

# The insertion of renewables into the Chilean electricity market

Sebastian Mocarquer, *Member IEEE*, Hugh Rudnick, *Fellow IEEE*

**Abstract-** The Chilean electricity regulation introduced in 2008 an obligation to contract 10% of renewable energy, excluding large hydro, in the wholesale market. This paper assesses the impact of that obligation into the market, revises renewable projects that have been submitted for environmental assessment, the actual plants being built and the requirements they are imposing onto the transmission system as well as system operation. Challenges to investors introducing renewables are discussed.

**Index Terms**— renewable energy, electricity regulation, wind energy.

## I. INTRODUCTION

The insertion of renewable energy in Chile has been a major issue in the regulatory framework modifications in the past years. Chile's energy matrix has been traditionally composed by large hydro and thermal generation, both coal and natural gas. But recent events concerning energy security and the search of environmental sustainability according to global trends, have brought renewable energy to the center of the debate.

In this debate, it must be considered that energy policy is funded by three main principles; security of supply, economic efficiency of supply, and social and environmental sustainability. Depending on the context of the countries analyzed, these three principles may be balanced in different ways, in particular, if one is comparing developed countries with those of Latin America or Africa. The two latter do not yet satisfy the energy needs of much of their people, and where the additional objective of social justice equality becomes relevant.

While South America, as does Chile, contributes marginally to world's total greenhouse gas emissions, societies are becoming progressively more aware of the impact of large hydro power plants and fossil fuel burning plants. Private investors leading key investment decisions are facing growing opposition in the liberalized market, bringing the debate of balancing energy supply efficiency and security versus sustainability.

The Chilean legislation identifies Non Conventional Renewable Energy (NCRE) as the generation means from non conventional sources connected to the grid, such as geothermal, wind, solar, biomass, tidal, cogeneration, and hydro generation up to 20 MW. Recent legislation has set important incentives for this type of generation, forcing a market quota.

In this paper the evolution of the Chilean market is revised and the regulatory changes that were introduced to

incentivize investment are explained as well as the current investment situation. A simulation of the future development of the energy market until the year 2030 was performed in order to compare two scenarios; business as usual as a base case and a second scenario, where the nonconventional renewable energy has a 20% share of the generation. Results are analyzed and challenges to be confronted are presented.

## II. EVOLUTION OF THE CHILEAN MARKET

Chile was the world pioneer country deregulating and privatizing the electricity industry after the enactment of the Electricity Law in 1982. The electricity market was restructured in generation and distribution companies that were successively privatized at the end of the 1980's.

The Chilean electric market consists of three segments: generation, transmission and distribution. According to the law, the generation segment is defined as a competitive market, while the transmission and distribution segments are regulated by the State. In the generation market, the different agents compete for supplying power to consumers according to marginal theory through a centralized minimum dispatch cost. The market competition takes place mainly as regards generation costs; thus, the most economic technologies define the system's development.

Availability of natural gas from Argentina, whose price was much lower than any other thermal technology of the 1990's and beginning of the 2000's, defined the development of the Chilean market due to its favorable import price. Therefore, participation thereof (since year 1997) gained a significant importance in the Chilean electric market. In addition, the hydrology component of the generation park in the Central Interconnected System (SIC) allowed supplying power at a low cost – approximately 20 US\$/MWh – from year 2000 through year 2004. However, restrictions imposed on import of natural gas from Argentina since 2004 created an unbalance in the Chilean electric market between the generation capacity and the system's demand. The foregoing led to a boost in the energy price, which in 2008 exceeded 300 US\$/MWh, and to the adoption by the National Congress of a series of measures for promoting proper development of the generating park (Short Law II). Figure 1 depicts the marginal price from 2006 to 2009, together, with the energy generation disaggregated by technology; the replacement of natural gas with diesel is to be held accountable for the energy price boost. In addition, the diversification of the energy matrix has been promoted through exploitation of the NCRE, with the aim of decreasing dependence on traditional sources (Short Law I, Short Law II, NCRE 2008 bill).

Figure 2 shows the composition of the energy matrix for the Central Interconnected System (SIC) according to installed capacity. Large hydro, both dam and run of river, account for 47%, while thermal generation, mainly natural gas, coal and diesel, account for 49% of the capacity. Renewable and others account for less than 4% of the matrix. If large hydro is

---

Sebastian Mocarquer is with Systep Ingeniería y Diseños, Chile (email: smocarquer@systep.cl)

Hugh Rudnick is with Pontificia Universidad Católica de Chile (e-mail: hrudnick@ing.puc.cl).

considered, more than 50% of the capacity in SIC can be considered renewable, hence the need by the government to differentiate nonconventional renewable energy from traditional large hydro generation.

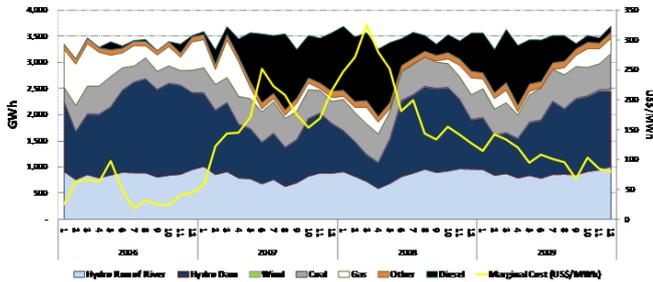


Figure 1. Generation by technology and marginal cost in SIC 2006-2009.

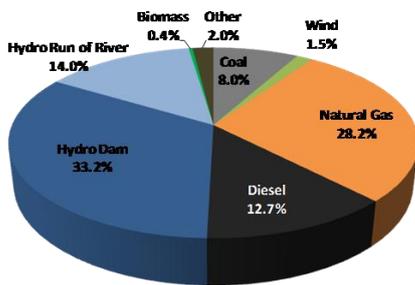


Figure 2. SIC installed capacity by type-December 2009.

Alternatives for future development of the energy generation matrix include large hydro, coal, LNG and renewables. Table 1 shows the estimated potential for nonconventional renewable energy in Chile, according to the National Energy Commission. Solar energy is not quantified given the enormous potential in Chile.

Technology	Estimated Potential [MW]
Geothermal	2.000
Wind	6.000
Biomass	1.000
Mini Hydro	2.600
Solar	-
<b>Total</b>	<b>11.600</b>

Table 1. Renewable energy estimated potential (National Energy Commission)

Discussion is taking place regarding the construction of hydroelectric projects in Patagonia, and in particular in the rivers Baker and Pascua, located in the extreme south of Chile. The investor group has announced that the project consists of the construction, from year 2013 until year 2022, of five hydroelectric power plants with a joint installed capacity of 2,750 MW. In addition, the project involves the construction of a DC transmission line of 2.000 kilometers to link the power stations directly to the capital of Chile, Santiago, the largest demand center. The project involves an investment superior to 4,000 million dollars.

Nuclear power plants are being considered, but are still in a very early stage of evaluation, where preliminary studies

are being performed by the government. In case the evaluation of the nuclear alternative results convenient, it is an option that will need between 10 to 15 years to develop.

### III. REGULATORY FRAMEWORK CHANGES

On April 2008 Law No. 20,257 was enacted, which encourages the entry of nonconventional renewable energy projects into the Chilean energy matrix. This law introduces the obligation for power traders, distribution companies and generators that make energy withdrawals from the system to supply regulated and non regulated consumers, to certify that at least 10% of the energy being traded comes from non conventional renewable energy, being self produced or bought from other generators. This new law establishes that the requirement will start with a 5% obligation in January 2010 until 2014, and from then on there will be an increase of 0.5% annually until reaching 10% in 2024.

In case the requirement is not met, non complying traders will have to pay a fine of approximately 28 US\$/MWh for every MWh in compliance. If the in compliance is repeated in a three year period, the fine becomes 42 US\$/MWh.

In order to comply with the nonconventional renewable energy law, heavy NCRE investment is expected to take place over the next years. Figure 3 shows the estimated energy required and also the renewable energy available or under construction that will help meet these new requirements, where different plant factors were assumed according to the different renewable technologies. It is important to notice that due to the different plant factors, the actual installed capacity will have to be much larger.

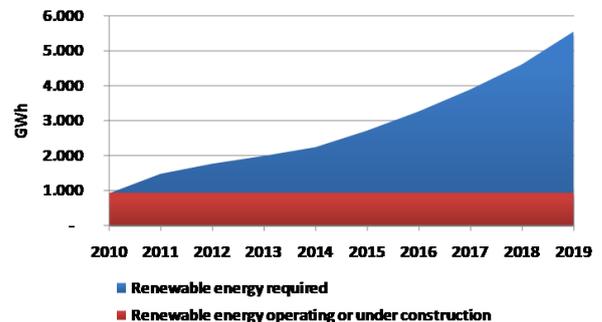


Figure 3. Renewable energy required 2010-2019

Other regulatory changes have been made in order to facilitate renewable insertion, especially regarding the access to the grid, both at transmission and distribution levels. Also, incentive programs have been implemented, such as a direct subsidy to pre investment assessments.

### IV. INSERTION OF RENEWABLES

There has been a significant interest in investing in nonconventional renewable energy, especially in mini hydro and wind farms, and in some degree of solar energy, especially considering the enormous potential of Chile. In table 2 the investment in nonconventional renewable is shown, where a total of 218 MW has come into operation in recent years. The great interest is shown in the large number of projects who have obtained or submitted for environmental licensing, adding

up to a total of approximately 2,266 MW. The feasibility that these projects will ever be constructed is discussed later.

Status	Fuel	Capacity (MW)
In operation	Biomass	-
	Wind	172
	Mini-hydro	46
	Solar	-
	<b>Total</b>	<b>218</b>
Projects with approved environmental licensing	Biomass	211
	Wind	1,079
	Mini-hydro	212
	Solar	9
	<b>Total</b>	<b>1,510</b>
Projects with pending environmental licensing	Biomass	23
	Wind	674
	Mini-hydro	59
	Solar	-
	<b>Total</b>	<b>756</b>
<b>Total Renewables</b>		<b>2,484</b>

Source: Environmental Impact Evaluation System (SEIA), Systeem Table 2. Renewable energy projects- December 2009.

The first wind farm connected to the central interconnected system is located 300 km north of Santiago, which started as 19 MW farm and was subsequently expanded to a total of 60 MW. Figure 4 shows the energy generated in 2009 by that farm. It can be observed that the plant factor achieved was approximately 23.7%. Most of the new wind development has occurred nearby to this first project.

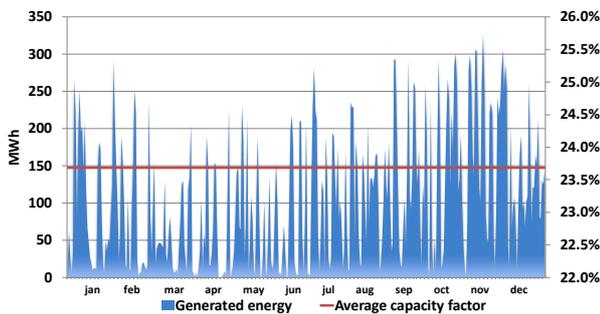


Figure 4. Energy generated in 2009 by the first wind farm connected to the SIC

## V. IMPACT OF THE INSERTION OF RENEWABLES

A heated discussion has taken place in Chile concerning the need to deepen the participation of renewable energy. The development of large hydro projects in the Patagonia, an inhabited and pristine region, has raised an intense debate in Chile, facing opposition mainly by nongovernmental organizations (NGO's). The basic proposal of the NGO's is to replace the development of large hydro projects and coal projects with renewable energy and energy efficiency.

Chile, as a developing country, has an energy consumption that is strongly correlated with economic growth, with energy consumption annual growth rate above 5%, in spite of recent efforts to increase energy efficiency.

The discussion arises as the NGO's alternative implies a higher cost for energy in a country that already has one of the most expensive electricity rates in Latin America. Different

electricity expansion scenarios are being formulated by the opposing parties, green ones based just on renewables and traditional ones favoring large hydro. A simulation considering two alternative scenarios was performed in order to assess the impact of different levels of renewable penetration in the market, and is reported in the following section.

### A. Generation expansion scenarios

Simulations of the future development of the electricity market were performed until the year 2030 in order to compare two scenarios; a business as usual as a base case and a second scenario where the nonconventional renewable energy has 20% share of the generation. The parameters used to make the comparison are the annual average marginal cost, new installed capacity, operation and investment costs, CO<sub>2</sub> emissions and land area occupied.

The methodology used to obtain a generation expansion plan is intended to reproduce the investor's behavior in a competitive electricity generation market, without oligopolistic conditions. In this environment, investors are assumed to act rationally based on public information, trying to maximize their profits with projects that offer, at least, a desired internal rate of return for a 30 years evaluation horizon. Investments plans informed by the generation companies as under construction are considered as certain if they meet certain conditions, and their entrance dates are not optimized nor subject to the evaluation of profitability.

To simulate the operation of the system, the OSE2000 simulation model is used. This is a hydrothermal and multimodal dispatch model used by the National Energy Commission to determine each semester the regulated prices for final small consumers. The simulation is performed using 50 different hydrological conditions, and considering the evolution of input variables, such as fuel prices, energy demand, investment plans and transmission expansion plans. From the results of the simulation, an economic and financial evaluation for the power plants is performed, in order to determine the feasibility of the investment plan.

The economic evaluation of investments considers the following items: income from capacity and energy sales, generation costs, transmission tolls and other operational costs, such as maintenance. Depreciation and taxes are also included. With this information, a Free Cash Flow (FCF) is constructed, and then the Internal Rate of Return (IRR) of the FCF is calculated and compared to a WACC (Weighted Average Cost of Capital) rate assumed for the energy market in Chile. Then, when the IRR is greater than the WACC rate, it triggers the entry of a new player to the market, and thus modifies the expected energy price in the system.

In simple terms, this process produces a generation expansion plan that avoids underinvestment, since higher prices stimulate new investments, but not reaching overinvestment, because lower prices would affect the cash flows of incoming projects reducing their benefits. Then, the expected answer to lower prices would be a delay in the entry of new investments, waiting for higher consumer needs and consequently higher prices. If any incoming project does not fulfill the threshold rate of return constrain, it forces to delay or advance the project, looking for the improvement of its financial results. If under any circumstance this requirement is not fulfilled, the project is retired from the expansion plan. This iterative process (simulation of the system and evaluation of

the power plants) over new projects considered as feasible within the evaluation horizon generates an expansion plan adapted to the investments requirements in the electricity industry.

In summary, the market model uses assumptions of perfect competition to build, through an iterative process, adapted expansion plan that fulfill the objectives of the investors to meet a minimum IRR, and capable of supplying the forecasted demand. This process is schematized in Figure 5.

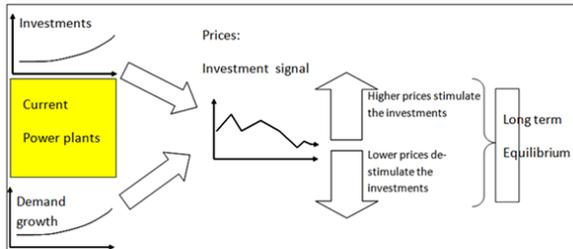


Figure 5. Generation expansion plan construction methodology.

### B. Main assumptions and scenario construction

In order to construct the two simulated scenarios one needs to determine the evolution of the input variables such as: demand, fuel prices, generators investment plans (only for the first 10 years approximately), LNG availability and the evolution of the transmission system (specifically in the first 10 years). It is important to note that for the period from 2020 to 2030, practically no information of future projects is available. Also in this decade, transmission restrictions are not considered as active, because it is expected that the transmission system investment plan will follow adequately the evolution of the power plants investment plan. Energy efficiency at an annual rate of 1% is considered, which is discounted from energy growth.

The Base Scenario considered that the evolution of the system will not change radically, and the generation technologies will maintain approximately the same proportion as the current situation. Additionally, the Base Scenario needs to comply with the legal requirements, which impose that a proportion (10% by the year 2024) of the energy traded, must be generated using nonconventional renewable energy sources.

On the other hand, the Renewable Scenario considered a stronger development of the installed capacity in renewable energies, in order to achieve that approximately 20% of the total energy produced in the year 2030 is generated using renewable technologies. This requirement was fulfilled with the installation of wind generation.

After the resulting investments plans for both scenarios were obtained, the comparison of the two scenarios required the calculation of several factors such as the total CO2 emissions, total costs of investment and operation, average marginal costs, and total capacity installed by technology over the study horizon, among other factors.

### C. Results

The results of the simulations are presented in Table 3, where the total capacity installed in the 2010-2030 period is shown. It must be noticed that in the Renewable Scenario 21% of the coal capacity was replaced by 1.446 MW of wind farms,

representing a 45% increase in the installed capacity. The remaining technologies continue invariable due to the simulation construction and information constraints, especially regarding hydro generation, where further exploitation of hydro resources will become exponentially difficult.

Technology	Installed capacity in 20 years [MW]		% of difference
	Base	Renewable	
Run of river	2.772	2.772	0%
Dam	2.750	2.750	0%
Wind	3.276	4.742	45%
Biomass	184	184	0%
Geothermal	635	635	0%
Coal	3.141	2.481	-21%
Dual	1.360	1.360	0%
Diesel	980	980	0%

Table 3. Total installed capacity in Base and Renewable scenarios 2030.

The parameters used to make the comparison are the annual average marginal cost, new installed capacity, operation and investment costs, CO2 emissions and land area occupied, which are shown in Figure 6.

In terms of economic efficiency, over a total of 20 years, the Renewable Scenario's installed capacity and investment are 5% and 7% higher than in the Base Scenario. This was expected since high plant factor technology, such as coal fired generation, is being replaced by lower plant factor technology, such as wind. On the other hand, total operation costs over 20 years are 3% lower in the Renewable Scenario, explained by the replacement of fossil fuel with almost nil variable cost generation. The total economical effect, which is total investment and total operational cost for the period, results in a 3% increase over the 20 year period for the Renewable Scenario. In terms of effects on the market, the annual average marginal cost increases by 5% in the Renewable Case, explained mainly by the operation of alternative fuels, such as LNG, to replace generation in low wind conditions. For a fast developing country the last effect must be seriously considered since electricity is an important component of the production costs of Chilean products in a globalized market, imposing an additional tax, lessening competitiveness and resulting in lower economy growth. Also, social justice equality, or social sustainability, must be considered, since a higher electricity cost impacts less protected social segments.

Environmental sustainability was measured in terms of two important variables; CO2 emissions and land occupation where two very different results were obtained. In terms of CO2 emission, a very important annual average emission reduction is obtained, were a 16% is avoided compared to the base case. Figure 6 illustrates this, where a greater effect is appreciated after the year 2020, where coal fired plants are replaced with wind farms. On the contrary, land occupation results in a 28% increase in the Renewable Scenario compared to the Base case, explained mainly by the land extension required for wind farms. A discussion can be held of effective land occupation of wind farms since the land below the generators could be utilized. Hence, an important trade off occurs in terms of sustainability, important CO2 reductions are achieved, but more land is occupied.

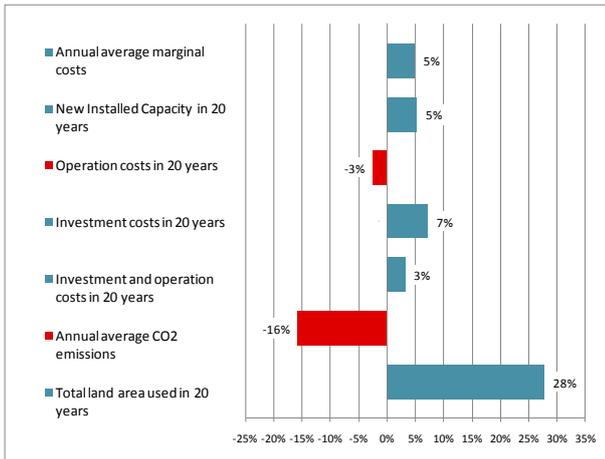


Figure 6. Renewable Scenario compared to the Base Scenario

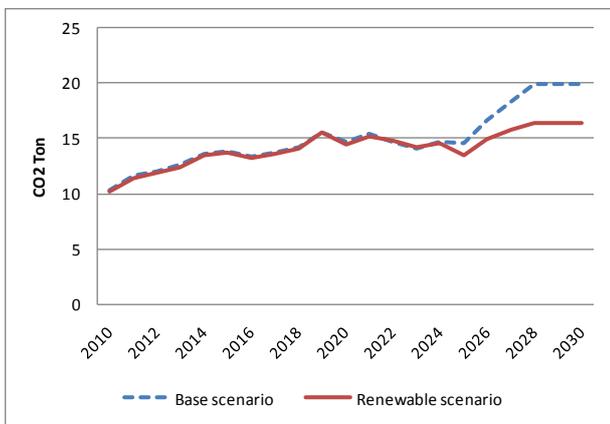


Figure 7. CO2 emissions of the Renewable Scenario compared to the Base Scenario

## VI. MAIN CHALLENGES

While there has been a significant interest in investing in renewable generation, up to date major unresolved challenges keep the investment locked and it is not clear that the projects approved environmentally will be finally constructed. The following are the main challenges that must be resolved to enable a greater degree of competitiveness for these technologies in the Chilean electricity market.

### A. Financing and business model

The characteristics of wind resource, with both its seasonal and daily variability of the generation, results in a difficulty for establishing adequate energy contracts to obtain financing based on project cash flows. First, the low plant factor of this technology combined with its variability in generation only allow energy supply contracts subscription for a low proportion of its total power generation, otherwise they are exposed to excessive risks in the spot market, causing limited flows to ensure sufficient funding. Moreover, the direct energy sale to the spot market does not allow flows to ensure stability for the debt service.

Then, wind projects may not materialize not because of technological innovation or cost competitiveness barriers, but because financial instruments and the tools available are insufficient to finance projects, which today constitutes the

main obstacle for investment. The investments that have materialized to date, and under construction, have been developed by major generators using corporate finance, with guarantees of a parent company, and using particular opportunities that the market has given. Large customers have also developed wind generation as part of their sustainability programs in order to supply part of their consumption.

In general it is possible to characterize the Chilean contract market as closed and inaccessible for renewable energy. In particular, the supply contracts resulting from tenders for regulated supplies are long term and for large amounts of energy, which have a relatively low renewal fee in time. This challenge is not particular to renewables, on the contrary it is common to any new entrant, but it becomes particularly difficult to overcome for renewables, given the characteristics of this generation. One could say that the same situation happens for bilateral contracts with unregulated clients. In short, the contract market liquidity is low and the market is closed for long time horizon contracts, making it difficult for a new entrant to obtain contracts to expedite financing.

Nevertheless, it is possible to note that there has been a gradual learning process of banking and investment funds, which have begun to look forward to these projects. If this limitation is not overcome soon, it is possible to anticipate a drop of wind projects approved or presented by non-traditional developers, selling their projects to traditional utilities.

### B. Permits

Another aspect that has become a challenge in implementing renewables is the processing of permits. While it is possible to say that in general the processing of permits is a barrier that crosses all generation technologies, wind generation is particularly sensitive to long processing times due to the financial cost involved for non-traditional investors.

The long delays in obtaining environmental permits and local territorial permits, with a share of uncertainty on the latter, add a major barrier for these projects.

### C. Transmission access

The connection to the transmission system is always a barrier for the integration of generators, especially in Chile, given the radial property of the transmission systems that have been developed and adapted to generation and demand. In particular, in areas where there is high wind development potential, transmission systems require expansions. This generates a significant challenge for planning and pricing of transmission systems for two main reasons: first, there is a time lag in investment in wind generation and transmission, because on the one hand a wind farm can be installed in 18 months, while a transmission line requires 4 to 6 years to complete, and second, wind generation can condition transmission design in terms of sizing, but participates little in its remuneration given the low plant factors for wind generation.

### D. Renewable resources information

Finally, although studies have been done to characterize renewable resources in Chile, in practice this information is still limited and requires a major effort from

private investors to identify areas with potential, adding a barrier of entry for these technologies.

## VII. CONCLUSIONS

The evolution of the Chilean market is revised and the regulatory changes that were introduced to incentivize investment are explained as well as the current investment situation.

The comparison of two future development scenarios up to 2030 reveals important effects depending on the renewable penetration, which need to be balanced. Although it is clear that a higher market penetration of renewable energy can provide a significant CO<sub>2</sub> emission reduction, other effects must be considered in order to maintain an energy policy that balances the three main objectives; security of supply, economic efficiency of supply, and social and environmental sustainability. The biggest trade off with the environmental sustainability is the economic effect and the social sustainability, since higher renewable penetration in the Chilean market convey a higher energy price and a higher total cost, combining investment and operation. Great caution must be exercised if higher penetration of renewable generation is to be pursued with regulatory changes.

Challenges to be confronted remain in the market, such as financing and business model, transmission access, permits and resources information. All of the aforementioned contribute with barriers that impede a higher renewable penetration.

## VIII. BIBLIOGRAPHY

- [1] S. Mocarquer, L.A.Barroso, H. Rudnick, B.Bezerra, M.Pereira, "Balance of Power", IEEE Power and Energy Magazine, Vol 7, pp. 26-35, September/October 2009.

- [2] H. Rudnick, L. Barroso, S. Mocarquer, B. Bezerra, "A delicate Balance in South America" IEEE Power and Energy Magazine, Vol 6, pp. 22-35, July/August 2008.
- [3] L. A. Barroso, S. Mocarquer, H. Rudnick, T. Castro, "Creating Harmony in South America", IEEE Power and Energy Magazine, Vol 4, July-Aug. 2006.
- [4] H. Rudnick, S. Mocarquer, "Hydro or Coal: Energy and the Environment in Chile", Proc. IEEE PES General Meeting 2008, Pittsburgh.

## IX. BIOGRAPHIES



**Sebastian Mocarquer**, IEEE Member, graduated as Industrial Electrical Engineer from Pontificia Universidad Católica de Chile. He is presently the General Manager at Syste Ingenieria y Diseños. He has conducted several tariff studies in all segments of the energy market, led investment analysis studies, Due Diligence, Project Finance, planning of transmission and distribution systems, regulatory frameworks design, among other areas, in Chile and abroad.



**Hugh Rudnick**, IEEE Fellow, is a professor of electrical engineering at Pontificia Universidad Católica de Chile. He graduated from University of Chile, later obtaining his M.Sc. and Ph.D. from Victoria University of Manchester, UK. His research and teaching activities focus on the economic operation, planning and regulation of electric power systems. He has been a consultant with utilities and regulators in Latin America, the United Nations and the World Bank.