment;
  - Proactivity: as well as reacting to their environment, agents are also able to take the initiative, engaging in goal-directed behavior

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Multi-Agent Simulation

- **Multi-Agent Simulation**
  - allows modeling a system with heterogeneous agents, each having personal motivations and incentives, and to represent groups and group interactions
  - the systems behavior emerges as a result of the actions of the agents, and their interactions with other agents and the environment
  - powerful computational tool, for which dynamic aspects are based on interactions between agents, rather than centralized control
  - the model may be easily enlarged

Adequate for Electricity Markets studying?

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Electricity Markets Simulation

- **Electricity Market Restructuration** and **Increase** of **Distributed Generation** Sources

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- Increase in **Competitiveness and Complexity**

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- Greater **need** for **Decision Support** tools

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- **Several simulators** appear

Electricity Markets Simulators

- **SEPIA**
  - The Simulator for the Electric Power Industry Agents provides an agent-based simulation that combines both the economical and technical issues; considers bilateral contracts;
  - "Sepia: A Simulator for Electric Power Industry Agents", S.A. Harp, et al., 2000
- **SREMS**
  - The Short – Medium run Electricity Market Simulator (SREMS) is based on game theory and is able to support scenario analysis in the short-medium term and to evaluate market power
  - "SREMS-electricity market simulator based on Game Theory and incorporating network constraints", M. G. Migliavacca, 2007

Electricity Markets Simulators

- **Power Web**
  - It is a Web-based market simulator, allowing the various participants to interact from very distinct zones
  - It is a rather flexible system that allows the definition of simulations with a large set of scenarios and rules
  - "PowerWeb: a tool for evaluating economic and reliability impacts of electric power market designs", R. Zimmerman and J. Robert Thomas, 2004
- **AMES**
  - Agent-based Modeling of Electricity Systems (AMES) is an open-source computational laboratory for the experimental study of wholesale power markets restructured in accordance with U.S. Federal Energy Regulatory Commission (FERC)'s market design
  - "Development of Open Source Software for Power Market Research: The AMES Test Bed", H. Li and L. Tesfatsion, 2009

Electricity Markets Simulators

- **EMCAS**
  - Electricity Market Complex Adaptive System (EMCAS) uses an agent based approach with agents' strategies based on learning and adaptation;
  - Different agents are used to capture the restructured markets heterogeneity
  - It allows undertaking electricity markets simulations in a time continuum ranging from hours to decades, including several pool and bilateral contracts markets
  - "Real-World Market Representation with Agents: Modeling the Electricity Market as a Complex Adaptive System with an Agent-Based Approach", V. Koritarov, 2004

MASCEM Overview

- **The restructuring of the energy markets led to an enormous increase of the competition in this sector**
  - Multi-agent simulation combined with Artificial Intelligence techniques may result in sophisticated tools very helpful under this context

- **MASCEM – Multi-agent Simulator of Competitive Electricity Markets**
  - includes a complex simulation infrastructure able to cope with
    - different negotiation mechanisms
    - several players competing and cooperating in a dynamic and complex environment
    - the diverse time scales of the supported market mechanisms
    - balanced approach of technical and economic issues

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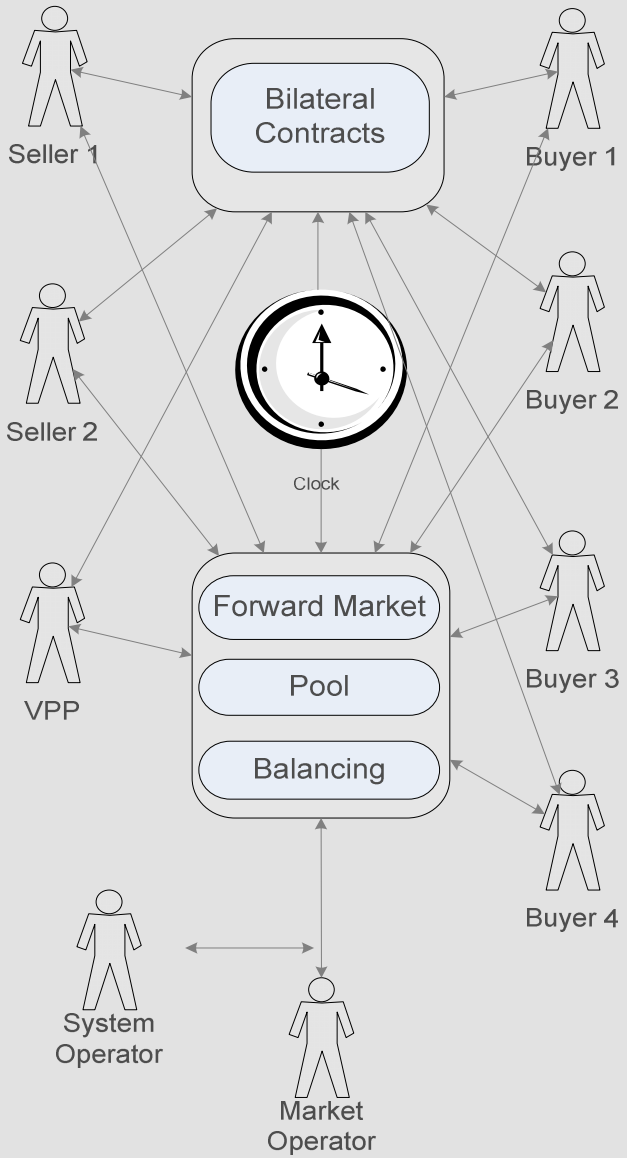
MASCEM Overview



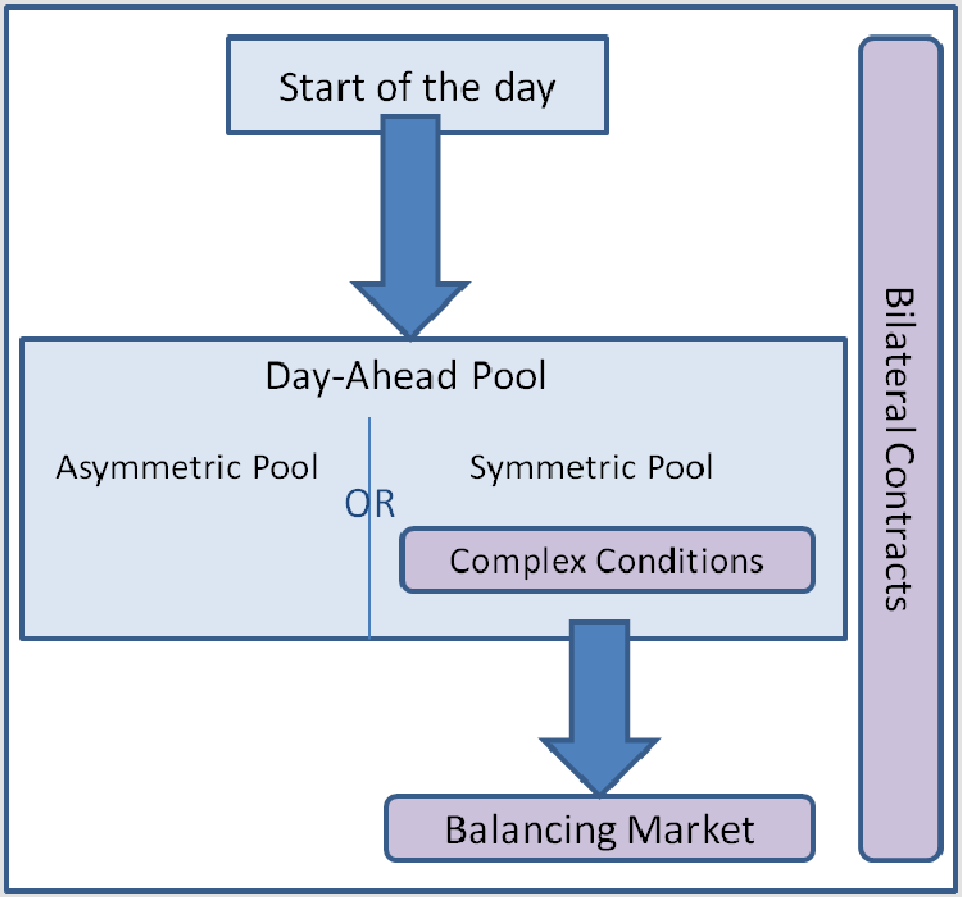
MASCEM Players include

- System Operator Agent
- Market Operator Agent
- Market Facilitator Agent
- Seller Agents
- Buyer Agents
- Virtual Power Players (VPPs)
- VPP Facilitator Agents

MASCEM Overview

Market Types and Features

- day-ahead markets, with or without complex conditions
- balancing markets
- ancillary services
- internal markets for SG
- bilateral contracts
- technical operation
- congestion management
- demand response
- tariff mechanisms
- ...



MASCEM Overview

- **Development tools**
  - communications platform started to be supported by the OAA platform (www.ai.sri.com/~oaa/)
  - nowadays, supported by JADE framework (jade.tilab.com/)
  - agents are implemented in JAVA (www.java.com)
  - some agents and strategies for bidding definitions are developed in Prolog (www.lpa.co.uk)
  - calculations algorithms are mostly programmed in MatLab (www.mathworks.com/products/matlab/)

MASCEM Overview

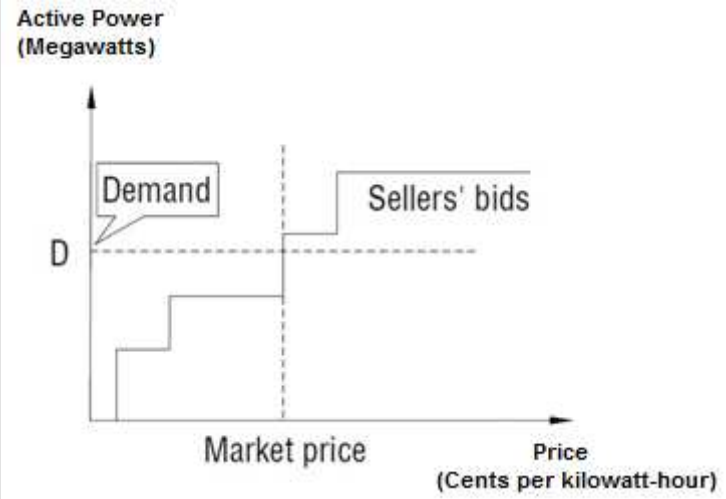
- **Regulatory Models**
  - Spot Markets
  - Complex Market
  - Balancing Market
  - Bilateral Contracts

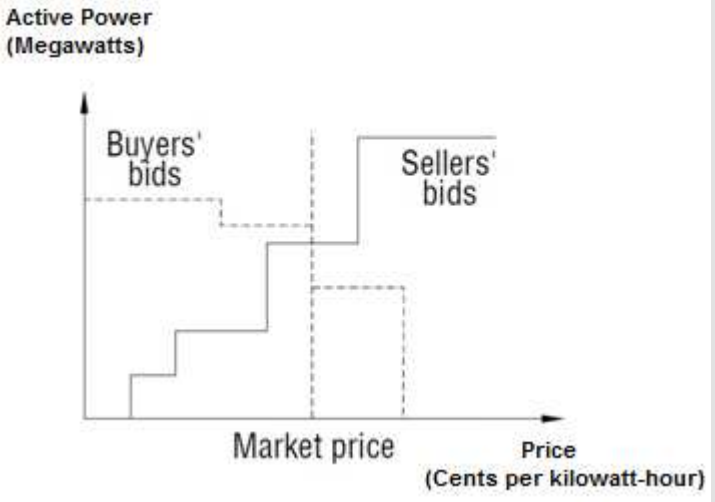
Spot Markets

- Daily basis functioning market
- Usually divided into 24 or 48 negotiation intervals

Asymmetric Pool
Submission of selling proposals
Buyer players present only a demand estimative

Symmetric Pool
Both sellers and buyers submit bids
Usually based on adouble auction





Complex Market

- **Indivisibility**
  - allows setting a minimum value of operation in the first offer of each period
  - below this value, the participation of the production unit on the market is not possible
  - this condition applies to generating units that cannot work under a technical limit

- **Charge Gradient**
  - allows establishing the maximum difference between the initial and the final power, between periods, for a production unit
  - allows avoiding abrupt changes between consecutive periods (resulting from technical impossibility of achieving such changes)

Complex Market

- **Minimum Income**
  - is used to ensure that the production unit does not enter the market if it cannot obtain a minimum amount in €, in the total of all periods, plus a variable fee per transacted kWh
  - this restriction depends on the sales strategy of each agent

- **Scheduled Stop**
  - is used in situations where the production unit has been withdrawn for not meeting the condition of required Minimum Income.
  - this condition ensures that the production stopping is not done abruptly, rather undertaking a scheduled stop in a maximum time of 3 hours, avoiding production to immediately decrease to zero, from the last period of one day to the first period of the next

Balancing Market

- **The Balancing Market (BM) is a complementary platform to the day-ahead market**
  - Players negotiate for the present day
  - Allows players to re-adjust their needs
  - Complex conditions present some peculiarities

- **The Market Operator ensures the best market price, taking into account the different market possibilities**

  - BM comprises (six in the Iberian market) daily sessions of trading
  - Buyers are allowed to sell and Sellers to buy
  - Agents use their strategies in order to obtain the best possible advantage
  - The BM covers all the hours of the day with the specificity of each session

Balancing Market

- **BM increases MASCEM's horizon of simulation**
  - brings it closer to the reality of competitive electricity markets
  - allows to study more accurately the development of these markets

- **Players can take advantage of it**
  - ensure conditions for smooth fluctuations
  - adjust their forecasted production and consume deviations
  - use BM's particularities in what concerns their strategic behavior

Bilateral Contracts

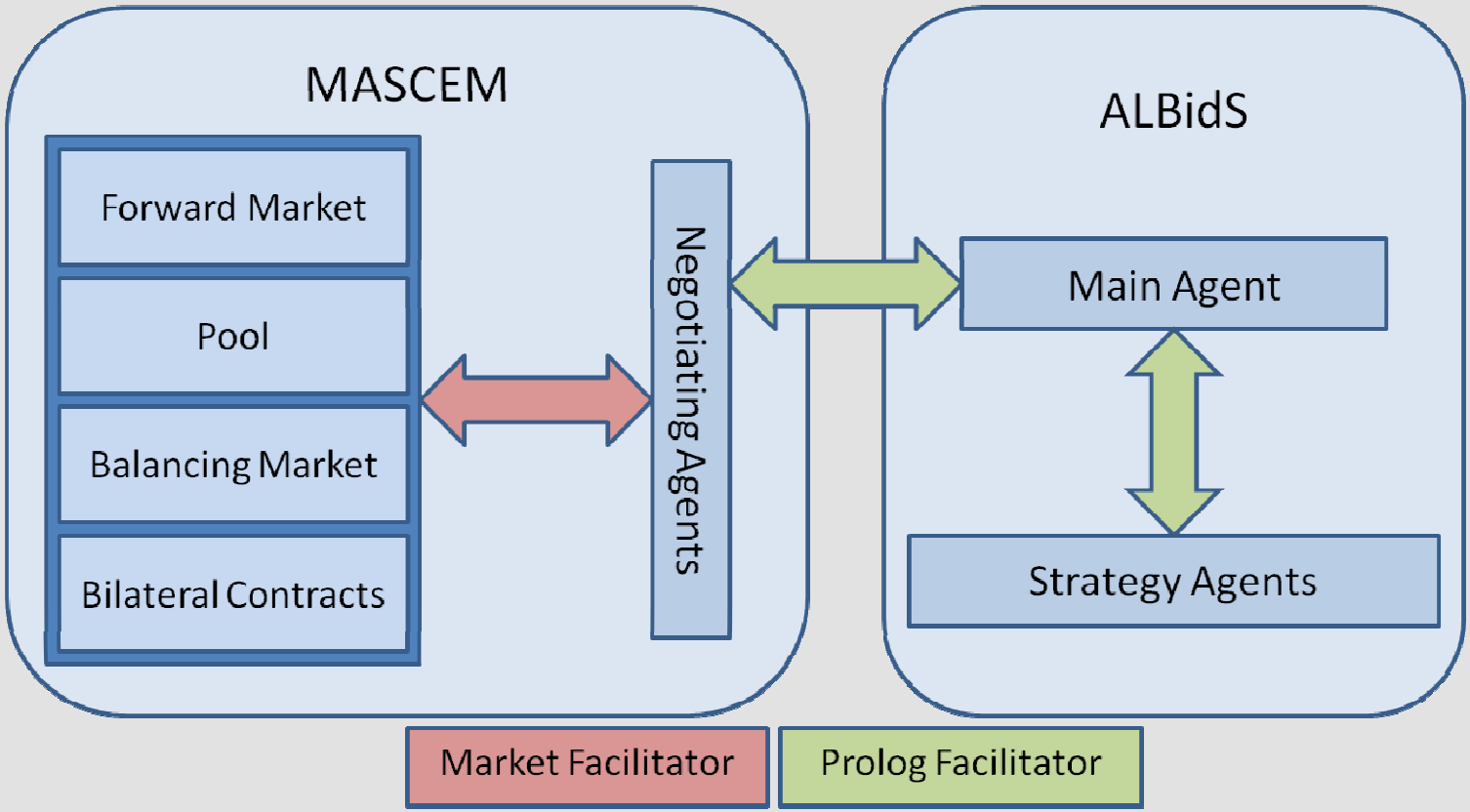
- **Allow players to negotiate directly with each other**
- **Opportunity to establish contracts with varying timelines,**
  - higher security for companies that require constant demands over time
- **The seller must be sure that it is feasible to deliver energy to the buyer's location**
  - It must get the network operator's feedback before reaching an agreement with the demand agent

MASCEM Overview

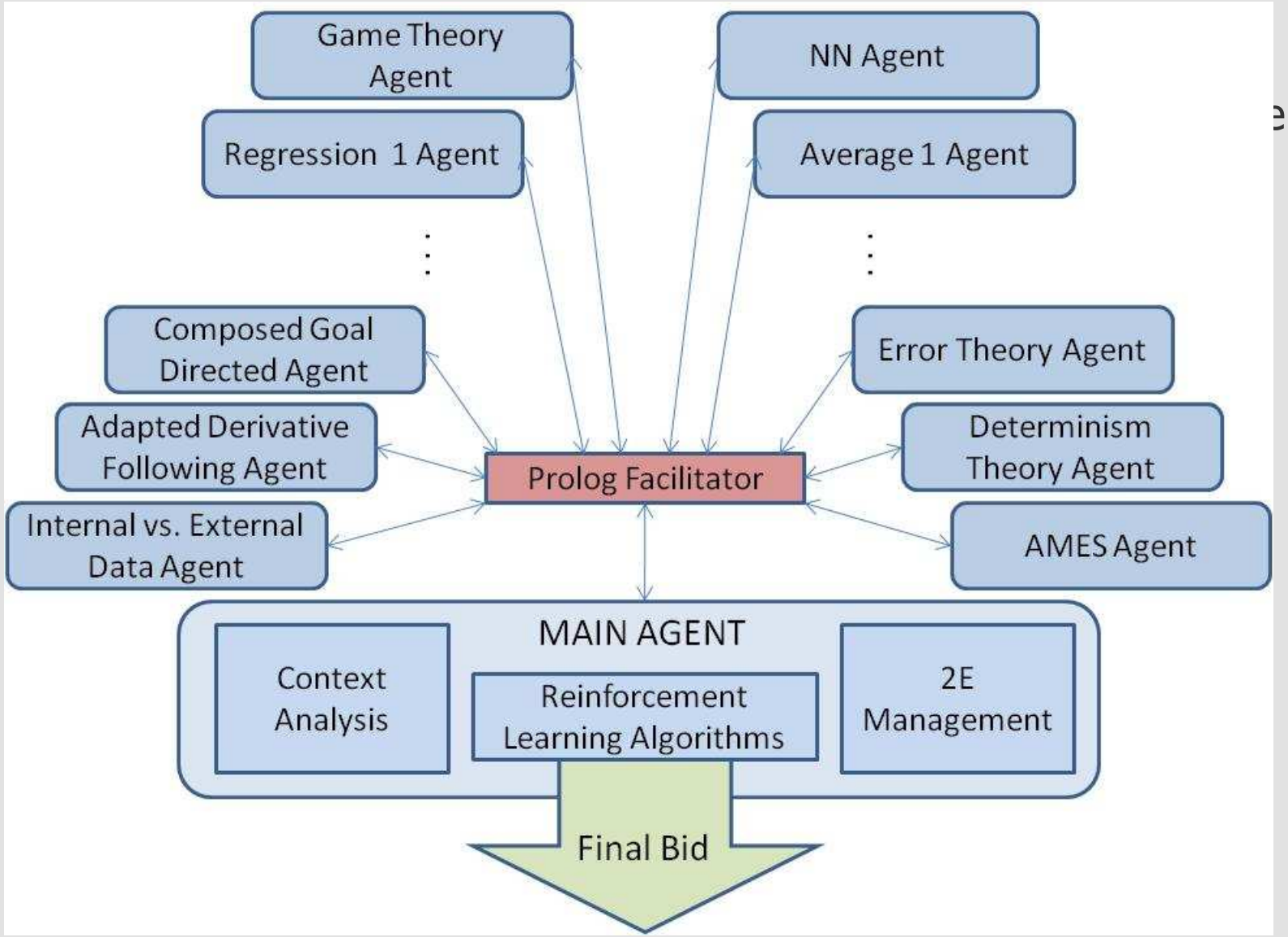
- **Strategic Bidding**
  - Based on previously obtained results, buyer and seller agents review their strategies for future transactions
  - Each agent's strategic behavior defines its desired price and the amount of power to be negotiated in each Market
  - Considering the expected production of one player for each period of each day, the amount of power to be negotiated in each market is optimized to get the maximum profit that can be achieved
  - Taking advantage of the individual characteristics that each particular market offers

ALBidS - Adaptive Learning strategic Bidding System

- **Main agent**
  - Communication with MASCEM players
  - Communicates with ALBidS agents



ALBidS – Main Agent



MASCEM Overview

- **Distributed Generation**
  - Although renewable energy sources use increases at a high rate, the whole power system is showing difficulties in adequately taking fully profits from these resources
  - Present operation and tariff methods are not able to cope with the new distributed generation characteristics and are unable, for instance, to prevent important wind curtailment
  - To get more negotiation power in the market and to get advantages of scale economy, distributed generators can be aggregated giving place to a new concept: the Virtual Power Palyer (VPP)

VPPs are multi-technology and multi-site heterogeneous entities that should adopt organization and management methodologies so that they can make DG a really profitable activity, able to participate in the market

Coalition Support in MASCEM

- **Coalitions are an important form of interaction in multi-agent systems**
  - Coalition formation is the coming together of a number of distinct, autonomous agents in order to act as a coherent grouping in which they increase their individual gains by collaborating
  - In all applications (e-commerce, grid computing, e-business) the formation of coalitions aims to increase the agents' abilities to satisfy goals and to maximize their personal, or the system's, outcomes

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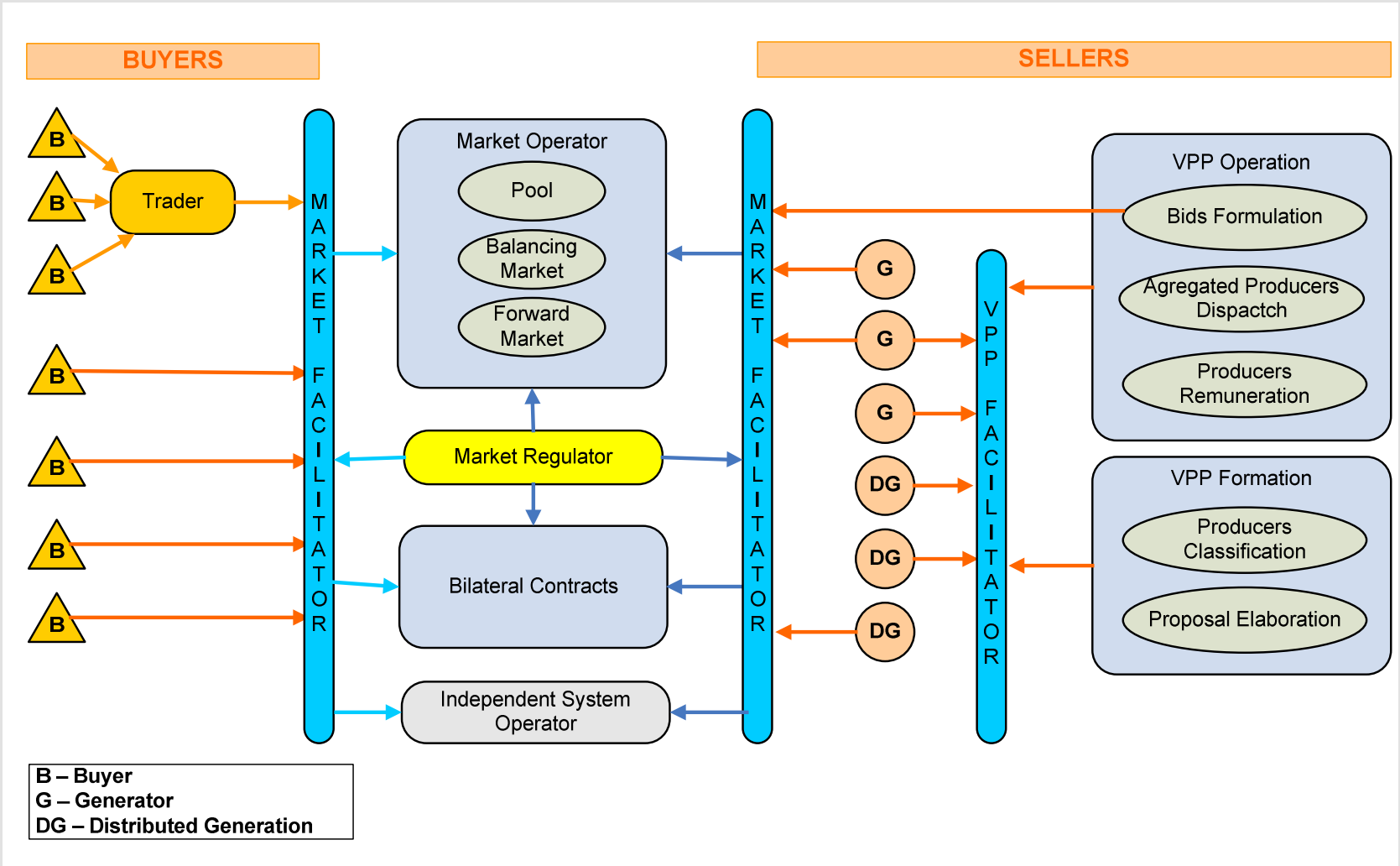
Coalition Support in MASCEM

- **Coalition formation process can be viewed as being composed of three main activities**
  - Structure generation: forming coalitions of agents such that those within a coalition coordinate their activities, but those in different coalitions do not
  - Optimization of the value of each coalition: pooling the resources and tasks of the agents in a given coalition to maximize the coalition value
  - Payoff distribution: dividing each coalition's value among its members

VPPs in the scope of MASCEM

- **Facilitators are used in the scope of Multi-Agent Systems (MAS) in order to ease relationship management**



Coalition Support in MASCEM

- **MASCEM includes a negotiation mechanism regarding coalition formation which considers the strategies associated with the three phases of a coalition's formation process**
  - The producer's selection criteria are different for each VPP, depending on the dimension and on the already aggregated producers
  - Decision making for VPP formation and subsequent aggregation of more producers take into account a large set of producers' characteristics
    - The weight of each of these characteristics depends on the VPP type

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Coalition Support in MASCEM

Characteristics / VPP Type	PVPP	LSVPP	µVPP	GVPP	SVPP
Speculative cost of energy	10	10	9	9	10
Dispatchability	7	9	7	10	7
Reliability	7	8	2	8	7
Use of installed power	5	7	2	5	5
Lifespan	3	3	1	3	5
Volatility of prices	7	8	3	7	7
2nd Market	9	4	4	6	5
GHG emissions	7	6	5	5	5
Location	4	2	8	6	5
Dimension	4	3	8	5	5
Technology type	5	5	6	6	5
Social Impact	5	5	5	4	5
Maturity of technology	4	5	2	4	5
Commercial behavior	5	6	3	5	5

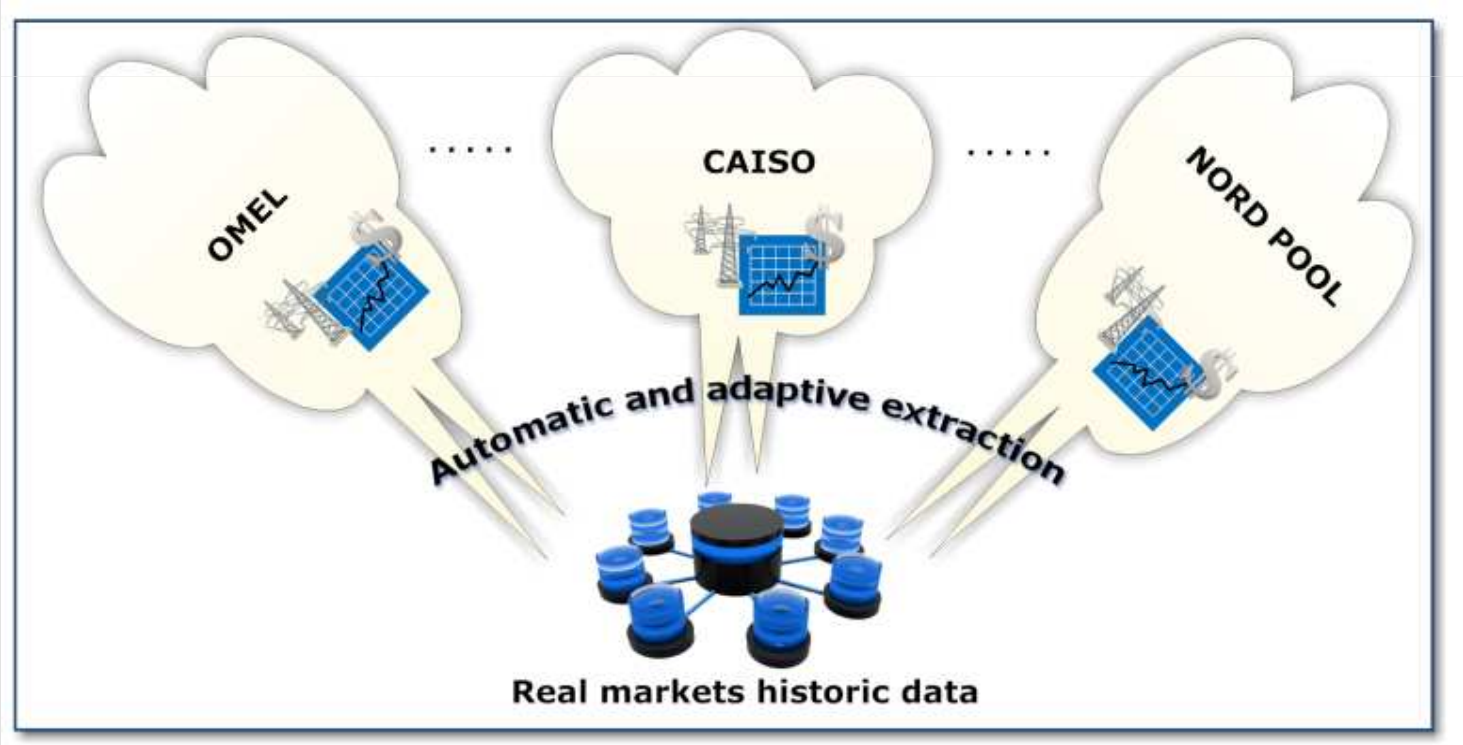
Coalition Support in MASCEM

- **These values have been determined based on a set of a priori analyzed cases, considering possible VPP strategies and are used by MASCEM as default values**
  - MASCEM users can modify these values to adjust the VPP strategy according to their own needs
  - The user also has the possibility of developing and simulating scenarios in which VPPs change their aggregated producers, in order to improve VPP strategy based on market evolution

Supporting VPP modeling, VPP formation and operation, MASCEM can provide a powerful tool to support DG integration in competitive markets

Scenarios Definition

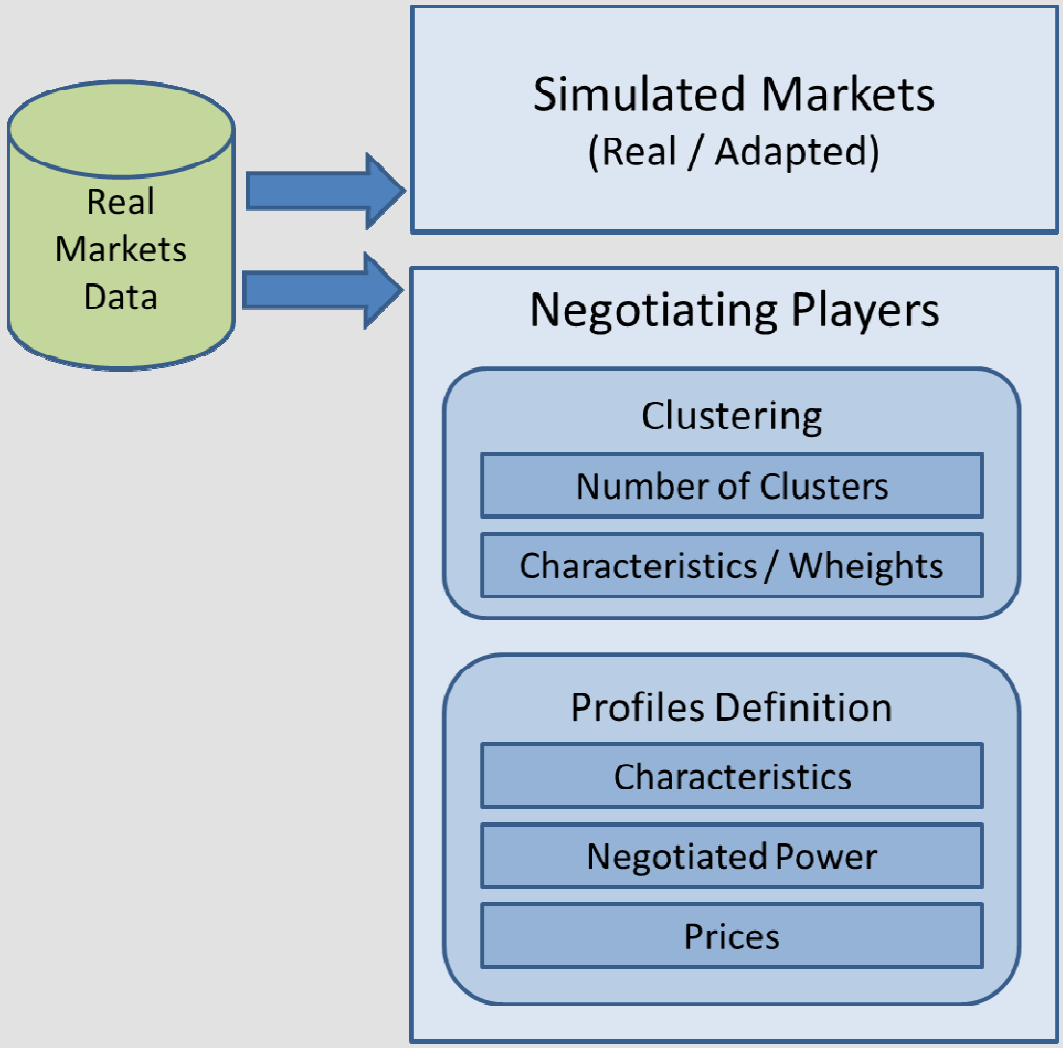
- **Nowadays**
  - there are several market simulators
  - market operators make available huge amounts of data
  - valuable decision support tools: simulator needs for solid representation of realistic electricity market scenarios



Scenarios Definition

- **Scenarios Generator**
  - The main goal is the appropriate representation of real electricity markets
  - Take advantage of the valuable information that is available to the community
  - Generating scenarios for different types of electricity markets
  - Representation of real markets of a specific country
  - Testing different alternative market rules
  - Characterization of the participating players

Scenarios definition methodology



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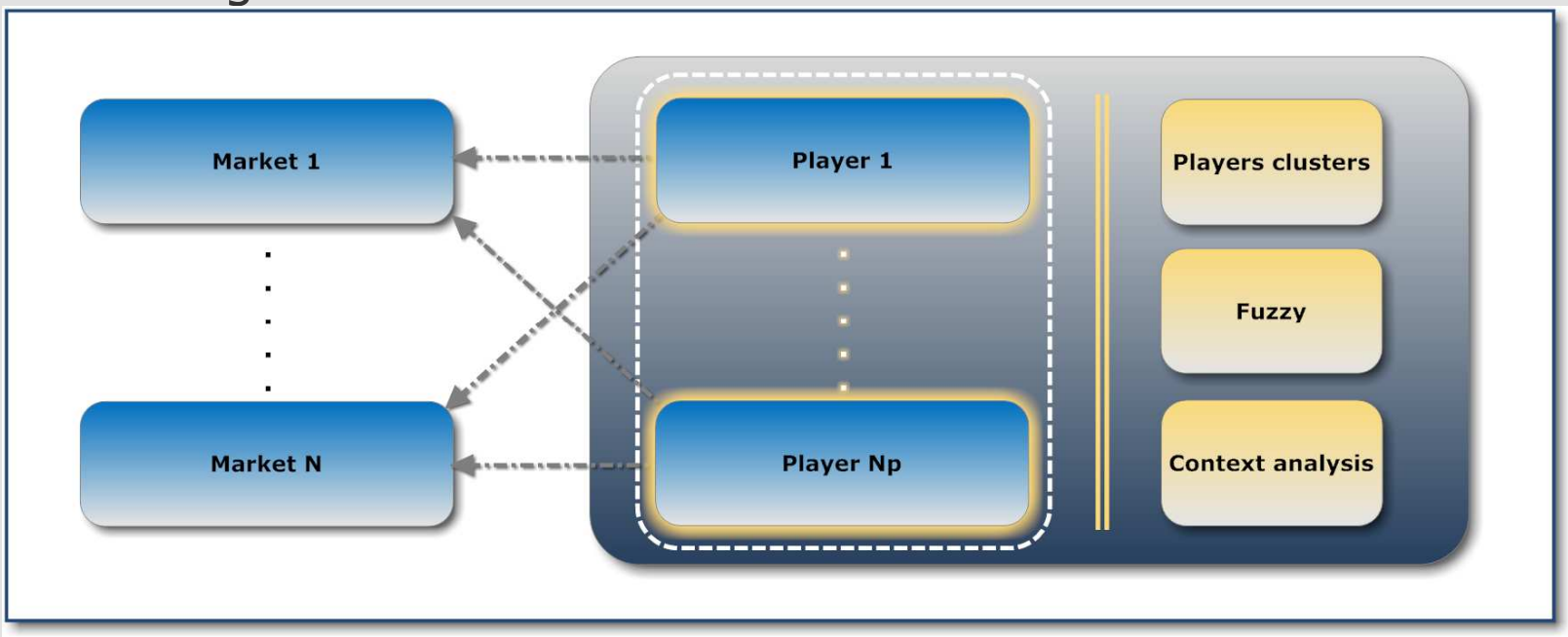
Scenarios Generator

- **Number of Negotiation Players**
  - clustering process for grouping the huge amount of real players into a smaller, summarized group
  - the clustering process considers the definition of different weights for different characteristics, allowing vital characteristics (e.g. players' localization, dimension, or production technology) to present a higher or smaller influence over the grouping process
  - number of players considered for the scenario is defined by the user
    - Fuzzy variable to define the preference for the scenario dimension

Scenarios Generator

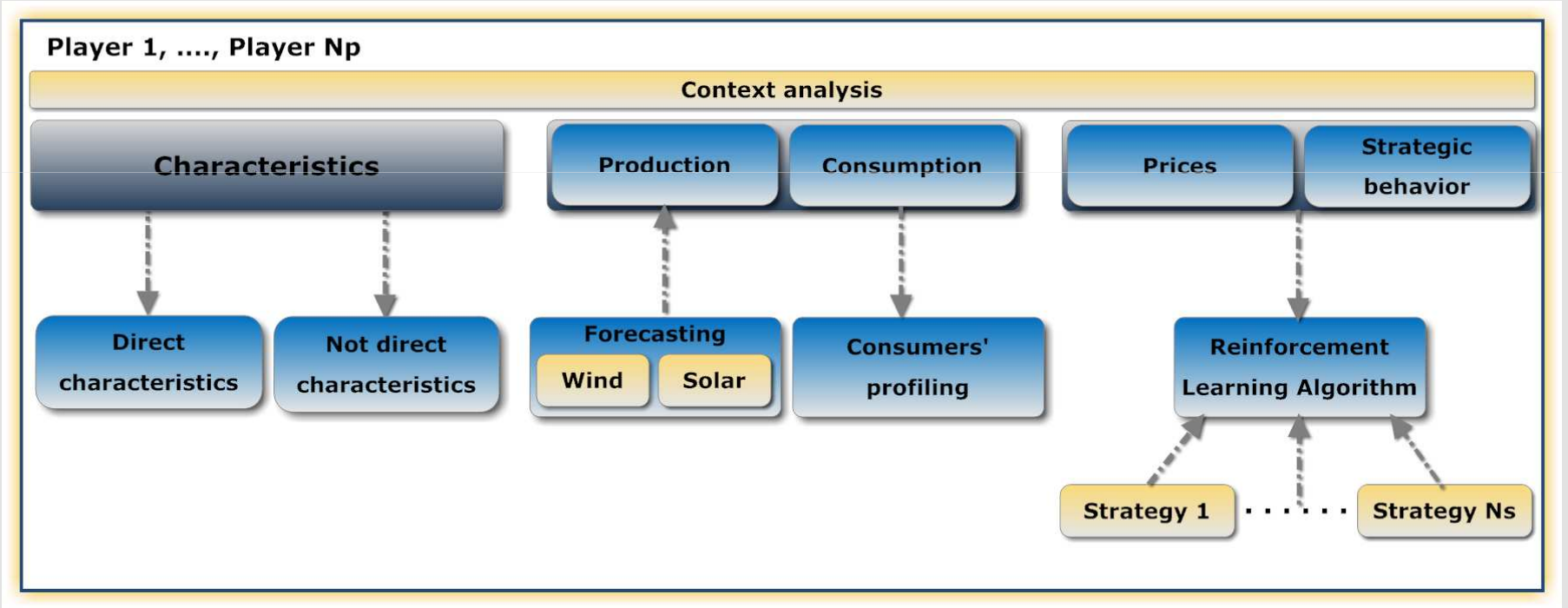
- **Context analysis mechanism**
  - define different market contexts, depending on the time of the day, the day of the week and month, and the season of the year
  - defines the times in the past whose characteristics are similar to the moments we are simulating with the scenario
  - data used by the clustering process is related to these timings in the past, translating the reality in some moment into a scenario defining that same moment



Scenarios Generator

- **Players Profiles**
  - Definition of the player intrinsic characteristics (e.g. localization, adopted technology)
  - The player production or consumption
    - to read from historic data of players' offers in the market
    - for players based on renewable sources it is necessary to forecast the wind and solar intensity, for that DM techniques will be used
    - regarding players' consumption, DM algorithms will be used to predict players' profiles, analyzing the historic of players' consumptions
  - The player proposed prices in each market during the time
    - using forecast techniques to predict prices
    - analyzing players' actions to try modeling each player's strategic behavior
    - inclusion of several distinct nature algorithms, and on the top of them there is a reinforcement learning algorithm (roth-erev, or q-learning), responsible for choosing the best approach for each market, depending on the context of the negotiaton

Scenarios Generator



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Publications

Tiago Pinto, Isabel Praça, Zita Vale, Hugo Morais, Tiago M. Sousa1, "Strategic bidding in electricity markets: An agent-based simulator with game theory for scenario analysis ", **Integrated Computer-Aided Engineering**, IOS Press, vol. 20, nr. 4, pp. 335-346, **2013**

Hugo Morais, Tiago Pinto, Zita Vale, Isabel Praça, "Multilevel Negotiation in Smart Grids for VPP Management of Distributed Resources", **IEEE Intelligent Systems** magazine, Special Issue "Sustainable Energy and Distributed AI", vol. 27, nr. 6, pp. 8-16, 2012

Tiago Pinto, Hugo Morais, Pedro Oliveira, Zita Vale, Isabel Praça, Carlos Ramos, "A new approach for multi-agent coalition formation and management in the scope of eletricity markets", **Energy**, vol. 36, no. 8, pp. 5004-5015, 2011

Zita Vale, Tiago Pinto, Isabel Praça, Hugo Morais, "MASCEM – Electricity markets simulation with strategically acting players", **IEEE Intelligent Systems**, vol. 26, n. 2, Special Issue on AI in Power Systems and Energy Markets, 2011

Isabel Praça, Carlos Ramos, Zita Vale, Manuel Cordeiro, "MASCEM: A Multi-Agent System that Simulates Competitive Electricity Markets", **IEEE Intelligent Systems**-Special Issue on Agents and Markets, vol. 18, nr. 6, pp. 54-60, **2003**

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So what?

Multi-Agent Simulation proves to be valuable to study Electricity Markets

MASCEM is capable of simulating several market mechanisms and players

The integration of a Realistic Scenarios Generator brings a new dimension to MASCEM decision support capabilities

MASCEM responds to european markets evolution

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