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Ανάπτυξη των φωτοβολταϊκών στην Χιλή

Development of PV in Chile

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ABSTRACT

The current period is very critical to the development of Chile, as it faces the enormous challenge of creating the necessary conditions and developing the infrastructure in order to join the group of developed countries within the next decade. One of the Chilean government’s greatest expectations is to accelerate the incorporation of Non Conventional Renewable Energy (NCRE) in the country’s energy mix.

To this end, the Chilean government has taken important steps with the adoption, in 2013, of Law 20.698. This Law determines specific and quite ambitious target for 2025, indicating that 20% of marketable energy should come from non-conventional renewable energy (NCRE). It also introduces specific mechanisms through which this very ambitious objective will be achieved.

The aim of this thesis is first to describe the current situation in Chile's energy mix, the existing and planned policies and regulations promoting non-conventional renewable energy sources. Then, we analyze the impact of policies aimed at increasing the penetration of renewable energy into the grid. Furthermore we analyze the effects of increasing the share of renewable energies in the energy mix, with particular emphasis on the intermittency problem, presenting estimates of the cost of resolving the problem. The thesis concludes with the presentation of concrete proposals and the formulation of general conclusions.

ΠΕΡΙΛΗΨΗ

Η παρούσα χρονική περίοδος είναι πολύ κρίσιμη για την εξέλιξη της Χιλής, καθώς αντιμετωπίζει την τεράστια πρόκληση της δημιουργίας των κατάλληλων συνθηκών και υποδομών ώστε να περάσει στην ομάδα των αναπτυγμένων χωρών την επόμενη δεκαετία. Μία από τις μεγαλύτερες προσδοκίες της κυβέρνησής της είναι να επιταχύνει την ενσωμάτωση των μη συμβατικών ανανεώσιμων πηγών ενέργειας (NCRE- Non Conventional Renewable Energy) στο ενεργειακό μείγμα της χώρας.

Προς την κατεύθυνση αυτή, η κυβέρνηση της Χιλής έχει κάνει σημαντικά βήματα με την έκδοση το 2013 του νόμου 20.698. Ο Νόμος αυτός προσδιορίζει συγκεκριμένο και αρκετά υψηλό στόχο για το 2025, προσδιορίζοντας ότι το 20% της εμπορεύσιμης ενέργειας θα πρέπει να προέρχεται από μη συμβατικές ανανεώσιμες πηγές ενέργειας (NCRE). Επίσης εισάγει συγκεκριμένους μηχανισμούς μέσω των οποίων θα επιτευχθεί ο πολύ φιλόδοξος αυτός στόχος.

Στόχος της διπλωματικής εργασίας είναι αρχικά να περιγράψει την παρούσα κατάσταση όσον αφορά το ενεργειακό μείγμα της Χιλής, τις τρέχουσες αλλά και τις σχεδιαζόμενες πολιτικές και τους κανονισμούς προώθησης των μη συμβατικών ανανεώσιμων πηγών ενέργειας. Στη συνέχεια, πραγματοποιείται μία ανάλυση των επιπτώσεων των πολιτικών, όσον αφορά την διείσδυση των ανανεώσιμων πηγών ενέργειας στο δίκτυο. Επίσης αναλύονται οι συνέπειες της αύξησης της συμμετοχής των ανανεώσιμων πηγών ενέργειας στο ενεργειακό μείγμα, δίνοντας ιδιαίτερη έμφαση στο πρόβλημα της μη συνεχούς παραγωγής ενέργειας από ανανεώσιμες και του κόστους συμπλήρωσης των κενών από συμβατικές πηγές. Η διπλωματική ολοκληρώνεται με την διατύπωση συγκεκριμένων προτάσεων και με την διατύπωση των γενικών συμπερασμάτων.

0. Introduction

Chile is living a crucial moment in its history. It faces the enormous challenge of creating the right conditions to become a developed country in the next decade. One of the biggest expectations of the Government is to accelerate the incorporation of non-conventional renewable energy (NCRE) in the energy mix. Chile offers a compelling case for investors in the non-conventional renewable energy (NCRE) sector.

As it lacks fossil fuels, the country imports large amounts of oil and gas for electricity generation, resulting in the region's highest electricity prices. It has a friendly business environment coupled with a regulatory framework that encourages open competition. In addition, Chile has seen record economic growth in recent years, mainly driven by a voracious appetite for commodities, has translated into a deficit between energy produced and power demanded. This has further increased the need for renewable energy projects. A key juncture for Chile's energy sector came in 2008. The gas supply crisis, originating in Argentina, prompted a reassessment of the country's power infrastructure investment scheme as well as important regulatory changes to foster the diversification of the energy mix.

Key legislation enacted in April 2008 – Law N° 20,257 – aimed to promote NCRE sources, such as geothermal, wind, solar, tidal, biomass and small hydroelectric plants. Afterwards, through the National Energy Strategy 2012-2030, updated information tools will be consolidated and implemented in order to guide and facilitate private investment decisions on projects of NCRE. In 2013, Chile went forward to achieve that goal: Law 20.698 was published, an amendment to the previous law in 2008. It states that by 2025, 20% of the commercialized energy should come from non-conventional renewable sources, and introduces NCRE tender mechanisms in blocks to support the achievement of this new goal.

This thesis is divided into nine chapters. The first five chapters introduce the Chilean Energy mix as well as its policy and regulations, while the four last chapters analyze the effect of that policy in the penetration of NCRE to the grid and the consequences of that increase of NCRE to the energy mix, as well as the possible solutions. One last chapter gives some general conclusions of this study.

1. Country profile

Chile is one of the most attractive countries worldwide in terms of solar resources, with more than 2,000 kWh/m^2 and year in areas as Atacama Desert. This potential has not passed unnoticed by international PV players, who have focused their attention in this Latin American market in recent years. The PV market in Chile already reached 1GW in operation in Q1 of 2016, and there is currently an administrative boom with more than 2 GW of PV capacity in environmental processes.

Chilean government has shown a positive attitude towards renewable development in order to reduce the energy dependency of the country. The National Energy Strategy 2012-2020, published in February 2012, laid the foundations for the future development of renewable technologies in the next decade and suggested favorable incentives for PV energy. While these incentives do not come into force, the obligation of 10% of renewable generation in 2024 for large generators is one of the main driving forces of Chilean RES market. The recent approved net billing regulation will also drive a new distributed market of rooftop installations under 100 kW. Below Fig.1 shows the evolution of the cumulative electricity capacity of last years by technology, representing the projection until 2025 following the expectations established by the Chilean government on its National Energy Strategy:

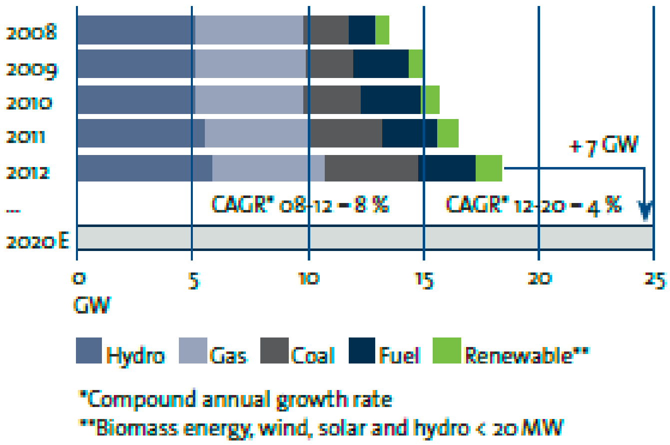

Fig. 1. Cumulative Electricity Capacity in Chile 2012 (Source: CNE, Systep, National Strategy 2012-2020)

Mining companies are playing a critical role in the development of the photovoltaic market as the main PV developers in the north of the country. It is the most important industrial sector of Chile, reaching almost the 15% of the GDP, and the biggest energy consumer (35% of the total consumed energy in Chile). New regulations make these companies sign PPA (Power Purchase Agreements) with IPP (independent Power Producers) that allow the construction of NCRE plants to supply them green energy and cover the requirements of the law. IPPs are tendering PV plants (either on-grid or off-grid installations) to international EPC constructors and they are expected to increase their renewable demands in the next years. Related to this, Fig.2 shows the evolution of the industrial energy consumption according to the main sectors in Chile:

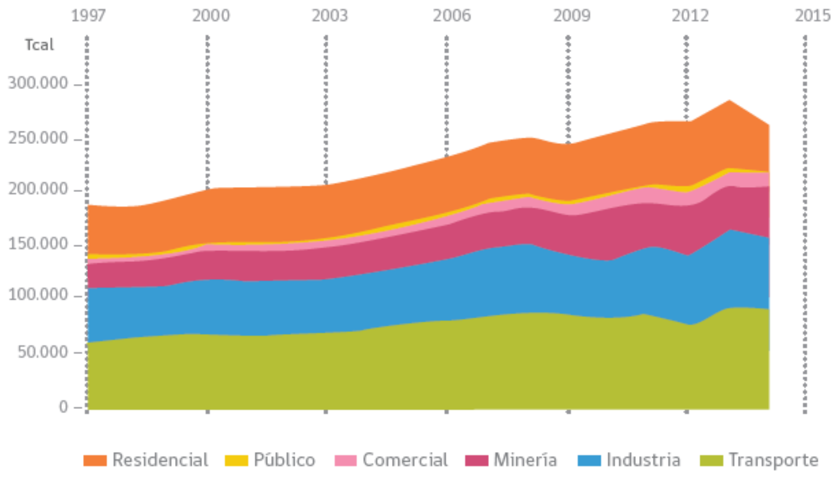

Fig. 2. Historical Consumption of Energy by Sector (Source: Balance Nacional de Energia)

Chile, as the Latin American economy with smallest corruption rates and as one of the world's ten freest economies, is called to become a natural entrance to the PV Latin American market.

With a total population of over 17 million people, Chile is located in the southwest of South America. The country is composed of 15 different regions, although 40% of total population is concentrated in the Metropolitan Region, whose capital city is Santiago de Chile. Chile is considered the most politically and socially stable country throughout Latin America. The country risk rating is similar to attractive European countries (Fitch and

Standard & Poors ratings: A+ with stable perspective) and the corruption perception index is similar to countries like the U.S. or UK.

The economic development of the country in recent years is enviable: from 2004 to 2011, Chile's GDP grew at an average annual rate of 4.8% according to the Central Bank of Chile. In 2012 the GDP growth reached 5.5 % , in 2013 reached 4 % and 5 % in 2014. In the figure below (Fig.3) it is represented the evolution of the Chilean GDP compared to the growth of the consumption of energy. Energy efficiency increases over time (energy input/GDP) which is important, probably equally so as moving to alternative sources:

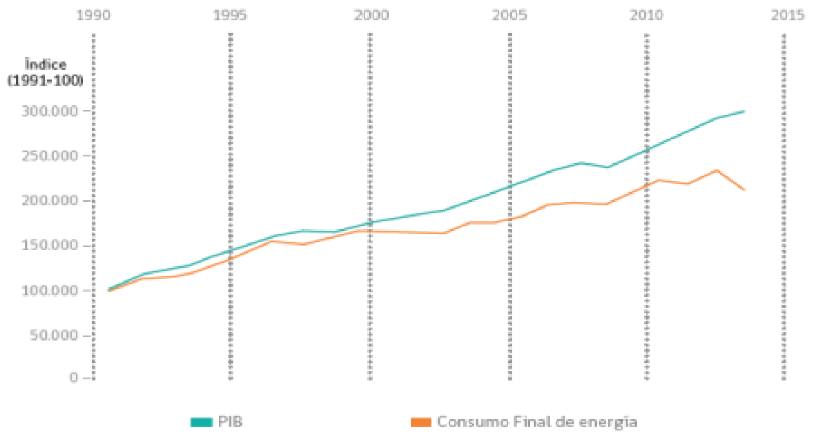

Fig. 3. Final Energy Consumption Index related to GDP (Source: World Bank, Balance Nacional de Energia)

2. Electric Market Overview

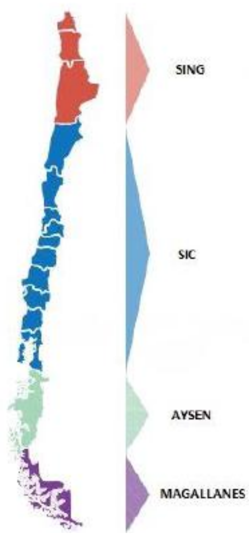

Fig.4. Chilean Electricity Grid

The remarkable economic growth is bringing a new energy situation: a lack of generation capacity. According to official sources, within the next decade electricity demand is expected to grow an annual rate of 5 – 6 %.

With an electricity market of over 18 GW of total installed generation capacity, this increase in the demand will lead to a need for approx. 8 GW of new capacity, in which renewable energies will play a major role. Congestion problems in some sections of the Chilean electricity system (especially in the central regions) could delay new energy projects. The government has already put new transmission lines out to tender but it is estimated than improvement works will take a minimum of 5 years.

The Chilean electricity market is split into 4 electric systems:

- **Central Interconnected Grid (SIC)** with over 13.5 GW of installed capacity, the system covers the central geographical part of the country; it supplies more than 90% of the country's population but less than 75% of total electricity consumption.

- **Northern Interconnected Grid (SING)** with an installed capacity of 4.5 GW approx., it serves the north part of the country (between Arica and Taltal); it supplies 5% of Chilean population and 25% of total electricity consumption (mostly, industrial demand)

- **Aysén and Magallanes Systems** they are the least important electricity markets in the country, with less than 200 MW of installed capacity

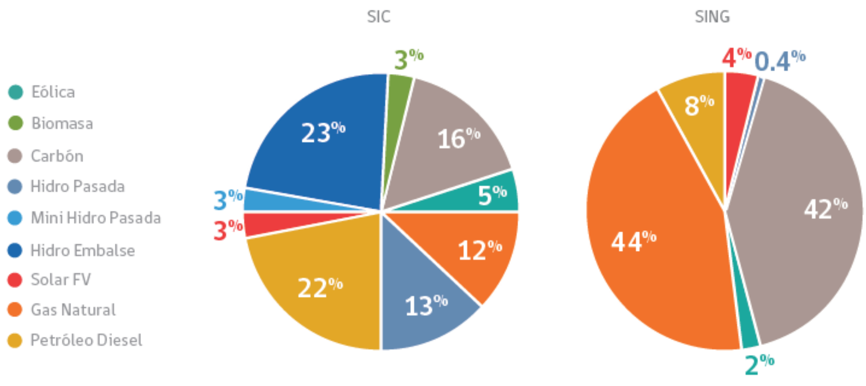

Fig. 5. Installed Energy Capacity SIC and SING 2015 (Source: Energia Abierta)

Chilean regulated electricity prices are among the highest rates of LatAm. Their values are set by governmental decree and rates can significantly vary depending on the considered area, on the utility and on the chosen tariff. In relation to generation prices (spot market), it is necessary to differentiate between the 2 main electricity markets: SIC and SING. While spot prices in the central area hovered at 14.5 cEur/kWh in 2012, in the northern area prices fluctuated around 6.6 cEur/kWh. Spot markets have shown extremely large volatility rates in the last decade, with annual differences of up to 15 cEUR/kWh.

Both SIC and SING markets present attractive conditions for PV installations, with irradiation levels between 1,300 and 2,200 kWh/m2 and year. In fact, Northern Chile is considered to have the highest solar resource in the world.

Besides big PV plants in the north of the country, there is also a growing interest for a new PV distributed market in urban areas: the new net metering regulation and the government interest could consolidate this type of market.

3. Evolution of the Energy Mix

In the last decade, society is more concerned about the environmental matter. The necessity of reducing pollution created by the generation of electricity through coal, gas and diesel (fossil fuels) plus the fact that availability and costs of fossil fuels are becoming critical matters as their use is increasing, developed other technologies with less impact to the environment. Electricity generation in Chile is produced mainly by fossil fuels (65% average of the last 4 years) while just 1% by NCRE (Non Conventional Renewable Energies) like solar and wind (CNE, 2014). Next figures represent the evolution of electricity generation the last decade in Chile (Fig. 6) and Electric Mix of Chile compared to the rest of the world (Fig.7):

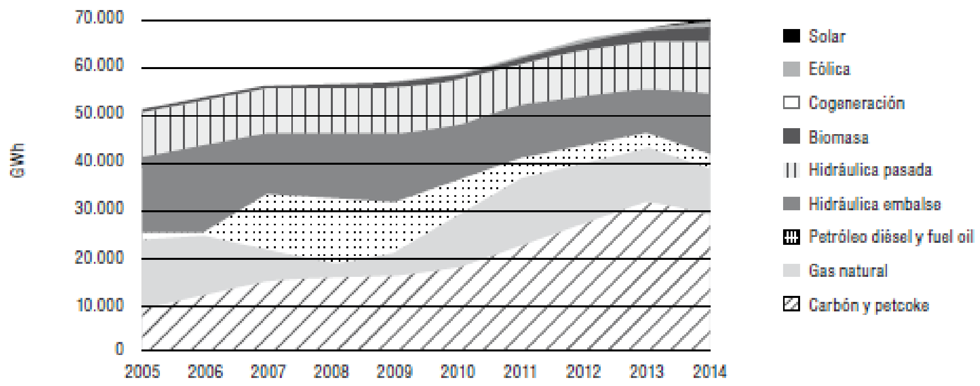

Fig. 6. Energy Evolution in Chile (Source: CNE 2014)

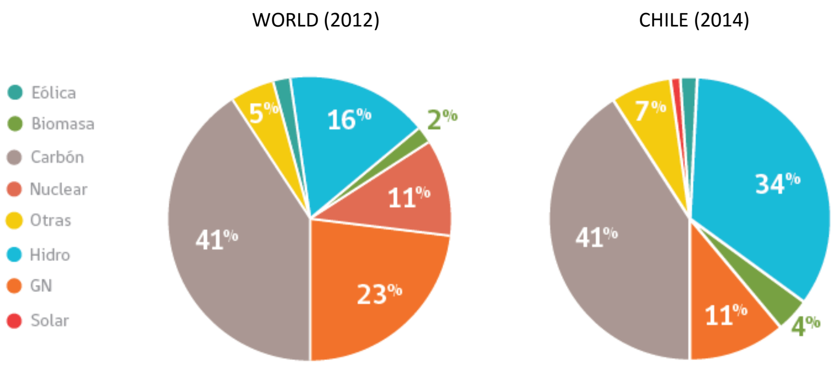

Fig. 7. Energy Mix Chile and rest of the World (Source: IEA. Ministry of Energy 2014)

4. Regulation framework

Nowadays, the main alternatives for renewable energy commercialization in Chile are the following options:

- **Participation in the energy trading spot market**

In the past years, the spot market has presented extremely high volatility which increases the risk of this commercialization option

- **Regulated tenders where renewable energy competes in equal terms with other technologies**

Currently, PV energy is not competitive in regulated tenders yet

Future specific renewable tenders (suggested in the National Energy Strategy 2012-2020) would be a great opportunity for renewable companies based in Chile

- **PPA contracts with free clients**

Large electricity consumers who perform a bilateral contract with a renewable generator (typically, mining companies in the North of the country with high needs of energy)

Although the conditions of the PPA contracts are still very tight, there are already several PV installations working under these conditions and this selling option is expected to keep on growing in attractiveness

- **Auto-consumption systems (on-grid)**

Electricity on-grid generation for auto-consumption is permitted and a net billing system is in force since 2012

Energy surpluses are valued in financial terms for later consumptions for systems under 10 kW

- **Off-grid systems**

Auto-consumption in isolated áreas

On February 2012 the Chilean government published the National Energy Strategy 2012-2020, which introduces the general guidelines which will rule the energy regulation in Chile over the next decade. This is a public document published by the Government that sets at a very high level the future backbone of the energy policy in Chile in the next decade.

Chilean government is determined to promote Non Conventional Renewable Energies (NCRE) and energy efficiency measures to cover the country needs for energy in the next years. The National Energy Strategy enumerates several measures that will positively impact on the renewable energy development and should be developed in the coming years, e.g.:

- Rising renewable generation quota to 20% of total electricity consumption in the next decade
- Developing new financing mechanisms for renewable projects
- Specific strategies for each renewable technology (individually)
- Easing grid connection processes for NCRE installations
- Supporting Chilean PV industry to become an international technological leader
- Specific regulated tenders for renewable technologies
- A net metering regulation to promote distributed generation

Since the National Energy Strategy was disclosed, some of the listed measures have been already published. Among them the new net billing system and the first renewable tenders (e.g., a new CSP tender has been announced in 2013), which will be an important push for the NRCE development.

4.1. Permit procedures

In general, land securement and grid connection procedures can delay ground-mounted installations but it is difficult to estimate the usual length of the permit process because of the scarcity of operating installations in the market. The following information can be extracted from official sources as indicative of the procedure implications:

Environmental procedures

An Environmental Impact Assessment (EIA) is compulsory in any PV project (isolated or grid-connected) with any of the following characteristics:

- Installations over 3MW
- High voltage transmission grids or electrical substations
- Any construction in special protection areas. Official periods for this administrative requirement vary between 90 and 210 days, but most PV players in the market alert about the usual delays which can extend the procedure to almost 1 year.

Land securement

In Chile there are many ways of securing land for the execution of a NCRE Project. In the case of a PV project, the State of Chile, through the Ministry of National Assets has assured a number of developers the possibility to exploit lands owned by the state through lease and gratuitous bailment, when such developers fulfill certain requirements (solvency, technical capacity to carry out the project, insurance, achieving financing, feasibility studies, among others).

If the Ministry of National Assets grants the tenancy of the land it owns for the development of PV projects, such land cannot be expropriated by the State nor assigned to a third party, which gives the developer sufficient security under this point of view.

Another form of securing land is through an enforceable promise to purchase agreement of the property where the project will be located. In this case, the execution of the sale purchase agreement will be subject to the condition that certain requirements are fulfilled (mainly technical). Therefore, if the project is declared unfeasible or if it does not comply with the necessary technical requirements, the share purchase agreement of the property will not be entered into. However, as long as the enforceable promise to purchase agreement is effective, the owner cannot sell or encumber the property.

Lastly, in all NCRE projects it is highly recommended to constitute mining rights in the areas and surrounding areas where the project will be located. The purpose of the foregoing is to prevent third parties from exploiting minerals in such land. It also serves the purpose of preventing speculation from third parties who constitute such rights in order to obtain an economic benefit from the developers of the project who may see their project suspended due to the constitution of such rights.

Grid connection

There are 2 different procedures depending on the characteristics of the project:

- PV projects connected in distribution subsystem level: from 75 to 125 days of administrative process, according to official sources
- PV projects connected in transmission subsystem level: around 6 months

4.2. Main Energy laws

Meanwhile the measures presented in the National Energy Strategy are not passed, the main regulations affecting the development of the PV energy in Chile are the following:

Law 19.940 / 2004. First renewable incentives

- It introduces modifications to the General Energy Law in order to regulate the transmission grid development and to incentivize renewable generation
- It permits selling renewable energy in the spot market to any generator
- Generators under 9 MW are able to sell energy with stabilized prices

- Renewable installations under 20 MW does not have to pay transmission fees (totally or partially)

Law 20.018 / 2005. Long term contracts

- Distribution companies are able to tender long term contracts with stable prices (not adjusted to the “node price”)

Law 20.257 / 2008. Renewable quotas

- Large electricity generators over 200 MW must prove that a 5 % of its annual traded electricity (in any of the electric systems they operate) comes from renewable sources
- In 2014 the obligation increases gradually from 5 % to 10 % in 2024
- Economic penalties for non-compliance are set (26.17 EUR/MWh in the first 3 years; 39.26 EUR/MWh onwards)
- Utilities can produce their own renewable energy or buy it from other energy companies.

Law 20.571 / 2012. Net billing scheme

- Electricity surpluses from PV installations < 100 kW are valued in financial terms and can be used for later electricity consumption

5. Analysis of the Effect of the Energy Policy on the Production from NCRE

Unlike conventional technologies (such as coal, gas, diesel and hydropower), generating through ERNCI is characterized by being variable and strongly dependent on the daily weather conditions, for this reason they cannot supply electricity continuously, and they need to be complemented by other technologies. Nonstop research on technologies of non conventional renewable energies is essential to achieve the development of them and thus ensure competitive prices compared to conventional alternatives (based on fossil fuels and large-scale hydropower).

The learning curve in technologies' development requires significant time, often decades, which makes the initial costs to be quite high, but as long as technology advances, these costs tend to be gradually lower. That is why policies to promote NCRE were absolutely necessary in order to make them progress. The type of strategy has been different around the world, but the most common mechanisms are: subsidy (or preferential loans) for investment, subsidies and tariff quota system for Renewable (RTQS). The first two were widely used in Europe, allowing the massification of photovoltaic and wind in the first decade of the century, but with a high cost.

In Chile they chose to use a Renewable Quota System (RQS), which was done through the Law 20.2573, promulgated by 2008, which established to move gradually up to 10% of generation through Non Conventional Renewable Energies (NCRE) by 2024, starting from 5% in 2010. This policy was well evaluated, which led to the Law 20.6984, that modifies the target of Law 20,257, raising it to 20% of generation through NCRE by 2015.

Consequently wind and solar generation in Chile reached about 2.2% in 2014 compared to 0.8% in 2013 and 0% in 2008. These laws promoted NCRE's experience in Chile, fact that will reduce pollution and dependence on fossil fuels in the future. However, possible negative consequences should be considered, and mainly the impact of the intermittency of the generation through some NCRE. Intermittency means that certain electricity generating plants cannot control when to operate, due to the fact that they work when the resource is available. This occurs for technologies based on renewable resources, being more critical for solar and wind technologies as its intermittency is higher and varies a lot during the day.

New NCRE Law

Chile followed the international trend by adopting policies to promote Non Conventional Renewable Energy (NCRE). In 2008, the National Congress approved the Law 20.2575 that obliged companies to consume 10% of NCRE by 2024. This applies to all electric system with more than 200 MW total power , so far, in the Central Interconnected System (SIC) and the Great Northern Interconnected System (SING). The law considers NCRE all the power plants with renewable generation such as geothermal, wind, solar, biomass, tidal, minihydro, cogeneration and some other established by the National Energy Commission (CNE).

The law allows companies to track their renewable energy surplus through a system of tradable energy certificates (TREC). They can use certificates produced one year before to meet the targets established by Law 20.257. In addition, companies that do not prove compliance, must pay a fee of 0.4 UTM per MWh. If companies do not comply again within the three next years, the fine rises up to 0.6 UTM per MWh (Law 20.257).

In 2013, the Law 20.6988 made some amendments to the Law 20,257, setting a target of 20% by 2025. Figure 8 represents the compliance chart for contracts made between August 31st 2007 and June 30th 2013, together with the targets established to contracts from July 1st 2013. Thus, old contracts will have to meet a target of 10% by 2025, while new contracts will have a 20% mixed target.

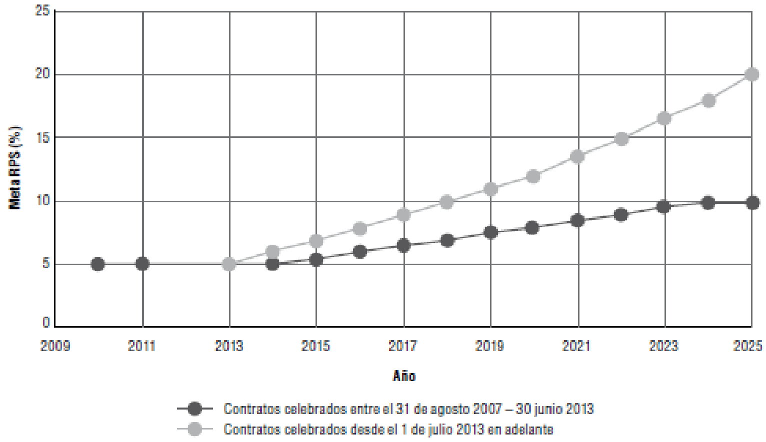

Fig. 8. NCRE Target Law (%) towards year. Control of old and new contracts (Source: Law 20.257 and 20.698)

This law is very relevant for the national energy planning, as clear targets are set grow gradually, applying just to new contracts. The main strengths of this national policy, unlike tariff subsidies policies to NCRE (highly criticized because of the high social costs involved), are the following:

- "Escaping way": the strategy establishes a way to escape through non compliance fines, which controls an eventual over-cost associated to this policy.

- No tax expense: the state does not generate long-term commitments to finance projects economically unfeasible, as it could happen if there is a subsidy. Projects are presented by private companies (with an expected acceptable return) and the energy generated is bought by consumers who are willing to pay that price. The law encourages NCRE contracts. This reduces the risk of investing in these technologies, which facilitates financing and thus lower costs of capital in such projects.
- Graduality: the law sets targets that grow slowly and do not affect contracts prior to the promulgation of the law. If there are high costs in NCRE technologies, electricity costs would increase gradually, while otherwise, implementation could exceed the required targets. The law gives time to NCRE technologies to progress, setting targets as it is expected to improve and get more competitive.
- Diversity of alternatives: the law establishes a broad set of technologies qualified to meet this target, not limited to a restrictive category, as photovoltaic and wind could be. Thus private can invest based only on the minimum cost. This makes any NCRE system to have an accelerated cost reduction.

All these advantages led to a faster penetration of NCRE. Analyzing the Central Interconnected System (SIC) and the Great Northern Interconnected System (SING), 5.85% of the total power generation came from NCRE on 2013 (Centre of Renewable Energy (CER), 2014), much more than the established by law, which requires 5% between 2010 and 2014. On 2014, after the amendment of the law, this effect increased even more. On 2014, the share of NCRE reached 7.9% of the total energy mix (CNE, 2014).

Despite the big benefits of the law that promotes NCREs, there are risks in the medium term regarding the proper operation of the electric systems. This is due to the increased generation from intermittent technologies, intermittent non conventional renewable energies (INCRE), mainly photovoltaic and wind technologies. These risks are a challenge worldwide that must be resolved to enable a better integration of the different technologies to the electric systems.

6. NCRE Project finance. Viability of Investment in PV

In Chile most of NCRE developers operate through project finance, by which banks loan funds based on the future estimated cash flows of a project. For granting project finance, the Chilean banking sector usually requires the existence of a Power Purchase Agreement (PPA).

This financing system has been applied only recently in Chile and is in the process of development. In any case, there is no doubt it is feasible to carry out a large portion of these projects, by convincing the banks through a PPA or participating in the spot market. In order to enable the financing of the projects, what ultimately matters is to eliminate or mitigate the different risks involved.

Another requirement is to have knowledge of the prices that shall apply throughout the whole period in which the loan is repaid. Therefore, it is necessary to have long term sale energy sales with low risk. In Chile these can be entered into with power distribution companies or others such as mining companies.

The financing of these projects is usually on a long term basis for 10 to 15 years, in which 50% up to 85% of the total investment is financed. The leading banks in domestic project financing of this sort are Banco Bice and Banco Security.

There are exceptions that show certain flexibility in project financing that has taken place recently in Chile. For instance, a Spanish firm is evaluating taking an insurance policy that would be activated in case the cash flow of the PV project is not able to repay the bank loan. Therefore, if this option were to be taken (unprecedented in Chile) a PPA contract would not be necessary in order to obtain funding. Nevertheless, the foregoing case does not constitute the general rule in which the access to financing still continues to be an obstacle for the development of NCRE Projects in Chile.

An alternative to obtaining financing with domestic banks is through foreign banks that are increasingly supporting the development of local NCRE projects, usually multilateral development institutions. An example of this is The International Finance Corporation (IFC), a branch of the World Bank that supports the development of industries in developing markets. In Chile, this entity participated in the financing of the Totoral (46MW) and La Higuera (155 MW) wind parks and La Confluencia (155 MW) and Lircay (20 MW) hydroelectric plants.

Another important source of funding that is emerging in Chile is through a program called Innovation in Alternative Renewable Energies of the Chilean Economic Development Agency (CORFO) and the Ministry of Energy that encourages companies to switch to alternative energy sources. This program funds up to 50% of the total cost of the projects (up to US$10.5 million). This method requires the companies applying for the funding to be associated with at least one entity that will be the end user of the energy. CORFO also offers long term credit for financing NCRE projects with considerate grace periods for repayment as well as providing subsidies for design and assessment studies.

Finally, PV projects that are already constructed were mostly financed via equity and bank indebtedness with an average interest rate over 11% (Banco Central de Chile). Consuming finance was also requested for smaller installations, although it was not the usual way of funding. In the last 5 years, consuming finance in Chile presented an average interest rate of 25% approx.

Viability of investment in PV

Chile is considered one of the most transparent countries worldwide. In Transparency International's 2011 Corruption Perceptions Index, Chile ranked among the 25 best-placed economies out of the 183 countries. This position has permitted Chile to lead Latin America and enjoy the transparency standards of a developed country.

According to the Business Environment Rankings of the Economist Intelligence Unit (EIU), Chile is the most attractive country in Latin American in which to do business between 2010 and 2014, and one of the 20 best countries all over the world. The International Finance Corporation (World Bank Group) also publishes every year their own report with a similar ranking in which Chile is the 37th country of the list (out of 185). This means an improvement of two positions compared to 2012 ranking and a significant advantage over other countries as Spain (44th), Colombia (45th), Mexico (48th), Italy (73th) or China (91th).

Chile also presents a high level of free trade according to international renowned sources. The Index of Economic Freedom 2012, published by the Heritage Foundation and the Wall Street Journal, scores Chile among the world's ten freest economies, ahead of all other Latin American countries. Chile presents a total of 22 trade agreements, which cover 59 countries. This represents over 4,302 million potential consumers around the world and it has helped Chile to consolidate as the Latin America's most competitive economy.

In general, PV industry perceives that Chilean companies and authorities support foreign players entering the country as an efficient and fast way to develop and consolidate a local market. Experts also consider that a foreign company that wants to succeed in this Latin American market must have local presence in the country (e.g., with an office or at least representative agents). Many PPA contracts or public tenders even require that the applicant company is formally based in Chile.

7. Problem of the Intermittency of the NCRE (Wind and PV)

Significant environmental benefits related to the INCRE generation can be identified. However, due to the great uncertainty and variability in the availability of such resources, it is big challenge their integration into the electric system. Variability and uncertainty are two very important concepts in relation to renewable energy generation. Variability refers to the unstable behavior of a phenomenon due to the change in a condition. For instance, the generation of photovoltaic energy varies between day and night. Uncertainty refers to a phenomenon difficult to predict with accuracy, and therefore, its behavior for a specific event cannot be predicted. For instance, wind power generation is defined as uncertain since it depends on wind's speed, which cannot be accurately characterized. Therefore, there is a limit on the maximum generation of plants INCRE that changes over time (variability), and that limit cannot be predicted with perfect accuracy (uncertainty). All kinds of plants are subject to variability (stop for a scheduled maintenance) and uncertainty (stop because of a system's failure), but the magnitude of these phenomena differ. Unlike conventional technologies (such as coal, gas, diesel and hydropower), the INCRE generation is characterized by its variability and dependency on weather conditions. For instance, the prediction of solar photovoltaic generation in northern Chile has less uncertainty than wind generation, because solar radiation can be predicted in much better than the wind. That is why wind energy is known as the energy source with greater uncertainty.

As INCRE technologies achieve higher levels of penetration, the relative inherent intermittency can be very important, affecting the management of the electric system. Intermittency could make not cover the electric system's demand. That fact makes INCRE technologies depend on the storage capacity and the way of operation of each system. This implies the need of keeping a balance between electric generation and demand. A good management of the system is needed to anticipate an eventual problem

7.1. Load Plant Factor Analysis. Data Analysis.

Before proceeding it shall be remarked that load plant factor is the energy produced by a plant divided into its maximum capacity, which means the proportion of time that the plant is operating:

Load Plant Factor = Generated Energy / Maximum Generation Capacity

This section Analyzes INCRE in the Chilean electricity system. Wind and Solar plants that went into operation until September 2014 in the SIC were Studied (14 wind farms and 10 Solar plants). Table 1 shows the average plant factor of each generating plants INCRE in the period between their connection to the SIC and September 2014.The weighted average plant factor of SIC between January 2011 and September 2014 is 0.22 for wind plants and 0.20 for for the solar power plants. The wind farm with higher average plant factor for the period under study corresponds to San Pedro, 40%, while Punta Colorada has the lowest value, 8%.

Type of plant	Region	Name	Study Period Start	Average Plant Factor
Wind	Coquimbo	Canela 1	January 2011	0.16
		Canela 2	January 2011	0.22
		Monte Redondo	April 2011	0.26
		Punta colorada	November 2011	0.08
		Talinay	March 2013	0.27
		Totoral	January 2011	0.20
		El Arrayan	April 2014	0.22
	O'Higgins	Ucuquer	March 2013	0.29
	Bio Bio	Cristoro Lebu	January 2011	0.28
		Negrete	December 2013	0.29
	Los Lagos	San Pedro	April 2014	0.40
Solar	Antofagasta	Santa Cecilia	April 2014	0.20
	Atacama	Diego de Almagro	May 2014	0.10
		Llano de Llampos	January 2014	0.25
		Salvador RTS	January 2014	0.24
		Solar San Andres	February 2014	0.22
	Coquimbo	Lomas Coloradas	July 2014	0.19
		PSF Pama	July 2014	0.18
		SDGx01	October 2013	0.06
		Tambo Real	December 2012	0.08
	Metropolitana	Techos Altamira	April 2014	0.01

Table 1. Plant factors in Chile, Wind and Solar (Source: CDEC-SIC, 2014)

This means that there is a significant variability of the resource depending on the location, where a plant is producing electricity for 40% maximum, while another plant is only producing 8% of the hours of the year. Analyzing solar plants, the one with higher plant factor average corresponds to Llano de Llampos, with 25%, while the lower factor corresponds to Techos de Altamira, with 1%. This is due to the location in Santiago, and only the generation of autumn-winter months was analyzed (April-September 2014). In 2011, SIC had an installed capacity INCRE of about 130 MW, increasing to 991 MW by the end of 2014, representing an increase of 662%.

Figure 9 shows the evolution of INCRE generation in the SIC as a percentage of total generation. We can see that the INCRE generation in SIC increases from 0.01% in 2007 to 2.3% in 2014. The increase is quite affected by the laws promoting NCREs. Although Law 20.257 was in effect from 2010, it is a notable increase in INCRE generation from 2008 (when the law was promulgated). It is clear that energy producers start getting ready to the expected new regulation by increasing INCRE generation. Until 2010, generation through INCRE increases significantly, but then kept stable until the promulgation of Law 20,698. After that moment it increases again in 2013 and 2014. Therefore, NCRE producers do trust the authorities and fully integrate into their decisions the forthcoming legislation.

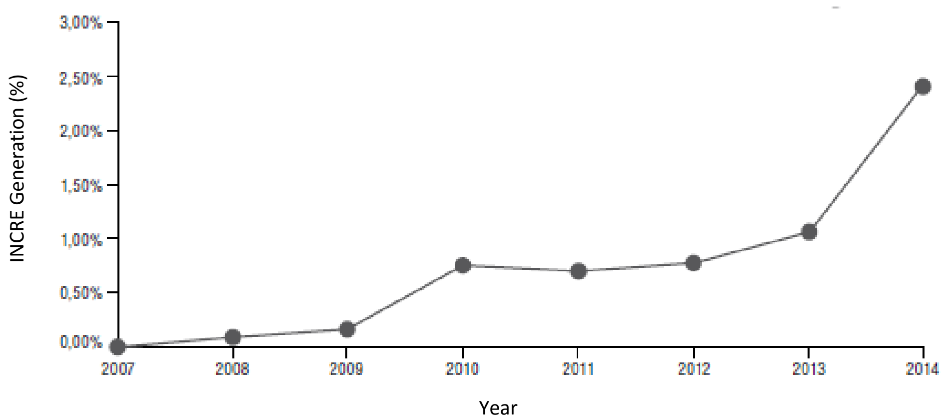

Fig. 9. Evolution (%) of INCRE generation in SIC, Interconnected Central System of Chile (Source: CDEC-SIC, 2014)

Table 2 shows the need of backup to INCRE in the SIC. The data in Table 2 presents the necessary support to ensure that supply meets the needs of aggregate demand for electricity. We can see that the necessary support tends to increase significantly over time. This is mainly because the installed capacity of the system has been increasing over time, so even though the diversification of central INCRE can partly compensate their generations, the need of backup will grow.

Year	Backup need (MWh)
2011	88
2012	78
2013	113
2014	230

Table 2. Plant factors of Wind plants in Chile (Source: CDEC-SIC, 2014)

7.2. Impact of the intermittency in the Electric System

This section analyzes the impact on costs and increasing probability failure of the electric system that can cause the intermittency of solar and wind generation.

Impact on system costs Increased penetration of INCRE implies the need to increase the availability of plants that can produce energy constantly and thus, have backup power when renewable power plants are not available. The increase of wind and solar participation makes conventional power plants to operate at lower production levels or to have electricity storage systems to allow entry of the INCRE. Thus, it is essential to study the different alternatives of support to reduce the economic impact of a higher penetration of renewable energy.

Increasing INCRE also implies the need to increase the capacity of the transmission system. This is because higher electricity flows are needed to be transported to the possible lack of energy caused by the uncertain availability of intermittent generators.

Regarding the distribution, significant investments in information technologies are needed in order to manage the interaction between flows and variability in demand, to optimize the daily operation of the electrical system. This could be solved partly with investments in infrastructure smart meters. Usually synchronization systems is done via global positioning systems (GPS) in order to obtain accurate data for the grid management.

Increase of system failure probability Any electrical system has some capacity to respond to contingencies, which depends on the storage capacity and the way that the system operates. However, generally speaking, the more INCRE are installed the higher probability of system failure is (if needed measures are not taken). This is because the fact of having a higher number of intermittent power stations makes more difficult the balance between electricity produced and consumed. Small deviations in the perfect balance can cause variations in the frequency of AC electricity, which affects the system stability.

7.3. Solutions for Wind and Solar. Cost Analysis

Failures in the system can be produced if there are no backup storage systems that offer immediate energy availability for any contingency and for transmission and distribution systems that are capable to support problems related to intermittency.

Backup Alternatives Mainly backup energy storage systems and central backup that can inject electricity to system contingencies. It should be differentiated photovoltaic generation solutions (oscillating generation, but predictable and gradual variations), than from wind generation solutions that are more limited (very unpredictable and sudden variations). Any technology that supports wind generation can also support photovoltaic systems, but not vice versa.

Power backup Technologies generation from natural gas and diesel can be used to support the intermittency of generation INCRE, because these technologies allow a rapid response to contingencies, which could be useful to offset the unpredictable swings of wind generation. Diesel plants may have a rapid response in any condition, but they have a large operating cost. On the other hand, natural gas plants need to operate at low or medium capacity to have a quick response. The higher level of renewable penetration, the more backup is needed.

The current regulation that promotes a high penetration of INCRE, diesel plants will be the ones to provide backup service, increasing the marginal cost of generation of the entire system. This is the worst scenario for electricity consumers because it causes an important increase in final energy prices. With regard to solar photovoltaic generation, since it can be known with quite precision how much energy will be generated the next day at any time, it is possible to backup this technology with other traditional alternatives with no fast response, such as coal-fired or hydroelectric generation.

Table 3 shows an estimation of the indicative Leveled Costs of Energy (LCOE) and the parameters used for their calculation. This was done for traditional technologies when operating as a backup:

	Coal	Natuaral Gas in Comb Cycle (NG CC)	Diesel	Dam Hydro
Scenario for the cost analysis				
A- Main Investment (USD/MW)	2.300.000	800.000	500.000	3.000.000
B- Operation cost (USD/MWh)	40	70	250	5
C- Life cycle (Years)**	40	20	20	40
D- Original Plant Factor	90%	90%	90%	70%
E- Backup Plant Factor	78%	74%	70%	70%
*Indicative Leveled Costs {A/(C*D)} + B or {A/(C*E)} + B				
Original LCOE (USD/MWh)	47	75	253	17
Backup LCOE (USD/MWh)	49	76	254	17

* For the real LCOE more parameters are involved
** Life cycle shall be used in hours for the calculation

Table 3. Backup Technologies costs (Source: Estimated scenario)

Based on the parameters above (main investment, operation cost, life cycle and plant factor) it is possible to calculate an indicative leveled cost of electricity (LCOE). This indicator shows how much the average selling price of electricity produced should be for a certain technology to cover all costs related to production, including the investment payment. The investment is very sensitive to the proportion of time that the plant operates (capacity factor). This is due to the fact that if a plant operates 80% of the hours of the year, instead of 40%, the cost of investment per MWh produced decreases by 50%. As shown, the increase in costs for the various traditional technologies operating as a backup is not very significant (between 0% and 4.2% - in the case of Dam Hydro there is no difference between Original and Backup LCOE, while in the case of Coal there are 2 USD/MWh difference between Original and Backup LCOE). Due to the development of technology, other support mechanisms have been created based primarily on the concept of energy storage.

Energy storage technologies Storage systems get electricity from the grid when there is electricity surplus and low costs for delivering it when there is a shortage and high costs. Electricity's marginal costs are calculated hour by hour for each system and show the energy shortage at every moment. Ideally we would like to maintain low average marginal costs, since that means a reliable energy system. Analyzing the example of SING on 2013, the difference between marginal costs in the first quintile (20% of hours with the lowest marginal cost) and the fifth one (20% of hours with the higher marginal cost) of the year, it was bigger than 300%. Energy storage systems can take advantage of these important differences in electricity costs. Currently, dam pumping water mechanism (PHS) and energy storage through compressed air (CAES) are the only two large-scale backup power systems commercially available.

The *PHS mechanism* has two water reservoirs at different heights. Water is pumped from the lower to the upper reservoir when marginal costs are low and in periods of high marginal cost electricity is generated. This technique, despite having significant losses in terms of energy (efficiency is between 65% and 80%), it is often economically efficient, since the marginal cost differences within a day have high variations. The capacity of the system depends on the volume and height of the falling water. This technology is already well established with more than 129 GW in operation worldwide, which represents the 99% of the worldwide installed capacity of energy storage systems. It is considered a mature technology with high energy storage capacity and with long cycle life, large-scale low-cost, high efficiency and low level of losses, in first instance quite adequate as backup system for INCRE. However, they have limitations due to the specific geographical conditions are needed to be installed. Besides this technology is recommended for the implementation of hybrid systems, where INCRE generates energy only to store and the reservoir injects energy into the grid. This is due to the fact that they cannot have an immediate answer to cover energy lacks because of the unexpected fluctuations of wind generation. The main disadvantages of this technology are long construction time and large capital investment.

Energy storage through compressed air (CAES) is quite similar to the water reservoir system in terms of applications and storage capacity. When electricity has low marginal costs, the air is compressed and stored under pressure, in order to be released when marginal costs are high, activating a turbine of power generation. Currently there are two operating plants of this type in Germany and the United States, but still with low efficiencies (between 40% and 50%). If we consider this option to backup INCRE, there are similar advantages to PHS, having a large energy storage capacity, large-scale low-cost and long life. Likewise, it requires special sites such as wells, high capital investment, gas as an input and a long construction time.

Another storage system consists of *flywheels*, which store kinetic energy through the rotation of a mass with low friction losses. A motor-generator accelerates the mass and gets kinetic energy. Flywheels are a type of technology with rapid response and efficiency between 70% and 80%. Flywheels are characterized by having high power density, high efficiency, low limitations to their location and low maintenance costs, but at the same time they have low energy density, high cost per KWh and large losses. However, currently these systems have a short duration and are not attractive to backup the grid in large-scale terms. Flywheels are mainly used to respond to rapid fluctuations in wind generation.

Another backup system is *energy storage via batteries*, which provides a rapid response to adapt the system to changes in demand. It has no limitation regarding its location and it has a high energy density and capacity (high ratio energy storage per physical space). The main technology is sodium sulphide (NaS) batteries. They are used to support the distribution network and the integration of wind energy. Currently there are 316 MW NaS battery installations worldwide, which means 1896 MWh generation. There are other types of batteries such as lead-acid (acid-Pb), lithium ion (Li-ion), vanadium redox (VRB), zinc bromine (Zn-Br), zinc air (Zn-Air), sodium nickel chloride (NaNICl2) chromium and iron (Fe-Cr). The main barriers to use batteries for INCRE integration are the high cost, low efficiency of some solutions, the toxic metals of some batteries and the limited life cycle. Flow batteries such as VRB and Zn-Br can play an important role in the future for large scale applications.

In order to compare economically storage technologies, it can be used the level of stored energy cost, which corresponds to the calculation of a constant cost per generation unit. This value corresponds to the cost associated to each produced MWh due to investment costs, operation and maintenance. Table 4 summarizes the worldwide leveled costs related to each of these technologies.

Technology	Leveled costs ($/MWh)
PHS	160 - 220
CAES	120 - 210
Flywheels	385
NaS	259 - 294
Acid-Pb	320 - 1380
Li-ion	680 - 1150
VRB	420 - 805
Zn-Br	195 - 880
Zn-Air	160 - 200
$NaNiCl_2$	310 - 905
Fe-Cr	65 - 248

Table 4. Leveled Costs of Storage Technologies (Source: Akhil, 2013)

Analysis of technologies to compare technologies, it is necessary to check their impact on the leveled costs of INCRE. Backup systems shall be distinguished whether they are for wind or solar farms. The investment required for the INCRE plants, the original plant factor (% of hours per year that the plant operates without support) and the plant factor with backup (% of hours per year the plant can operate with backup) are needed for the following analysis:

Scenario	Wind Plant	Solar Plant
Original Plant	30%	30%
Backup Plant	Min. 65%	Min. 65%
Investment	2.200 $/kW	1.800 $/kW

Table 5. Data of Wind and Solar plants to backup (Source: Estimated Scenario)

Considering the target of 100GWh from INCRE, technical parameters of the backup systems are needed:

- Backup Efficiency: percentage of the total available energy used for storage.
- INCRE MW to install: number of INCRE MW to install to produce 100GWh.
- Backup MW: number of backup MW to install, to meet the minimum plant factor required.
- Storage MWh: MWh that energy storage systems are able to save.
- % INCRE: percentage of electricity supplied by the supported system that comes from INCRE.
- Plant Factor: hybrid backup system plant factor, the proportion of hours per year that the system can deliver energy.

Table 6 shows the parameters for different hybrid backup systems. Figure 10 shows the leveled costs of the electricity produced by the different hybrid systems.

Backup Technology	Backup Efficiency	INCRE MW to install	Backup MW	Storage MWh	% NCRE System	Plant Factor System
Coal	100%	38	63	N/A	19%	71%
NG CC	100%	38	48	N/A	24%	68%
Diesel	100%	38	38	N/A	30%	65%
Dam Hydr	100%	38	42	N/A	28%	65%
PHS	77%	49	N/A	10.9	100%	65%
CAES	50%	76	N/A	16.8	100%	65%
Flywheels	92%	41	N/A	9.1	100%	65%
NaS	88%	43	N/A	9.5	100%	65%

Table 6. Parameters of different backup hybrid systems (Source: Different sources)

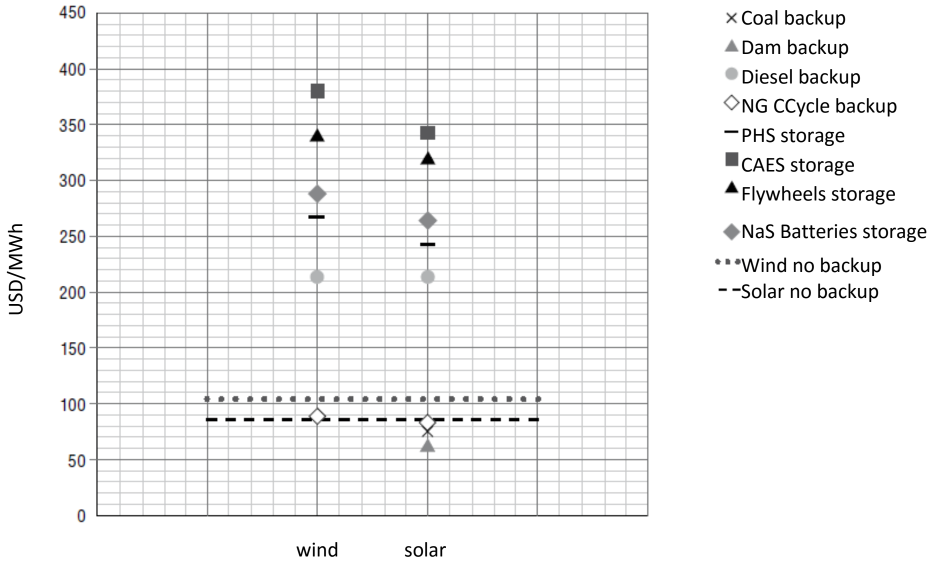

Fig. 10. Backup systems costs (Source: Different sources)

According to the Figure 10, the only technology that maintains and even lowers leveled costs in relation to 100% wind generation system is NG CC (Natural Gas Combined Cycle), the other options would imply at least double cost of energy. Regarding solar photovoltaic generation there are three alternatives that maintain or reduce costs in relation to 100% solar generation systems, since its oscillations can be predictable. It can be supported whether by NG CC, dam reservoir or coal. The most expected impact on system costs related to high penetrations of INCRE corresponds mainly to the diesel backup system. This implies an increase to the double of the leveled cost. It can be also observed that, currently, all storage systems are rather expensive than backup diesel costs. Thus, while there is no technological innovation, the use of storage systems to backup INCRE is not expected as long as their technology does not get developed. On the other hand, traditional backup systems except diesel, maintain or reduce costs compared to technology with no backup, which make them a preferable option.

8. Forecast. General goals and objectives

The main objectives set for the development of the NCRE in Chile are the following:

- Reduce the marginal costs of electricity during the current period of government by 30% in the Central Interconnected System (SIC), reduce the average marginal cost of electricity from 151.36 USD/MWh in 2013 to less than 105.96 USD/MWh by 2017.
- Reduce by 25% the price of the bids for electricity supply in the next decade, for homes, stores and small businesses from the prices offered in the last auction of the year 2013 (which were 128.2 USD/MWh). For this, it is necessary to develop hydroelectric and thermoelectric projects in the work plan of the National Energy Commission (CNE).
- Remove the barriers to Non-Conventional Renewable Energy (ERNC) in the country, and ensure that 45% of new electricity generation capacity to be installed in the country between 2014 and 2025 will come from renewable energy sources. In this way the goal of a 20% ERNC injection in the electric grid by 2025 can be achieved according to the current law.
- To promote the efficient use of energy as an energy resource, setting a goal of saving 20% by 2025, considering the expected growth in energy consumption in the country by then. The implementation of the Agenda for Energy Efficiency (EE) will allow Chile to save a total of 20,000 GWh / year by 2015, equivalent to an installed capacity of 2,000 MW coal-fired capacity.
- Design a system of price stabilization for fuels and effectively reduce the volatility of fuel prices at which households are exposed.
- Transform ENAP (National Oil Company) into a robust and strong company with a leading role in the country's energy challenges. To that end, a corporate governance regime will be provided to improve its corporate governance, focusing on safety indexes at work, efficiency, productivity, new ventures and business models. ENAP will be strengthened with a capital contribution (US$400 million).

- Develop a long term Energy Policy in 2015 validated by Chilean society through a participatory and regional process.

9. Conclusions

It is expected that the penetration of NCRE to the energy mix of Chile will continue increasing in the coming years following the Law 20.257. Within the next decade, mainly wind and solar will get more importance among all NCRE, since their leveled costs have been reduced significantly and there is a high availability of these resources in Chile. A big participation of INCRE within the electrical grid can considerably increase the risk of system failure if redundancy (backup) of the system is not likewise increased. Therefore, considering the current incentives, the technology used to support the system will be mostly diesel engines. That will mean an increase of marginal costs and an increase in the number of contracts signed in national electrical systems.

The support of INCRE at a minimum cost is possible. As far as solar photovoltaic energy generation concerns, through hydroelectricity dam, coal plants and natural gas combined cycle plants (NG CC). As far as wind energy generation concerns, the only alternative at reasonable costs is the natural gas combined-cycle plant. To promote the use of these technologies there should be an incentive to the backup service. It seems that the most efficient alternative is the implementation of a Additional Services market where backup system requirements are established as a whole and set the regulations that allow consumers and/or generators to get enough backup levels for the system, minimizing the average cost of the whole system.

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