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## **AC 2011-420: VIRTUAL POWER PRODUCERS AND DISTRIBUTED GENERATION IN ENERGY TRADING MARKETS: AN APPROACH TO THE INTEGRATION OF RENEWABLE ENERGY IN LATIN AMERICA**

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Being a member of several engineering societies and engineering education societies in several continents, including: the Society of Instrument and Control Engineers, SICE (Japan); the Institute of Electrical and Electronics Engineers, IEEE (USA), where he was the national CIS Chapter chair; and the World Scientific and Engineering Academy and Society, WSEAS (Greece), where he belongs to the board of directors. He was also a visiting professor in several universities around the world.

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# Virtual Power Producers and Distributed Generation in Energy Trading Markets: An Approach to the Integration of Renewable Energy in Latin America

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**Abstract - In order for governments from around the world, but more specifically from Latin America to be able to respond and meet increases in electrical power demand in the coming years and deal with the tightening of global environmental standards, a shift from the current conventional electricity production has to be altered, and new innovative energy production alternatives have to be evaluated and introduced. There is no silver bullet for tackling this issue: a profound change has to take place in all areas of the electrical energy spectrum – generation, transmission and distribution. However, Distributed Generation promises to be the best all-around solution for solving increasing energy demand, reducing peak loads, job creation, improving distribution and transmission reliability, positive environmental impact and providing electrical power to rural areas. This paper aims to examine the integration of Distributed Generation from Renewable Energy sources into electrical markets in Latin America; aided by an energy market simulation tool – MASCEM that creates a technical and organizational framework, allowing the trade of electrical energy from Distributed Generation to be competitive in existing energy markets.**

***Key Words – Latin America, Energy Market, Virtual Power Producers, Distributed Generation, Renewable Energy, Energy Education***

## I. Introduction

As developing countries gain importance in the world economy, global population increases and technology advances, the role of electrical energy plays an ever more important part in our society. The World Energy Council stipulates that in the next twenty years, world electrical consumption will increase by approximately 50%. This far exceeds the current trend of consuming fifty times more energy than one century ago<sup>[18]</sup>. Developing countries face the hardest challenge in providing solutions to the increases in electrical power demand and the tightening of global environmental standards; these challenges can however, be overcome with proper planning and adequate participation from governmental and local bodies, companies and academic institutions.

The way to approach a solution lies in the integration of renewable energy sources into the existing energy market, to gradually substitute the conventional power sources, satisfying all electrical energy needs in an affordable, reliable, efficient and sustainable manner. An interconnected system of Distributed Generation based on renewable energy sources promises to be the best all-around solution for solving increasing energy demand, reducing peak loads, job creation, improving distribution and transmission reliability, positive environmental impact in a sustainable manner and providing electrical power to segregated communities where the power grid extension is not an economical option.

Distributed Generation (DG) is commonly referred to small-scale generation technologies that produce electricity close to the consumption center and are usually composed of renewable energy sources<sup>[11]</sup>.

<sup>16]</sup>These alternate sources of energy can become an important component of Latin America's energy production; not only because of the region's market liberalization, governments push for clean energy and investment in new sustainable technologies, but also because of the enormous untapped solar, wind, and biomass (among other renewable energy sources) potential in the area. Even though there exists large disparities in terms of availability of conventional sources, Latin America is endowed with abundant renewable energy resources, which until now are grossly underutilized <sup>[10]</sup> (See Fig. 1, 2, and 3).

A key aspect in explaining the fast evolution of DG sources is the development of promotion programs, subsidies and compensation mechanisms, points which countries in Latin America are beginning to promote and implement in order to gain improvements in power supply availability, respond to economic development and environmental and security concerns <sup>[3]</sup>. With market liberalization, and thus private investment, renewable energy sources are becoming an interesting solution to environmental, social, political and economic problems. Countries like Argentina, Brazil, Chile and Colombia, where the pressure to keep up with international environmental standards, the need to diversify the electrical generation portfolio, and the desire to tap into the huge renewable energy source potential, has made their governments pass laws promoting these sustainable technologies, and integrate them into the existing electrical market.

Electricity markets in Latin America are 'competitive' and are generally separated between generation, transmission and distribution. These markets engage independent power producers (IPPs), with power purchase agreements (PPAs), and bulk market <sup>[2]</sup>. Argentina, for example, has been moving towards the increase usage and integration of renewable energy sources with Law 26.093 and Law 25.019 in 2009 - declaring solar and wind energy production as issues of national interest. These laws complement themselves, by setting a target contribution of 8% from renewable energy sources over a 10 year period, for all national electrical energy consumption <sup>[12, 13]</sup>. Similarly Colombia enacted in 2001 Law 697, which promotes rational and efficient use of energy, through the use of alternative energy sources <sup>[14]</sup>. Even though the current laws in Colombia lack important provisions to fully achieve their objectives, they create the foundation for promoting the use of renewable energy.

The power produced by these new technologies needs to be gradually introduced to the existing electrical network as to provide the majority of the population with clean renewable energy, sold through the electrical wholesale market. Most developed electricity markets have an organized *parallel market* for accommodating DG based on renewable energy sources. The *parallel market* acts as a transition period in the evolution of an energy market, until DG reaches a point of maturity to be able to participate in the wholesale market <sup>[3]</sup>. In most Latin American energy markets, there are no specific rules, regulations or the existence of *parallel markets* for the integration of DG sources. Because of this, DG is not able to participate in the wholesale market, where the market is being limited mostly to bilateral contracts with distribution companies.

This paper presents MASCEM – an energy market simulation tool that allows the modeling of DG from renewable energy sources to be integrated into the energy market, overcoming some of the drawbacks (mainly associated with renewable energies intermittent nature) through the concept of Virtual Power Producers (VPP). The integration of these intermittent energy sources must be evaluated using tools such as MASCEM, as the transition is made into a more sustainable, efficient and reliable system that will result in numerous social and economical benefits to Latin American nations. MASCEM provides the bridge for moving DG technologies into the wholesale market by connecting government energy initiatives, private investment and most importantly academic research.

## II. Distributed Generation & Virtual Power Producers in Latin America

During the last three decades the electrical sector in Latin America has gone through a profound change, moving from government and state owned protected monopolies, to privatized competitive markets <sup>[1, 16]</sup>. Recent restructuring of the electrical sector has created a vertical disintegration of the system, leading to the establishment of a healthy competitive market, based on the supply and demand model, allowing for multiple players to enter the market. The resulted privatization created a liberalized energy market that opened access to distribution networks, increasing competition and giving distributed generators the opportunity to sell their power on the wholesale market <sup>[9]</sup>. This new market structure coupled with the growing importance of Latin America in the world economic stage, the push for clean energies and the abundant natural resources, results in Latin America becoming the perfect playing field for private investment, academic research and government involvement in DG energy production.

Although countries in Latin America are at different legal, regulatory, institutional and financial stages of renewable energy integration, there is a clear indicator that all of these countries are pushing forward in trying to implement new sustainable technologies. The key market drivers for renewable energy and energy efficiency development in Latin America and the Caribbean are energy security, economic development, and climate change <sup>[2]</sup>. Figures 1, 2 and 3 exemplify the enormous potential that exists in Latin American countries.



Fig. 1. Hydro energy potential in Latin America

The highest energy potential from hydro power is found in Mexico with 8000 MW, followed by Guatemala and Nicaragua (4000 MW), Costa Rica (3500 MW), El Salvador (2000 MW), Colombia and Chile with 1500 MW, Peru, Ecuador, Bolivia and Argentina (all with 1000 MW) <sup>[15]</sup>.

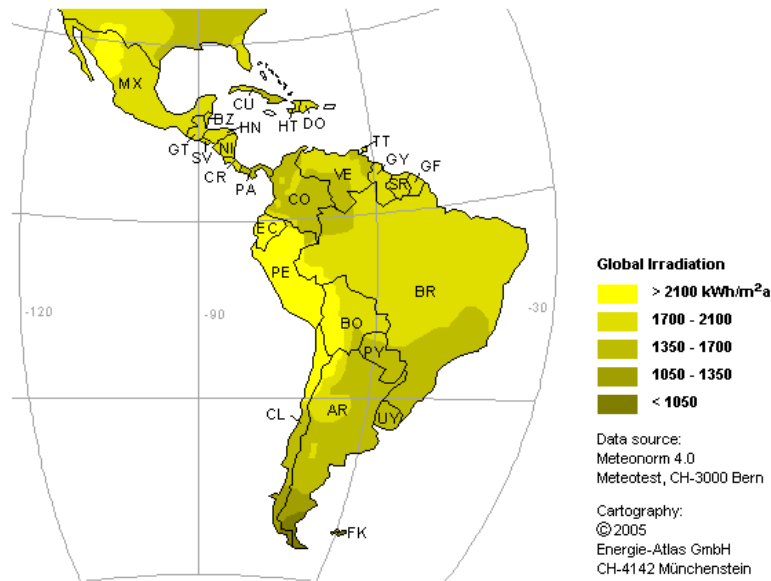


Fig. 2. Solar energy potential in Latin America, global irradiation

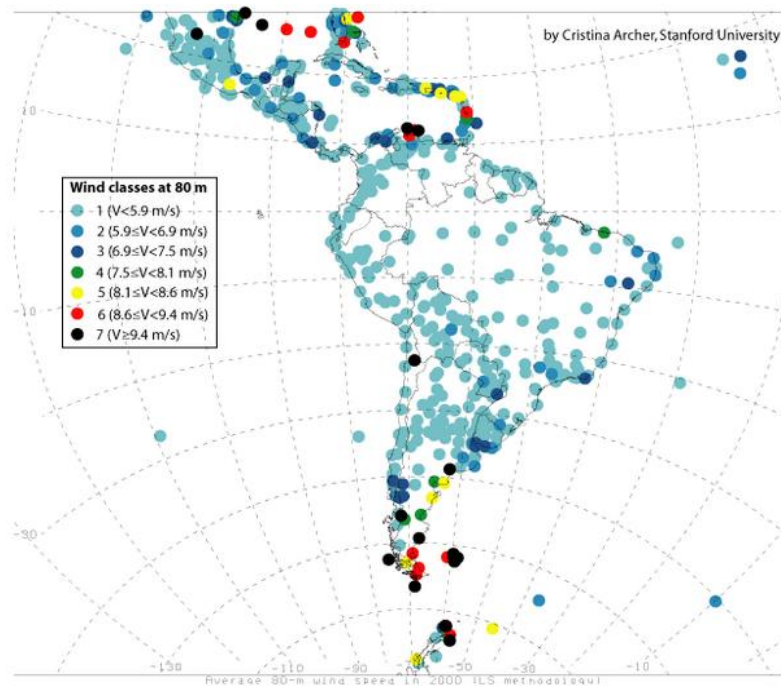


Fig. 3. Wind energy potential for Latin America

The growth of sustainable energy sources is appearing in the form of DG from renewable energy; which unlike conventional large-scale power plants that produce electricity far away from the intended consumption site; DG facilities are small-scale generation technologies, typically ranging from 5 kW to 20 MW, that produce clean electricity close to the consumption center and are usually composed of solar photovoltaic systems, wind turbines, co-generation units and micro-hydropower plants.

Energy producers who harness energy from DG sources suffer from intermittent issues and additional costs compared to those producers of conventional energy sources, thus facing a harder challenge when trying to compete in a larger geographical market. The transaction costs, associated with participating in the market as a small supplier or generator providing electricity as Distributed Generation can discourage

direct participation in the market <sup>[9]</sup>. The liberalization process was primarily characterized by the integration of new participants, bringing with it a wave of technical, logistical and commercial problems that were previously non-existent. One of the main problems associated with the surge of DG is the variable uncontrollable generation output of these sources. Large amounts of variable generation from renewable energy sources not fully forecastable, cause's problems in the electrical network. Renewable energy sources, suffer from intermittence problems, this being one of the reasons why their integration to the grid can create problems in physical balances and in adequacy of power <sup>[17]</sup>.

In order to counterbalance the inherent intermittent nature of renewable sources that make up the Distributed Generation facilities, a new concept called Virtual Power Producers (VPP) is created. This aggregate strategy enables DG producers to gain competitive advantage and overcome the intermittent disadvantages associated with renewable energy technologies <sup>[6]</sup>. VPP is the aggregation of DG sources which in turn reduces the risks associated with the non-controllable factors namely wind intensity, solar radiation and wave frequency – byproducts of renewable energy sources. Through aggregation, VPP's can be managed and operated as if they were a single generating power plant (See Fig. 4).

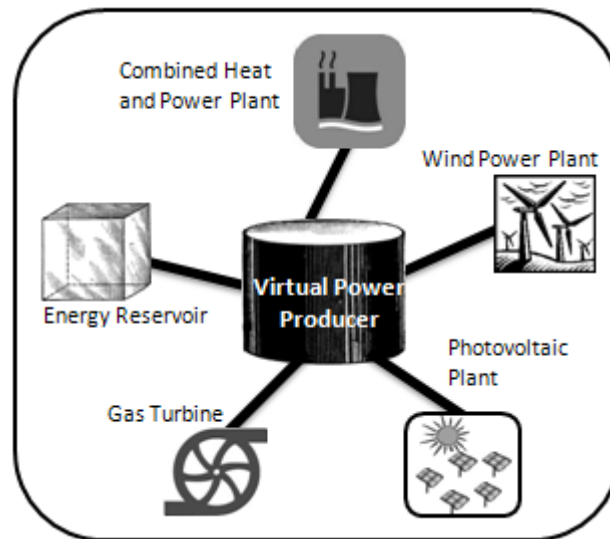


Fig. 4. Basic Virtual Power Producer Scheme: Various decentralized power producers are aggregated to form a Virtual Power Producer. Their combined power can be centrally controlled and treated like a large-scale power plant.

VPP's are a group of interconnected decentralized energy producers that are centrally controlled and grid connected, collectively run by a central entity. VPP's multi-technology are multi-site heterogeneous properties allow it to combine any type of technology combination (photovoltaic, Combined Heat and Power (CHP) wind turbines, controllable and non-controllable loads , mini and micro turbines and fuel cell) ranging from a few kW to several MW.

Strict environmental laws, growing population and increase electrical energy demand, creates a surge in DG from renewable energy sources which needs to be integrated to the energy market. Electrical power produces associated with VPP enjoy a number of benefits, namely; economies of scale from aggregated producers; the opportunity for small scales associated to the VPP to compete in the electrical market; multiple grid connections means improved reliability, flexibility and security of supply; and it can easily adapt to changes when integrating new renewable energy technologies.

### III. Mascem

Electricity markets' main objective is to guarantee the security of the overall system, improve the operational efficiency and reduce the cost of electricity through competition. The success of the electrical market however does not depend solely on having adequate regulatory policies, but also on the profitability of the participating entities. Electrical markets are competitive and dynamic environments, where different members play a variety of roles, making decisions that can drastically alter the market's outcome. With the increase in renewable energy sources and the need to introduce these into the electrical energy market creates an ever more volatile system that requires innovative support tools to mitigate this sporadic behavior.

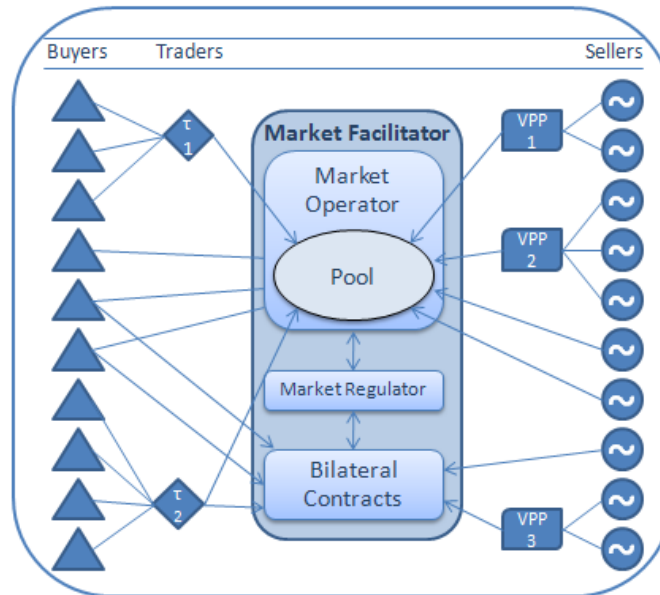


Fig. 5. MASCEM negotiation network

The playing field must be leveled in order to incorporate these up and coming technologies, through government regulation, private and public investment, local participation and academic research & development. MASCEM provides the link between the academic, government, and private sector, creating a technical and organizational framework that allows the trade of electrical energy from Distributed Generation to be competitive in the energy markets, being able to model four types of markets: Forward Markets, Pool Markets, Bilateral Contracts and Hybrid Markets.

MASCEM - Multi-Agent Simulator of Competitive Electricity Markets<sup>[3, 4]</sup>; is a simulation decision support tool designed to analyze and experiment with various market models, related to the day-ahead market and the 24 period trading periods. The program uses a multi-agent architecture that identifies the entities that will participate in the purchase and sale of electricity, and incorporates different strategies to better model the buyers and sellers behavior when participating in the electrical market structure. The MASCEM multi-agent model is a powerful tool for understanding the behavior of agents (buyers, sellers, market players, traders and operators) using dynamic strategies and scenario analysis, based on mathematical models of such as Game Theory, Machine Learning and optimization techniques to model market agents and to provide them with decision-support gaining competitive advantage.

MASCEM focuses on negotiation strategies for the purchase and sale of electrical energy, in order to provide the mean to obtain tangible results and make informed decisions, thus gaining competitive advantages. This advantage is obtained by studying the several negotiation mechanisms found in electricity day-ahead markets, providing a decision support tool, and helping VPP's improve their strategies to face

the market<sup>[8]</sup>. MASCEM model provides the base for VPP's to use strategies that enable aggregation of distributed generation facilities to obtain technical and economic advantages derived from the combined use of different production technologies, surpassing the disadvantages of such technologies and provides users with dynamic strategies, which can be specifically tailored to the desired characteristics of the agent.

The structure of MASCEM allows the user to recreate and analyze the market within a controlled environment, using several Artificial Intelligence and data mining techniques to show how the market behaves and evolves, and clearly showing which actions have to be taken when adapting to the changing market environment. Through the inclusion of VPP's in the software, MASCEM is able to study the effects of coalition management, negotiating the aggregate total power in an efficient and optimized way, managing the internal issues (e.g. remuneration, reserve management, production cost, etc) between the company and the generators and analyzing the impact of each particular generator in the VPP's operation. The integration of renewable energy sources and the continuous changes in government policies in Latin America, MASCEM is the perfect tool for studying the impact of new approaches, policies, operational procedures and decision rules. Similarly, the simulating tool created the desired structure for understanding how the electrical market works and a great tool for learning and training as it incorporates symmetrical pool markets, mixed markets (both symmetrical and asymmetrical) and bilateral contracts.

As energy and more specifically, renewable energy becomes a key 21<sup>st</sup> century topic, academic involvement in this area becomes crucially important. Engineering education becomes the driving force for innovation; pioneering the technologies that will power the future. MASCEM is one the projects that aims to pull together government, private entities and educational institutions to find solutions to the specific electrical needs and problems that Latin America faces.

#### **IV. Conclusion**

The Latin American market lends itself as an ideal candidate for implementing MASCEM simulator. The ongoing liberalization of markets creates a healthy competitive environment that promotes investment in the area of renewable energy. Additionally, most Latin American countries have rich natural resources with great potential for extracting clean energy, meeting the needs of increasing population and for powering rural electrification sectors. The ideas presented in this paper aim at highlighting the importance of decision support tools and simulations like MASCEM for the eminent integration of renewable energy sources into the existing electrical markets. MASCEM provides the structure to thoroughly analyze real market data and recreate various market structures in a controlled environment.

MASCEM has undergone a series of case studies namely in OMEL - the Spanish electricity market, looking at various aspects, mainly; profits for the producers, energy produced and energy sold. The results (See Appendix for software screen shots and simulation graphs) obtained in various case studies; indicate the potential of a practical application and a pilot project<sup>[6, 7, 8, 9]</sup>. As of the writing of this paper, a pilot implementation has been discussed in Argentina, Chile and Colombia. Both the process in Chile and Colombia are in preliminary development stages, trying to identify the correct technical university with the expertise in the electrical market that can lead the way in understanding the entire market structure for a successful application of the simulator. In Argentina however, a pilot project is under way, where the software will be used to model a distributed generation company that manages four hydroelectric plants in the province of Rio Negro. These plants will be integrated as a VPP under various grouping and production scenarios, closely monitored in site by a local technical university, ISEL and the generation company.



Academic involvement in MASCEM creates the needed foundation where students and faculty can work together on innovative research that will one day offer the needed answers to Latin America's energy crisis. During this initial step the MASCEM simulation tool provides the opportunity for engineering faculty and students to teach and learn about energy systems in a controlled environment. This will allow them to better understand the complex transition from conventional energy sources into the future renewable energy sources.

## V. References

- [1] C. Guzowski, M. Recalde, “Latin American electricity markets and renewable energy sources: The Argentinean and Chilean cases”, *International Journal of Hydrogen Energy*, 2010
- [2] [Department of Sustainable Development Organization of American States, Energy and Security Group, “Sustainable Energy Policy Initiative Report for Latin America and the Caribbean”, *Renewable Energy and Energy Efficiency Partnership*, 2007]
- [3] G. A. Jiménez-Estévez, R. Palma-Behnke, R. Torres-Avila, L. S. Vargas, “A Competitive Market Integration Model for Distributed Generation”, *IEEE Transactions On Power Systems*, 2007
- [4] H. Morais, I. Praça, M. Cardoso, C. Ramos, Z. A. Vale, “Virtual Power Producers Integration into Mascem”, *IFIP International Federation for Information Processing Vol.243*, 2007
- [5] H. Morais, I. Praça, C. Ramos, Z. Vale, H. Khodr, “Multi-Agent Electricity Market Simulation with Dynamic Strategies & Virtual Power Producers”, 2008
- [6] H. Morais, M. Cardoso, H. Khodr, I. Praça, Z. A. Vale, “Virtual Power Producers Market Strategies”, *IEEE*, 2008
- [7] H. Morais, T. Pinto, Z. A. Vale, Member, I. Praça, C. Ramos, “Multi-Agent Based Electricity Market Simulator with VPP: Conceptual and Implementation Issues”, *IEEE*, 2009
- [8] H. Morais, P. Oliveira, T. Pinto, Z. A. Vale, I. Praça, “MASCEM – An Electricity Market Simulator providing Coalition Support for Virtual Power Player”, 2009
- [9] International Energy Agency, “Distributed Generation in Liberalized Electricity Markets”, 2002
- [10] J. M. Huacuz, “Overview of Renewable Energy Sources in Latin America, *International Electrical Research Exchange*”, 2003
- [11] K. Purchala, R. Belmans, L. Exarchakos, A.D. Hawkes, “Distributed generation and the grid integration issues”, [http://www.eusustel.be/public/documents\\_publ/WP/WP3/WP%203.4.1%20Distributed%20generation%20and%20grid%20integration%20issues.pdf](http://www.eusustel.be/public/documents_publ/WP/WP3/WP%203.4.1%20Distributed%20generation%20and%20grid%20integration%20issues.pdf)
- [12] Ley 26.190 - Argentina, [http://www.argentinaeolica.org.ar/portal/images/stories/Argentina\\_LEY%2026190.pdf](http://www.argentinaeolica.org.ar/portal/images/stories/Argentina_LEY%2026190.pdf)
- [13] Ley 25019 - Argentina, [http://www.centrodeenergias.org.ar/portal/index2.php?option=com\\_content&do\\_pdf=1&id=89](http://www.centrodeenergias.org.ar/portal/index2.php?option=com_content&do_pdf=1&id=89)
- [14] Ley 697 - Colombia, [http://www.lawea.org/documentos/Colombia\\_Ley\\_697.pdf](http://www.lawea.org/documentos/Colombia_Ley_697.pdf)
- [15] Global Energy Network Institute, *Renewable Energy Potential Maps for Latin America*, <http://www.geni.org/globalenergy/index2.shtml>
- [16] M. Begović, A. Pregelj, A. Rohatgi, D. Novosel, “Impact of Renewable Distributed Generation on Power Systems”, 2001
- [17] M. M. Zuluaga, I. Dyner, “Incentives for renewable energy in reformed Latin-American electricity markets: the Colombian case”, *Journal of Cleaner Production*, 2005
- [18] R. Casilda Béjar, “Energía y desarrollo económico en América Latina”, *Boletín Económico de ICE*, 2002

## VI. Biography

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In collaboration with:

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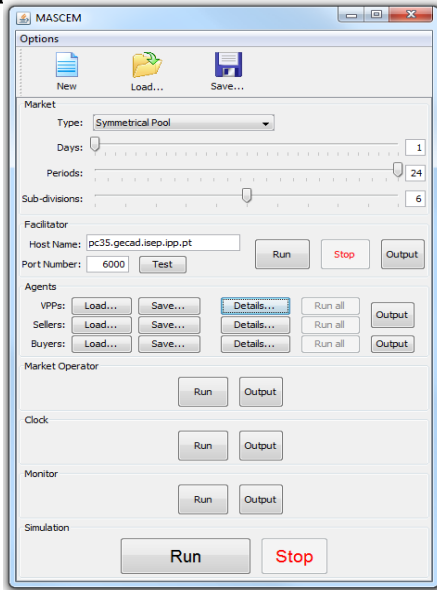
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**Tiago Pinto** received the B.Sc. degree in Computer Engineering from the Polytechnic Institute of Porto (ISEP/IPP), Portugal in 2008. Presently, he is a Researcher at GECAD – Knowledge Engineering and Decision-Support Research Center of ISEP/IPP and is taking a M.Sc. in Knowledge and Decision Technologies.

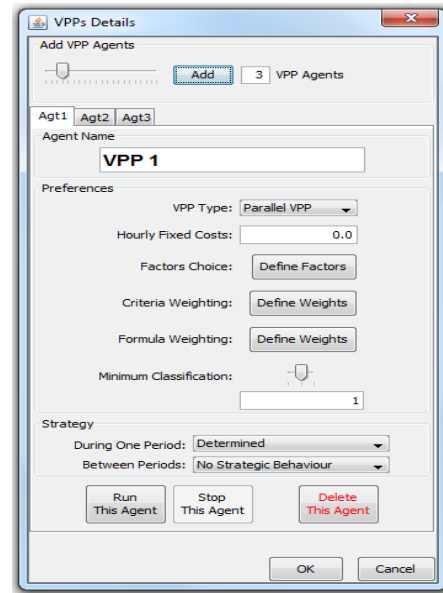
**Isabel Praça** graduated in the University of Porto in 1994 and received her PhD degree in Electrical Engineering from the University of Trás-os-Montes e Alto Douro in 2005. She is currently a Professor in the Polytechnic Institute of Porto and a Researcher at GECAD – Knowledge Engineering and Decision-Support Research Center. Her research areas include Multi-Agent Systems, Simulation, Decision Support Systems and Electricity Markets.

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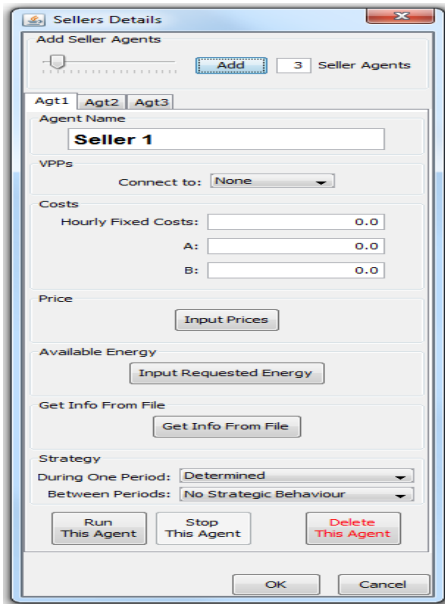
## VII. Appendix



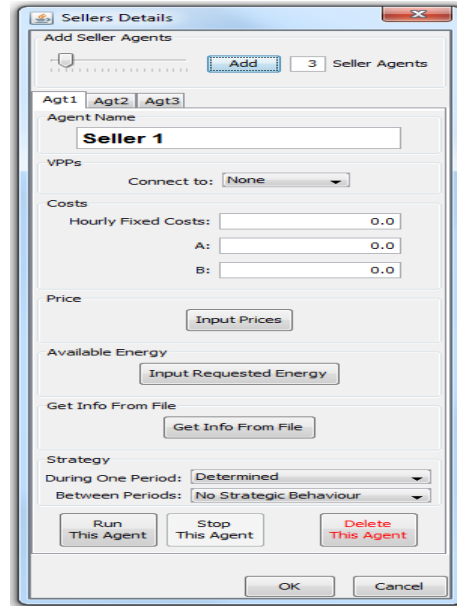
Main MASCEM Screen



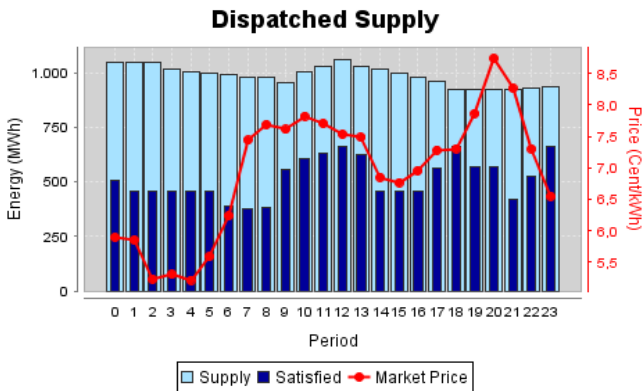
VPP's Details Screen



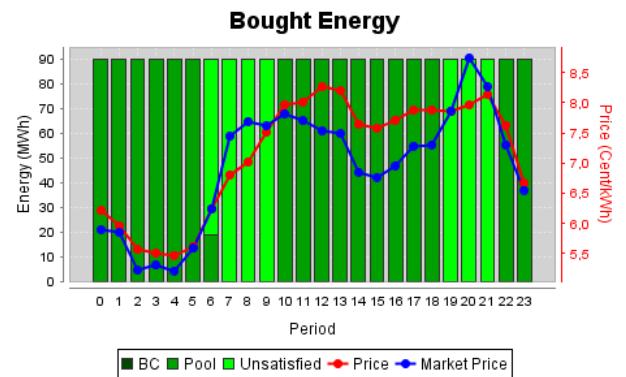
Seller Interface Screen



Buyer Interface Screen



Total energy dispatched by all sellers



This is the graph of the energy bought for an individual buyer  
When the buyer does not buy (light green-Unsatisfied) is because its bids were below the market price