Detailed Description of Undertaken Activities (PTDC/EEA-EEL/122988/2010)

This report presents a detailed description of the activities performed during the MAN-REM project. The description is complemented with a reference to the most relevant publications that have resulted from the project. We try to highlight the most important developments by presenting a summary of the publications together with some representative figures, instead of going into technical details, which can be seen in the original publications. This report also presents both the timeline of the executed activities and the initial timeline (submitted timeline), highlighting the differences between the two. A list of publications appears at the end of the report (all publications can be found in: https://www.gecad.isep.ipp.pt/projectos/MAN-REM/ followed by the "reference number.pdf", e.g., for reference 10: https://www.gecad.isep.ipp.pt/projectos/MAN-REM/10.pdf).

Detailed Description

Electricity markets (EMs) are a new complex reality, continuously evolving, meaning that researchers lack insight into numerous open problems that are being raised. EM simulators can help manage the complexity of competitive markets, providing market players with adequate knowledge and experience to act in dynamic environments, towards ensuring the major benefits of deregulation. Multi-agent systems (MAS) are essentially loosely coupled networks of software agents that interact to solve problems beyond the capabilities of each individual agent. Conceptually, a multi-agent approach in which software agents can perform actions to meet their design objectives is an ideal fit to the naturally distributed domain of a deregulated energy market. Accordingly, this project aimed at addressing the challenge of using software agents to help manage the complexity of EMs, particularly retail markets. It involved the following six tasks:

T1 – Software Agents for Competitive Electricity Markets.
Duration: 10 months Started: 01-04-2012. Ended: 31-01-2013.

T2 - Efficient Demand Response and Contract Negotiation.
Duration: 12 months Started: 01-10-2012. Ended: 30-09-2013.

T3 – Virtual Players and Coalitions.
Duration: 10 months Started: 01-04-2013. Ended: 31-01-2014.

T4 – Risk Management in Contract Negotiation.
Duration: 12 months Started: 01-10-2013. Ended: 30-09-2014.

T5 – Energy Management Software Tool.
Duration: 16 months Started: 01-06-2014. Ended: 30-09-2015

T6 – Iberian Market (MIBEL): Real Problem Simulation.
Duration: 6 months Started: 01-04-2015. Ended: 30-09-2015

T1 – Software Agents for Competitive Electricity Markets.

This task focused on modelling a deregulated electricity market as a collection of software agents. The first part of the task concentrated on the naturally distributed domain of a deregulated electricity market, specifically on defining an architecture for software agents participating in EMs. A detailed analysis of the most prominent agent architectures proposed in the literature allowed to conclude that the deliberative approach is probably the most widely used in multi-agent systems, particularly the belief-desire-intention (BDI) architecture. It was, therefore, initially considered for market agents. To investigate the main requirements associated with software agents participating in EMs, the behavior of market agents equipped with either a simplified BDI architecture or a traditional deliberative architecture was analyzed in different market situations. Several case studies were developed for both wholesale and retail markets. The results showed that market agents do not necessarily need to exhibit all the key features of BDI agents. A traditional deliberative architecture was, therefore, adopted for market agents.

The last part of the task concentrated on developing a multi-agent electricity market composed of various software agents equipped with the deliberative architecture, each responsible for one or more market functions, and each interacting with other agents in the execution of their responsibilities (see Figure 1). The following types of agents were considered: producers (business units that sell electricity), retailers (business units that buy electricity in wholesale markets and typically sell to customers), end-use customers (both small customers that buy energy in retail markets and large customers that can participate in wholesale markets), and market operators (coordinate pool trading). The agents were implemented as computer systems capable of exhibiting goal-directed behavior (pro-active behavior), able to interact with other agents (social behavior), and capable of executing actions to meet their design objectives.

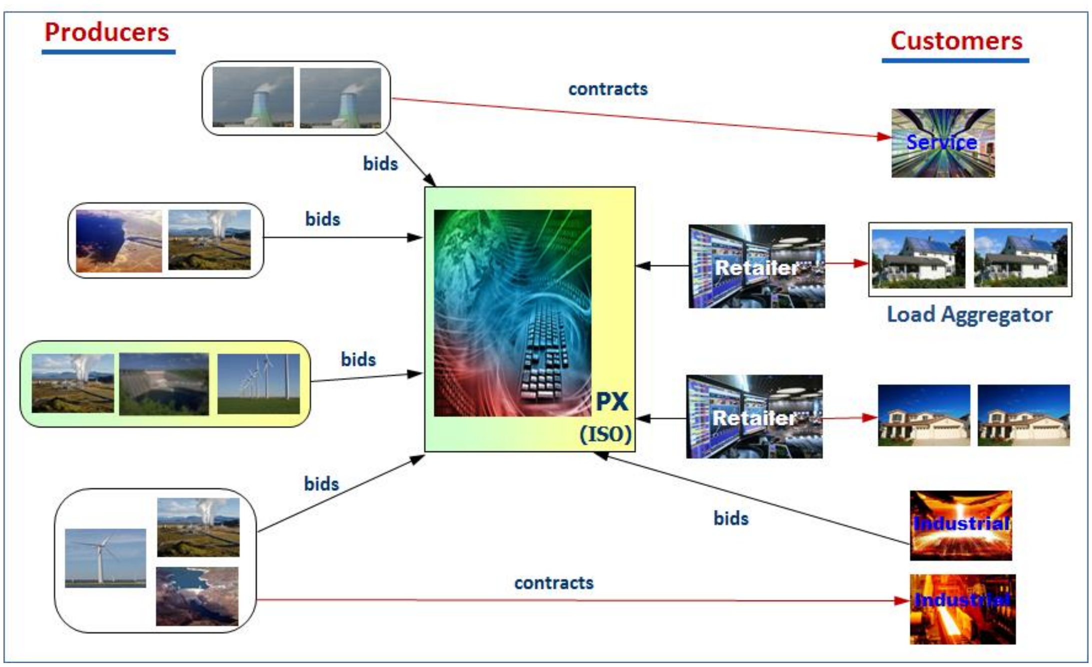
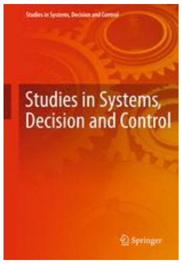


Figure 1. Multi-agent electricity market.

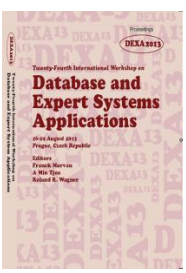
The conclusion of task T1 led to milestone M1: Multi-agent Electricity Market System. The development of the MAN-REM system, using the JAVA programming language and the JADE platform, started in parallel with the conceptual advances.



A new book [1], entitled "Advances on Multi-agent Energy Markets", to be published by Springer International Publishing, as part of the series "Studies in Systems, Decision and Control", presents some of the most important developments of the project. In particular, five chapters are devoted to the MAN-REM system and one chapter presents the MASCEM simulator (there are also several invited chapters written by leading researchers working in the area of competitive energy markets).

Chapters 1 and 8 are related to task T1. Chapter 1 examines the literature on agent-based simulation of EMs and describes, in considerable detail, the various components of a generic framework for this active area of research. The framework includes three groups (or categories) of dimensions, namely "market architecture", "market structure", and "software agents". It characterizes the essential features that are needed to model and simulate EMs using software agents. Also, it provides a coherent set of concepts, helping to understand the interrelationships of disparate research efforts, and thus facilitating the development of future models and systems.

Chapter 8 presents the key features of the MAN-REM system along the three groups of dimensions of the framework. In particular, it describes the different types of market participants (software agents) and the several models equipping them, including the model of individual behaviour of each agent. It also presents details of the system engine, to control trading simulations, and the graphical user interface of the system. The chapter ends with a summary of specific case studies.



Both chapters extend our previous publications. In particular, chapter 1 extends the previous work on a conceptual framework for agent-based EMs [16]. Chapter 8 both extends and refines part of the material presented in [17, 22, 24, 29]. These papers were presented in the workshops on Artificial Intelligence Techniques for Power Systems and Energy Markets (http://gecad.isep.ipp.pt/iatem/), organized by the project team, as part of the DEXA (Database and Expert Systems Applications) event.

T2 – Efficient Demand Response and Contract Negotiation.

This task focused on bilateral contracting of electricity and involved the design of software agents (market participants) able to enter into bilateral contracts. The following subtasks were completed:

ST1: development of a strategic framework allowing market participants: (i) to negotiate the terms and conditions of bilateral contracts, (ii) to consider dynamic pricing tariffs, and (iii) to reach (near) Pareto-optimal agreements.

ST2: evaluation of the framework and integrating it into the agent architecture previously adopted in task T1.

The first part of the task concentrated on developing a strategic framework for bilateral contracting of electricity. Buyer and seller agents equipped with the framework may interact and trade with one another according to the rules of either an alternating offers protocol or a contract net protocol. In the former case, negotiation is bilateral (one-to-one negotiation). Two agents – a buyer and a seller – may iteratively exchange offers and counter-offers until either they reach an agreement or at least one agent decides to opt out of the negotiation. In the latter case, negotiation is multilateral (one-to-many negotiation). A buyer agent may negotiate concurrently with several sellers, each responsible only for stating and defending its own positions and needs. Negotiation may also involve an iterative exchange of offers and counter-offers.

Price negotiation is based on offers and counter-offers over two or more energy prices. In other words, agents may consider two-rate tariffs to smooth the daily demand profile (cheaper night tariffs), three-rate tariffs, or even more complex tariffs (e.g., hour-wise tariffs). Several price negotiation strategies were formalized and incorporated into the framework. In particular, buyers and sellers can pursue strategies motivated by rules-of-thumb distilled from good behavioral practice in real-life negotiations, particularly concession making strategies – agents change energy prices to accommodate the opponent. These strategies model concessions on energy prices by considering typical criteria, such as the time elapsed since the beginning of the negotiation or the previous behavior of the opponent. Also, a novel price negotiation strategy was formalized by considering a criterion directly related to bilateral contracting of electricity – the amount of energy to be traded in a certain period of time. For a given energy price, the predominant factor to decide the magnitude of the concessions to be made is the energy quantity.

In addition to price negotiation, the focus was also placed on demand response (DR) in bilateral contracting – that is, changes in electric usage by end-use customers from their typical consumption patterns in response to changes in energy prices throughout negotiation. Accordingly, buyer and seller agents are able to negotiate over both energy prices and energy volumes. In particular, customers may respond to price concessions made by the opponent by adjusting energy quantities (and, if desired, also making price concessions). Four novel strategies for promoting DR were developed and incorporated into the framework, namely two foregoing strategies and two shifting strategies. The former strategies are based on reducing energy usage in high-priced peak periods without making it up later, whereas the latter consider rescheduling energy usage away from times of high prices to other times. The strategies can be (indirectly) associated with consumption efficiency.

Agents equipped with the strategic framework for bilateral contracting are able to negotiate the terms and conditions of forward contracts – that is, agreements to sell or buy specific amounts of electricity at a certain future time for specific prices. However, and since contracts for difference (CFDs) are common financial instruments to hedge against price volatility, the framework has been extended to consider CFDs – that is, bilateral contracts in which the purchaser pays the seller the difference between the contract price (or strike price) and the spot price.

Several case studies were developed for price negotiation and also negotiation over both energy prices and energy quantities. The main aim was to investigate the behavior of negotiation strategies – notably the novel price management strategy and the DR management strategies – and their effect on the outcome of the trading process. The results showed that the novel price management strategy yielded superior outcomes for both parties (when compared to several traditional strategies). Also, the DR management strategies behaved as expected, leading to a reduction in energy costs (and improved energy efficiency). A computational study was also performed to empirically evaluate price negotiation strategies in a market scenario. The conclusion of task T2 led to milestone M2: Negotiation Framework to Efficiently Manage DR and Reach (near) Optimal Agreements. The development of the MAN-REM system continued in parallel with the conceptual advances.

The strategic framework was built on the negotiation model presented in chapter 3 of [2]. As stated, the model was extended and refined to capture relevant features of market participants. The papers [10, 28, 29] and chapter 9 of the new book to be published by Springer [1] present details of the new strategic framework, introduce the novel price management strategy, and describe several case studies involving different tariffs, including three-rate tariffs and hour-wise tariffs.

The Master thesis [39] presents a detailed description of an experiment conducted to empirically evaluate price negotiation strategies. The experimental method was controlled experimentation. Thesis [33] extends the framework by allowing agents to interact and trade according to the rules of a contract net protocol. A case study on bilateral contracting involving a real consumer (Portuguese company) was also presented.

Papers [9, 27] and the Master thesis [38] introduce novel strategies for promoting DR in bilateral contracting and describe several case studies involving different rate tariffs. Paper [4] and the thesis [32] describe the electrical equipment of a public library (large building), present a model of the library developed with the software DesignBuilder, propose actions to improve energy efficiency and reduce energy costs, and describe the negotiation of a bilateral contract based on a real time-of-use tariff.

Paper [3] and the Master thesis [35] extend our previous work by describing the key features of software agents able to negotiate contracts for difference, paying special attention to risk management, notably risk attitude and price negotiation. Also, [18] describes a case study to assess the performance of CFDs as a risk management instrument, specifically by comparing their performance with the performance of forward bilateral contracts in a market scenario.

T3 – Virtual Players and Coalitions.

This task focused on coalition formation and management and involved the design of software agents (market participants) able to ally into coalitions to better achieve their objectives. The following subtasks were completed:

ST1: development of an operational framework enabling software agents to form coalitions, particularly coalitions involving end-use customers, to achieve more powerful positions;

ST2: evaluation of the framework and its integration into the agent architecture defined in tasks T1 and T2.

The first part of the task centered on developing an operational framework for coalition formation. End-use customer agents equipped with the framework are able to form coalitions to strengthen their bargaining positions and negotiate better agreements. Two or more end-use customers can join together as a single negotiating party. The customers rely on a trusted coordinator or mediator to act as a representative – a virtual customer agent representing an alliance of end-use customers. The coordinator sends team decisions to a seller agent and broadcasts decisions from the seller to the team members. These two agents – the coordinator and the seller – interact according to the rules of an alternating offers protocol, i.e., trading proceeds by an iterative exchange of offers and counter-offers.

In addition to modelling the interaction between team coordinators and energy sellers, the focus was also placed on the interaction between team coordinators and their aggregated members. Specifically, a team coordinator may interact with end-use customers to help them in two key decisions: which offer should be sent to a seller agent and whether a counter-offer received from the seller should be accepted. Both decisions depend on the strategy adopted by the coordinator. Several well-known strategies were formalized and incorporated into the operational framework. A common strategy is the "similarity simple voting" strategy – it considers a plurality rule in the voting process employed to decide which offer should be sent to the seller agent, and a majority rule in the voting process employed to decide the seller's offer acceptance.

Agent equipped with both the strategic framework (develop in task T2) and the operational framework are able to interact and negotiate in four different ways. As noted earlier, end-use customers can negotiate directly with energy sellers a mutually acceptable agreement – that is, two individuals can negotiate for their own interests according to the rules of an alternating offers protocol. Also, customers can negotiate concurrently with several different sellers to obtain a better agreement – that is, a single buyer can negotiate with a number of sellers at the same time according to the rules of a contract net protocol. In addition to these two different forms of interaction and trading, end-use customers can ally into coalitions to achieve more powerful bargaining positions and thus negotiate better tariffs – that is, a virtual customer agent can negotiate directly with a single seller agent according to the rules of an alternating offers protocol. Furthermore, a coalition of end-use customers can negotiate concurrently with several different sellers to pursue superior outcomes – that is, a virtual customer agent can negotiate with a number of sellers according to the rules of a contract net protocol.

Several case studies were developed for bilateral contracting of electricity involving coalitions of end-use customers. The main aim was to investigate how customer coalitions can strengthen their bargaining positions and obtain superior negotiation outcomes. The results indicated that coalition formation can indeed be beneficial to end-use customers. A specific case study is described, in considerable detail, below. The conclusion of task T3 led to milestone M3: Operational framework to form Coalitions in Energy Markets. The development of the MAN-REM system continued in parallel with the conceptual advances.

Paper [19] presents several key features of a model for coalition formation and decision making in bilateral contracting of electricity. It describes the trading process and several strategies for coordinator agents. It also introduces a novel strategy for individual retailers.

Additionally, [19] presents a case study involving three large industrial customers (generically denominated Frank Owen, John Ferguson and Ashley Gerrard), a retailer agent, and two negotiating situations with more than two parties: (i) each customer negotiates a forward contract directly with the retailer agent, and (ii) the customers intentionally form a coalition and a coordinator agent interacts (and negotiates) with the retailer agent to achieve a desired outcome that meets shared objectives. In each of these situations, the agents negotiate a time-of-use (TOU) tariff characterized by three different energy prices for three different blocks of time (peak, mid-peak and off-peak) of a 24-hour day.

Figure 2 shows the main results obtained with the simulations. As expected, the prices agreed in the coalition contract are more favourable to end-use customers (only one customer – John Fergusson – slightly increases the peak price). The difference between the prices agreed in the individual agent contracts can be considered a premium that the retailer is willing to pay to supply energy to all customers.

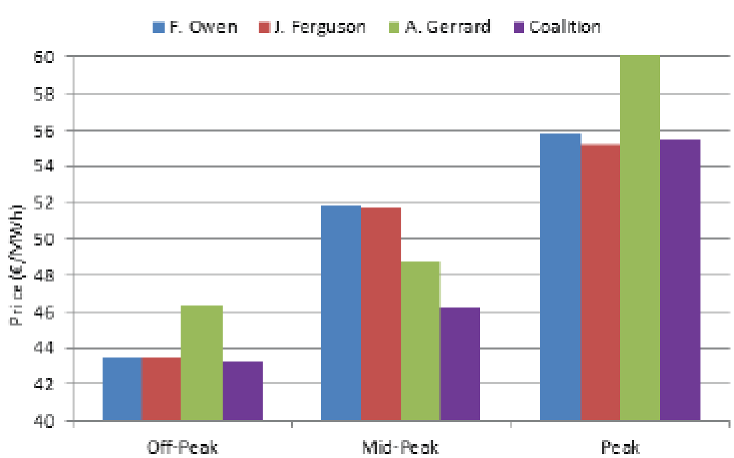


Figure 2. Prices of individual agent contracts vs. the coalition contract

In a somewhat topic related to coalition formation and selection of reliable partners, we have looked into a decision support methodology for bilateral contracting enabling the selection of the most appropriate competitor players to negotiate with, aiming at optimizing the gain of a specific player in its transactions.

More specifically, paper [11] presents a novel model to support the decisions of players participating in bilateral contracting of energy. The model applies both game theory and artificial intelligence concepts to enable the analysis of several distinct potential scenarios that a supported player is likely to face when assuming a bilateral negotiation.

The alternative scenarios are created based on the historic analysis of the past actions of the potential opponents. The outputs of the model are: (i) the selected competitor players to negotiate with, (ii) the suggested amount of power that should be negotiated with each of the selected competitors in order to maximize the outcome of the supported player, and (iii) the expected target price of each selected competitor player. The model was validated using realistic simulation scenarios and real data from the Iberian market operator (MIBEL). In particular, data from MIBEL was used to assemble a historic database concerning the past log of established contracts of 37 electricity market participating players. The results show that agents equipped with the model achieve superior negotiation outcomes. The PhD thesis [30] also presents details of the new decision support methodology.

T4 – Risk Management in Contract Negotiation.

This task focused on portfolios of customers and bilateral contracting, involving the design of software agents (market participants), particularly retailers and end-use customers, able to define and negotiate efficient tariffs. The following subtasks were completed:

- ST1: development of two risk management models enabling retailers to build and manage portfolios of end-use consumers;
- ST2: development of a risk management model enabling end-use customers to evaluate and propose changes in tariffs;
- ST3: evaluation of the models and integrating them into the agent architecture previously defined in tasks T1, T2 and T3.

The first part of the task concentrated on developing two models for portfolio creation and management – a model enabling retailers to maximize profit, but involving no risk, and a model to maximize profit subject to risk minimization. Retailer agents equipped with the first model are able to define tariffs to propose to end-use customers (e.g., three-rate tariffs), analyze consumption profiles of customers, and select particular customers to add to their portfolios, i.e., sets of customers that maximize profit. Retailers value customers according to their contributions to portfolios' profit, which in turn are related to consumption profiles of customers.

In addition to profit maximization, the focus was also placed on modeling risk. Accordingly, retailer agents equipped with the second model are able to make decisions, regarding the addition of customers to their portfolios, by taking into account tradeoffs between the risk and return of such decisions. Retailers value customers according to their contributions to both retailers' portfolios profit (related to consumption profiles) and retailers' portfolios risk (related to the variability of consumption profiles). The model incorporates several risk management strategies, notably strategies that compute efficient portfolios based on the Markowitz efficient frontier.

Then second part of the task focused on customers and financial risk management. End-use customer agents were equipped with a risk model enabling them to adopt different attitudes toward risk – namely, risk-averse (prefer a setting with guaranteed outcomes to any other riskier setting), risk-neutral (have no preference over two settings with different risk) and risk-seeking (prefer a setting with bigger profits, although they could be not guaranteed). Also, customers are able to evaluate tariffs proposed by retailers using decision functions (e.g., the von Neumann-Morgenstern expected multi-objective utility function). Furthermore, they can propose changes in tariffs by using risk-based strategies for price negotiation.

Retailer and customer agents can negotiate desirable (optimal) tariffs by exchanging proposals and counter-proposals. Both their risk attitudes and their risk-based strategies were considered key factors to define their negotiation behavior. Specifically, risk-averse agents were modeled as exhibiting more flexibility to secure deals, and therefore may concede more to avoid that negotiation ends prematurely without agreement. Conversely, risk-seeking agents were modeled as exhibiting more firmness, tending to win negotiation without great regard to its success or failure, and thus conceding less to get a deal. Negotiation follows the rules of an alternating offers protocol.

Several case studies were developed for bilateral contracting of electricity involving risk management. The aim was to investigate: (i) how retailer agents can define tariffs and optimize portfolios' profit by selecting specific end-use customers to interact and possibly negotiate with, either considering or not risk minimization, and also (ii) how end-use customers can obtain better tariffs by evaluating and possibly proposing changes to received tariffs. A specific case study is described below. The conclusion of task T4 led to milestone M4: Operational Framework for Risk Management in Contract Negotiation. The development of the MAN-REM system continued in parallel with the conceptual advances.

Paper [21] formalizes the portfolio optimization problem as a mixed integer linear problem, in situations with no uncertainty, whose solution allows retailers to maximize profit – that is, the solution provides the optimal selection of clients to add to retailers' portfolio, considering specific tariffs. The paper introduces the typical consumption profiles of five different types of customers: street lightning (SL), residential (Res), small commercial (SCom), large commercial (LCom), and industrial (Ind).

Table I. Retailer tariffs and energy shares according to client type.

Tariff (€/MWh)			Energy share (%)					Benefit	Energy	Return
base	inter	peak	SL	Res	SCom	LCom	Ind	€/MWh	kWh	€
T_1: 22.21	37.75	43.93				100.0		≈0	10821	≈0
T_2: 24.61	40.90	48.38				28.7	71.3	3.08	11818	36.38
T_3: 24.91	41.34	48.92		1.0	2	8.8	88.2	3.43	12124	41.55
T_4: 25.31	41.94	49.82		4.8		6.7	88.5	4.00	12309	49.28
T_5: 25.61	42.39	50.18		20.4		2.7	77.0	4.05	13364	54.15
T_6: 35.01	57.24	67.42	4.9	23.6		2.4	69.1	18.04	13714	247.45

Additionally, [21] presents a case study involving a retailer agent, six different three-rate tariffs (T1 to T6) and the five aforementioned types of customers. The retailer pursues the goal of defining optimal portfolios of clients for each tariff. Table I shows the tariffs and the main results obtained with the simulations. The composition of the optimal portfolios ranged from one client type only (large commercial customers) to the five different types of clients. Relatively small changes in one or more prices of tariffs T2 to T5, favourable to the retailer agent, resulted in considerable differences in the composition of optimal portfolios. The reference time period considered was one-week.

Chapter 10 of the new book [1] to be published by Springer extends and refines the material presented in [21] by considering tradeoffs between risk and return. The portfolio optimization problem is formalized as a dual-objective (multi-criteria) optimization problem, whose solution allows retailers to obtain optimal portfolios of customers. The formalization takes into account the attitude of retailers toward risk. Also, several risk factors (e.g., variability of consumption patterns) are measured using the VaR method. The chapter presents a case study involving the five aforementioned types of customers, but tariffs considering higher prices (when compared to tariffs T1 to T6 above). All tariffs take into account current regulated tariffs in Portugal. The reference time period considered was one-year.

Papers [5, 8] formalize software agents able to adopt different attitudes toward risk and introduce decision functions for price negotiation. They also introduce several new risk-based strategies, notably strategies that model concessions on energy prices by considering two criteria directly related to risk management – risk attitude and risk asymmetry. Thus, for a given energy price, the predominant factor to decide the magnitude of concessions to be made throughout bilateral negotiation is related to risk management.

The papers [5, 8] also present several case studies on forward bilateral contracting involving risk management and different tariffs (three-rate and hour-wise tariffs). They illustrate (and investigate) the behaviour of the novel risk-based strategies.

T5 – Energy Management Software Tool.

This task focused on developing an energy management software tool using the JAVA programming language. The following subtasks were completed:

ST1: integration of the MAN-REM system developed in tasks T1 to T4 with part of the MASCEM system (previously developed by the team members of ISEP);

ST2: evaluation of the agent-based simulator resulting from ST1 in different market scenarios.

The first part of this task concentrated on developing a multi-agent simulator of electricity markets. As mentioned, the computational agents of the MAN-REM system are able to execute actions to reach their private goals. Specifically, they can negotiate customized contracts, pursue different negotiation strategies to reach (near) Pareto optimal agreements, ally into coalitions to strengthen their bargaining positions and negotiate better agreement, create and manage portfolios of clients, and negotiate tariffs. In other words, the MAN-REM system accounts mainly for key aspects directly associated with bilateral trading of electricity in retail markets.

The MAN-REM system was, therefore, extended to account for both pool trading and bilateral trading (see Figure 3). A day-ahead market sells energy to retailers (and possibly other market participants) and buys energy from sellers in advance of time when the energy is produced and consumed. The pricing mechanism is founded on the marginal pricing theory. Under system marginal pricing (SMP), these bids are stacked in the merit order, and the market clearing price is defined by the intersection of the associated curve with the cumulative load curve. This price is determined on an hourly basis and applied to all generators uniformly, i.e., regardless of their bids or location. Locational marginal pricing (LMP) is a more complex variation of marginal pricing – as in SMP, the system collects both generation and load purchase bids, and then determines the optimal generation dispatch. However, the system runs now an optimal power flow procedure that defines the energy price at each bus of the network.

Bilateral trading includes both the negotiation of customized long-term contracts and electronic trading. Customized long-term contracts involve typically the sale of large amounts of power (hundreds or thousands of MW) over long periods of time (several months to several years). The terms of such contracts are flexible and are negotiated privately to meet the needs and objectives of both parties. Electronic trading involves typically smaller amounts of energy to be delivered. This form of trading is used by buyers and sellers to refine their positions as delivery time approaches. Market participants submit bids to sell and offers to buy energy in a marketplace. When a new bid is submitted, the system checks for a matching offer for the period of delivery of the bid. In case it finds an offer whose price is greater than or equal to the price of the bid, a deal is struck. If no match is found, the bid is added to the list of outstanding bids and will remain there until either the submission of a matching offer, or the withdrawal of the bid, or the closing of the market for the delivery period.

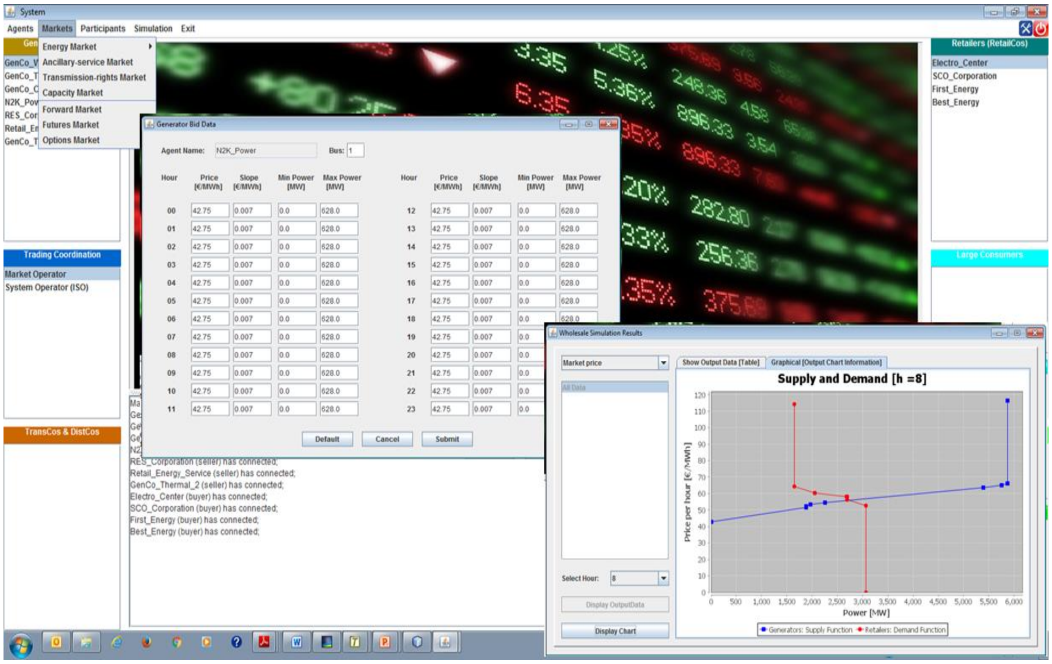
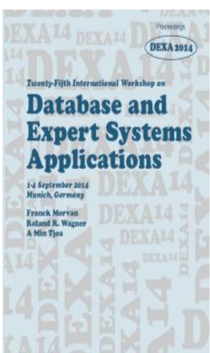


Figure 3. Energy management software tool (part of the graphical interface).

Several case studies were developed to analyze the behavior of the agent-based simulator in different market scenarios. The conclusion of task T5 led to milestone M5: Energy Management Software Tool.



Variable generation (VG), such as wind power, has several unique characteristics compared to those of traditional power plants, including significant fixed capital costs but near-zero variable production costs. Large penetrations of VG tend to influence the prices and schedules of day-ahead energy markets. Paper [21] presents a case study aiming at analyzing the behavior of the agent-based tool in situations with increasing levels of wind generation, notably comparing market schedules and prices in situations with either low levels and high levels of wind generation. Master Thesis [34] also presents several details of the case study.

The agents are six generic producers (involving thermal, combined cycle and renewable technologies) and four retailers. We considered two simulations differing mainly in the level of wind generation. In particular, we considered one day with “moderate” wind conditions (case 1) and other day with low levels of wind generation (case 2), with the main aim of comparing the outcomes of the day-ahead market. The results are presented in Table II. In particular, Table II shows the hourly market prices for the two cases and the differences between prices (in €/MWh). As expected, the introduction of high penetrations of wind generation leads to a reduction of prices over time, because of the associated low bid-based cost. The results are also consistent with reduction in schedules that have been observed with increased penetrations of wind generation.

Table II. Market prices: high wind generation (HG) vs. low wind generation (LG).

Hour	Market Price (HG) (€/MWh)	Market Price (LG) (€/MWh)	Difference (€/MWh)	Hour	Market Price (HG) (€/MWh)	Market Price (LG) (€/MWh)	Difference (€/MWh)
0	48.51	51.44	2.93	12	51.43	51.95	0.52
1	47.99	51.21	3.22	13	51.38	51.92	0.54
2	47.50	48.36	0.86	14	51.36	51.89	0.53
3	47.36	48.19	0.83	15	51.38	51.89	0.51
4	47.35	48.09	0.74	16	51.34	51.85	0.51
5	47.37	48.09	0.72	17	51.37	51.87	0.50
6	47.89	49.95	2.06	18	51.26	51.81	0.55
7	47.95	50.37	2.42	19	51.24	51.82	0.58
8	50.72	51.39	0.67	20	51.20	51.87	0.67
9	51.36	51.68	0.32	21	51.32	52.00	0.68
10	51.44	51.84	0.40	22	51.29	51.99	0.70
11	51.50	51.91	0.41	23	51.14	51.89	0.75

T6 – Iberian Market (MIBEL): Real Problem Simulation.

This task centered on the Iberian market (MIBEL) and involved the development of two case studies (CS1 and CS2) using data from MIBEL. The case studies are as follows:

CS1: Influence of renewable based generation in day-ahead market outcomes;

CS2: Strategic behavior of renewable based generation players in the electricity market.

Both case studies focused on the Iberian electricity market, which is composed by Portugal and Spain areas. For case study 1, real data from MIBEL were used as follows:

CS1: Data offers from all players of the day-ahead market, concerning the period of one week, between January 1st, 2015 and January 7th, 2015. The purchase and sale offers of each player are the real bids submitted in the day-ahead spot market of MIBEL, provided by the market operator OMIE (Operador del Mercado Ibérico de Energía). Data concerns 826 distinct players, from which 714 are sellers and the remaining 112 players are buyers. From the sellers, about 397 players consider wind power generation in their portfolio mix.

CS1 centered on the influence of wind based generation in the day-ahead market and involved the following two main parts:

P1: study of the influence of the participation of wind based generation in the market;

P2: study of the impact of wind based players' bids on market outcomes.

For P1, the base case scenario considered was the exact scenario that was verified in MIBEL during the simulation week (a week characterized by a particularly high wind speed, thus resulting in a large participation of wind generation). The market results from the base scenario were compared with the results achieved in the market considering a reduced participation of wind power. For this, five additional scenarios have been developed, where the wind generation assumes the values of 95%, 90%, 85%, 80% and 75% of the real values. In this way, it was possible to compare market outcomes when considering larger and smaller participations of wind generation.

For the second part P2 of CS1, which focused on the influence of the bids of wind based generation players in the outcomes of the market, a specific player was chosen as test subject. Several simulations were executed, where the subject player used different biding strategies, allowing us to assess the impact of the bidding strategies in the market, in addition to the evaluation of the player's individual results.

The second case study CS2 centered on the impact of players' participation in multiple electricity markets, namely day-ahead, intra-day and bilateral markets, and involved the following two main parts:

P1: study of bidding in the day-ahead spot market to guarantee the fulfilment of bilateral contract agreements;

P2: study of strategic bidding in both the intra-day market and the day-ahead market to guarantee the fulfilment of bilateral contract agreements.

CS2 involved the analysis of the market outcomes of an individual player considering different ways of participating in the market, in order to fulfil pre-agreed bilateral contracts, while trying to maximize its profits from the sale of the generated power. The simulations have been performed using real data from MIBEL, representing the real market environment by modeling all players that have participated in the market through specific software agents. The simulation day, from which real data has been used, was February 6th 2015.

In the first part P1 of CS2, the participating player submitted bids to the day-ahead market that reflected their expected production to the following day. This was done accordingly to the forecasted power for the following day. Two distinct forecast results have been considered leading to two different scenarios, differing mainly in the following: forecast 1 predicted higher values of production than forecast 2 for most of the 24-hours of the day. The second part of CS2 complemented part P1 by considering the strategic participation of the player in both the day-ahead and the intra-day markets. Specifically, part of the predicted generation power was traded in the intra-day market according to accurate forecasts. There was the possibility to adjust the total power traded in both the day-ahead and the intra-day markets by taking into account adjustments between the initial predicted power and subsequent forecasts closer to the actual generated power.

Details of both case studies (CS1 and CS2) are presented in a companion report (file: "Task-T6-Report.pdf"). Here, we focus on the main conclusions obtained. For CS1, the increase of wind power players' participation in the market has led to lower market prices, mainly due to the low bid prices submitted by this type of players. The bidding strategy of wind power players has mainly affected their own results. In particular, the submission of higher bid values, as an attempt to increase market prices, and consequently improve profits was inconsequent, and has only led to the chance of not selling all power (without increasing market prices).

For case study 2, wind power players exclusive participation in the day-ahead market may be considered difficult to conceive, due to the high variability of this type of generation, which makes day-ahead generation forecasts unable to deal with the uncertainty in real time production. Also, wind power players participation in intra-day markets can give them a chance to reduce the uncertainty and consequently the risk in power trading. Furthermore, intra-day markets can provide an opportunity for these players to increase profits.

Timeline of Activities Executed

Figure 4 presents the initial (submitted) timeline. The three-month delay in the project starting date resulted in a three-month delay in the starting date of the several tasks. Figure 5 presents the time window for the execution of the project tasks. In comparison to the submitted timeline, a few differences need to be highlighted: (i) the models developed in tasks T1, T3 and T4 were mainly evaluated by developing case studies for different market scenarios; (ii) task T2 dealing with the development of a strategic framework for bilateral contracting of electricity considered mainly negotiation of bilateral contracts, dynamic pricing tariffs, and (near) Pareto optimal agreements; (iii) task T3 dealing with coalitions of market participants was mainly undertaken for coalitions involving end-use customers; (iv) task T4 dealing with portfolios of customers and risk management considered a risk model for end-use customers (i.e., final consumers) based on the strategic framework developed in task T2, which was expanded with a number of risk-based strategies for price negotiation and several decision functions; (v) task T5 dealing with the development of an energy management software tool was the one using more resources and involved the integration of the MAN-REM system with the part of the MASCEM system directly related to energy markets (i.e., day-ahead and intra-day markets).

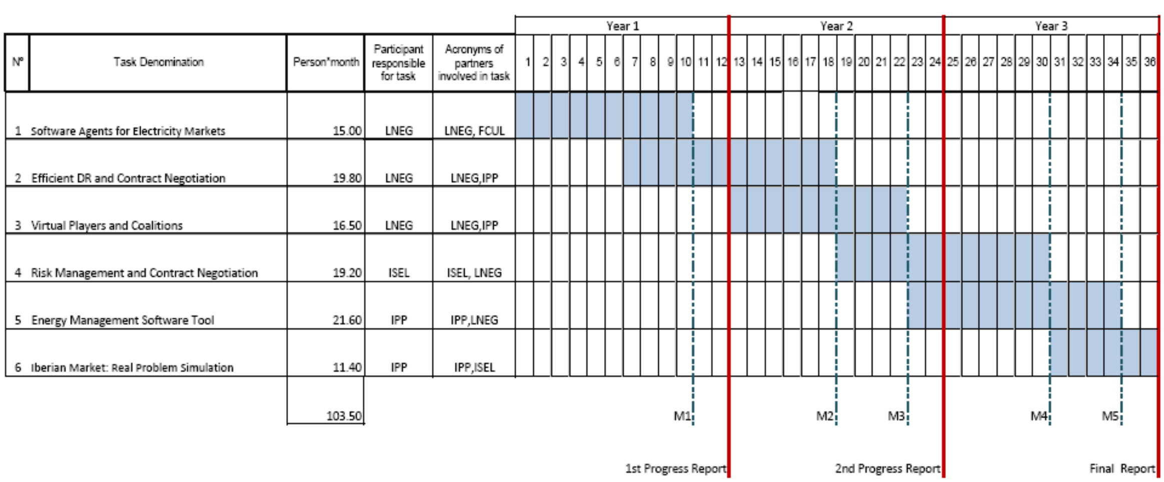


Figure 4. Initial submitted timeline.

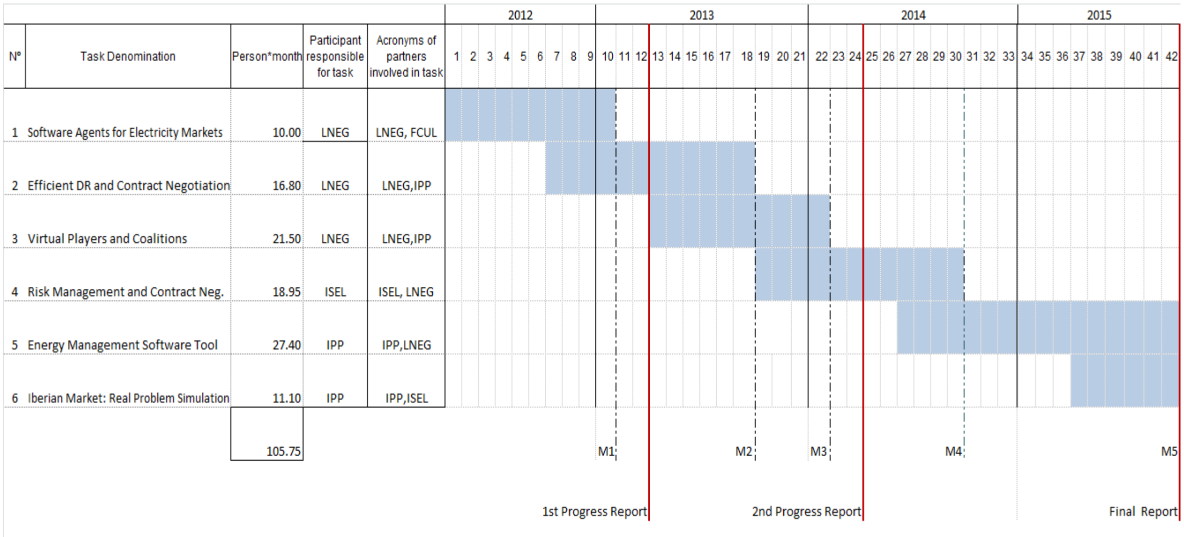


Figure 5. Rough time line of activities undertaken over the duration of the project.

List of Publications

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Book Chapters

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List of Organized Workshops and Seminars

2015. Fourth International Workshop on Artificial Intelligence Techniques for Power Systems and Energy Markets (IATEM 2015), September 1, Valencia, Spain.
URL: http://gecad.isep.ipp.pt/iatem/

2014. Third International Workshop on Artificial Intelligence Techniques for Power Systems and Energy Markets (IATEM 2014), September 2, Munich, Germany.
URL: http://gecad.isep.ipp.pt/iatem/ (and see option: "previous workshops)

2013. Second International Workshop on Intelligent Agent Technology, Power Systems and Energy Markets (IATEM 2013), August 28, Prague, Czech Republic.
URL: http://gecad.isep.ipp.pt/iatem/ (and see option: "previous workshops)

2012. First International Workshop on Intelligent Agent Technology, Power Systems and Energy Markets (IATEM 2012), September 2, Vienna, Austria.
URL: http://gecad.isep.ipp.pt/iatem/ (and see option: "previous workshops)

2012 First National Workshop on Power Systems and Energy Markets, December 32, Laboratório Nacional de Enegenharia e Geologia (LNEG), Lisboa, Portugal.