Integrated
Environmental
Strategies

Methodology for Determining the Impacts of the Introduction of Non-conventional Renewable Energies into the Chilean Electric System

O'Ryan and Febré Ingenieros Consultores

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Project "Technical Support to IES Program in Chile"

Report Nº1

"Methodology for Determining the Impacts of the Introduction of Non-conventional Renewable Energies into the Chilean Electric System"

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The project entitled "Technical Support to IES Program in Chile" (contract AEK-5-55035-01**)** is the second phase of the Chile Integrated Environmental Strategies (IES) program of the US Environmental Protection Agency (USEPA), and is being undertaken by O'Ryan and Febré Ingenieros Consultores, USEPA and NREL. The objective of this phase is to assist the Chilean government with further developing clean energy strategies. The work is being carried out by Professor Raúl 0'Ryan as head of the project.

This work is in support of the IES program which is managed by the National Renewable Energy Laboratory and is implemented in 8 countries in Latin America and Asia. The main goal of the IES program is to provide assistance to developing countries to identify and implement harmonized technology and policy measures to achieve local public health, economic, and environmental objectives in addition to significant greenhouse gas (GHG) reductions. In pursuing this objective, IES builds support and in-country capacity for analysis and quantification of multiple benefits from integrated environmental policies.

This work also builds on previously completed work and results generated by the IES team in Chile. The goal of this new project is to assist the Chilean government with further developing clean energy strategies.

This report **"**Methodology for Determining the Impacts of the Introduction of Non-conventional Renewable Energies into the Chilean Electric System" corresponds to the first of four reports considered in the project. This first report presents the Chilean electric system and describes the general methodology for evaluating costs and benefits associated to security of supply, and environmental impacts.

Outline

1. Introduction

Natural Gas is used to generate an important fraction of Chile's electric power. Argentina, the main natural gas supplier for Chile has severely restricted this input supply during 2004 and 2005 and has turned security of supply into a major issue. The crisis has highlighted the need to evaluate alternative energy sources –in particular non conventional renewable energies (NCRE)- as options for the future development of the electric system.

The purpose of this project is to examine the impacts of introducing non-conventional renewable energies into the energy matrix. The evaluation will consider two major tiers. The first is to examine sustainability targets (in particular energy security). The second is to analyze local and global environmental benefits (local air pollution and greenhouse gas emissions); human health benefits and benefits on agriculture. For this, the effects of reducing tropospheric ozone and particulate concentrations in Santiago and improving energy security, due to a change in the energy matrix toward more renewable energies, will be valued. The basic idea is to establish how much each of these factors contributes towards making the introduction of renewable energies more feasible. This work is very timely given the recent passage of the Ley Corta and the potential of an upcoming natural gas shortage caused by Chile's primary supplier.

To obtain the proposed objective, the main activities of the project will be:

1. Develop a baseline energy scenario and growth projections that includes the Ley Corta but does nothing else to provide incentives for further developing the renewable energy sector.

2. Apply an emissions based model that provides both air pollutants and GHGs to the baseline scenario

3. Develop an alternative scenario that would encourage rapid growth of the renewable energy sector within Chile

4. Analyze economic benefits of the alternative scenario compared to the realistic baseline, considering a shock to natural gas supply and eliminating polluting generating plants in Santiago.

5. Conduct a benefit/cost analysis of each casa.

6. Share results with policy makers and solicit their input on making the "best case" scenario a realistic goal, address any policy hurdles that could redirect or hinder the process.

In agreement with the contracting party of the project, and due to lack of models and base information, the tiers will be examined separately. Only Santiago has models that enable the estimation of environmental quality variations as a result of changes in the energy matrix. Therefore, to analyze and value the environmental impact, the case of removing generators that exist in Santiago, will de examined. The environmental impact of this removal will be analyzed and valued considering the potential impact on health and agriculture.

The study of sustainability targets, in particular the security of supply issue, does not present this problem. Therefore, a real schedule plan for the entire Central Electric System of the country will be considered as baseline for this issue. A second scenario considering alternative technologies will then be compared to this baseline. Potential environmental impacts (positive and negative) will not be considered in this case due to lack of proper models.

Thus, the environmental tier will be undertaken for a relevant urban setting, while the security of supply tier will be studied considering the entire system of central Chile. Both cases will allow establishing and comparing the magnitude of the impacts and serving as benchmark for analysis of similar cases.

In this first repot the methodological framework to analyze both tiers is presented. Section 2 describes the nature of the Chilean Electric System. The major systems, business organization, and related authorities are presented. A description of the operation of the system, regulatory framework and structure of prices and related markets is also considered. Section 3 presents the problem of security of supply and describes briefly how the international community and Chile have defined and dealt with this issue. Section 4 presents the methodology for evaluating costs and benefits associated to security of supply. Finally, section 5 provides the general methodology proposed to evaluate the environmental impacts of the inclusion of non-conventional renewable energies.

2. The Chilean Electric System

Chile was the first country in the world to deregulate and liberalize the electric sector. Up to 1980, electric regulation in Chile followed the usual pattern of contemporary electric systems: state-owned firms that were vertically integrated and subject to rate of return regulation. The operation of electric generation companies was inefficient, a consequence of the state not having an independent regulatory agency capable of regulating its own firms and of prices that were set in order to respond to short term political objectives.

In 1982 and after a difficult process, an important electricity law was issued, though it still remained within the framework of a largely state-owned system[1]. The law introduced a revolutionary price system. Electric generation was decentralized and functionally separated from transmission and distribution, and incentive regulation was introduced in distribution. These massive changes in regulatory incentives were supplemented with the creation of a new regulatory agency with a ministerial rank, the CNE, followed by the privatization of the industry in the late eighties. Today all transmission and distribution is privately held, while the small fraction of generation still in the hands of the state will soon be privatized, too.

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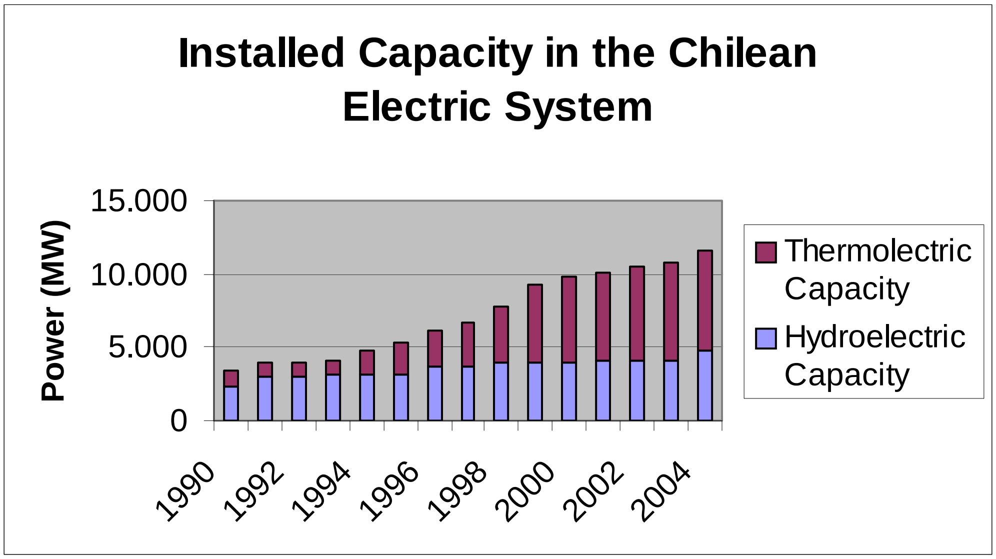
[1] The key law is the DL N± 1 of 1982. It can be found in http://www.cne.cl

The reforms have had significant results in the operation of the system. An explosive growth has occurred throughout the country not only in installed capacity, but also in total electricity generation. The graph below demonstrates how the installed capacity increased from less than 4,000 MW in 1990 to almost 10,000 MW in 2000 implying total capacity more than doubled during the last decade. In the end of 2004, total installed capacity is 11,561 MW from which 41% corresponds to hydroelectricity and 59% thermal generation.

Figure 1 Installed Capacity in the Chilean Electric Sector According to Type of Generation



In the case of total generation, the country increased from 18,000 GWh in 1990 to more than 40,000 GWh in 2000, an annual growth rate of 8.5% over the decade. Moreover, annual generation more than doubled from 1990 to 1998.

Chile's electrical generation is predominantly from hydroelectricity, except in drought years when it must rely on thermal generation. Table 1 presents the extreme variability in generation. In "good hydrological years" up to 75% of the total energy can be generated from hydroelectricity, whereas in "bad" years less than 30% is generated by this technology.

Table 1: Percentage of Hydroelectric and Thermoelectric Generation by Year

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
HYDRO	49%	66%	75%	72%	67%	66%	55%	57%	45%	35%	29%
THERMO	51%	34%	25%	28%	33%	34%	45%	43%	55%	65%	71%

The recent supply restrictions of natural gas makes it then very important to diversify the energy matrix in order to have options available especially during drought years

The rest of this section describes briefly the most important elements that make up the electric system. In particular, the different systems and businesses will be presented. Additionally, the regulatory institutions, legal framework and operation of the markets will be described.

2.1. National Electric Systems

There are four interconnected electric systems in Chile. These are presented and described briefly below:

Northern Interconnected System (SING)

The Interconnected System of the Norte Grande (SING) covers the area between Arica and Antofagasta. The system covers an area of 185,142 km^2 which represents 24.5% of the Chilean continental territory. This system provides energy to 5.6% of the Chilean population, which is concentrated in a few places far form each other.

Total capacity in the SING was 3.634,0 MW by the end of 2004. The system is made up almost entirely by thermoelectric generators representing 99.63% while only 0.37% corresponds to hydroelectric generators. The system accounts for 34.8% of the electric power capacity in Chile and its main function is to supply electric energy to major mining projects in the Northern region.

The transmission system is primarily made up of electric lines owned by the generation companies, by the clients themselves, and by electric transmission companies. Three energy distribution companies operate in the SING: EMELARI S.A., which supplies the city of Arica; ELIQSA S.A. which supplies the city of Iquique; and ELECDA S.A., which provides energy for the city of Antofagasta. A part of the SIC also corresponds to Taltal. Altogether these three companies supply a total of 218,553 clients.

Central Interconnected System (SIC)

The SIC is the country's primary electric system. The SIC extends from Taltal in the North to the island of Chiloe in the South. The system covers a surface of 326,412 km^2 which represents 43% of the Chilean continental territory. This geographical area concentrates about 93% of the Chilean population.

In 2004 total capacity of SIC reached 7.867 MW representing 68.1% of total national capacity making this system the most important in terms of generation and consumption. Of total installed capacity in SIC, 43.7% represents thermoelectric capacity and 56.3% hydroelectric power.

The transmission system is principally composed of electric lines owned by generation companies plus those lines owned by electric transmission companies. There are 31 distribution companies that operate in the SIC.

Electric System of Aysen

This system is located in the eleventh region of the country and in 2004 its capacity reached 33.5 MW representing 0.3% of national capacity. 50% of this capacity corresponds to hydroelectric energy, 44.1% to thermoelectricity and 5,8% to renewable non-conventional energies. A single company, EDELAYSEN S.A., is responsible for the generation, transmission and distribution of electricity

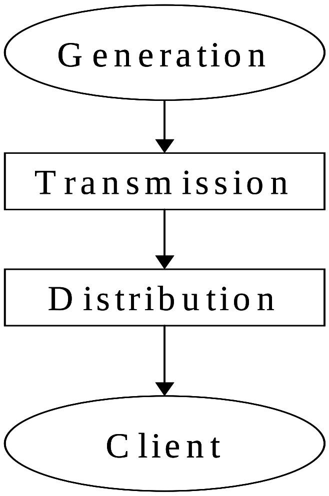
Electric System of Magallanes

The Magallanes System is composed of three electric subsystems: the Punta Arenas, Puerto Natales and Puerto Porvenir Systems in Region XII. The total installed capacity of these systems by the end of 2004 was 65MW, representing 0.7% of national capacity. All the energy generated in this system is produced by thermoelectric generators. Only one company, EDELMAG S.A., is responsible for generation, transmission, and distribution of electric energy in these systems.

2.2. Businesses of the Electric System

In the process of energy provision it is possible to identify three main activities or businesses. These are the generation, transmission and distribution businesses. From the regulatory perspective each activity is treated separately. The following figure shows the businesses of the Chilean electric system

Figure 2 Businesses in the Chilean Electric System



Generation Business

As discussed, generation of electricity is done mainly through to two types of sources: Hydroelectric and thermoelectric sources. Hydroelectric generation is generally low cost but feasible only in the southern regions of the country due to its abundant water availability. Therefore, in spite of low generation costs generally high transmission costs must be assumed.

Thermoelectric electricity is based mainly on coal, natural gas and increasingly diesel oil[2]. Thermo electricity as opposed to hydroelectricity presents no geographical restrictions. Thus, it is feasible to construct thermo generators throughout the country without the need of increased transmission costs. However, production costs are generally higher than those of hydroelectric generators.

Generators may be classified according to the destination of electric energy into the following categories:

- Public Service Generators.
  This category includes all those generators whose main objective is to supply electric energy to final consumers. The energy supply may be direct to final clients by means of contracts. However, this supply may also be indirect through contracts with distribution firms.

- Self-Producing Generators
  This category includes all industrial or mining firms that produce energy for their own consumption. In some cases, energy remaining is sold to public service generators or distribution firms.

Transmission Business

Transmission is the process through which electric energy is transported through high-tension cables generally over long distances. The transported energy may be delivered to final clients or distribution firms. This segment determines the transmission network which extends all over the country enabling the transport if energy.

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[2] Diesel oil has increased its participation in the generating park as a result of important availability restrictions of natural gas.

The operation, maintenance and commercialization of transmission are in charge of mostly private transmission firms.

Distribution Business

The distribution process corresponds to the sales of low-tension electricity to final users, which include the consumption of industrial and mining firms as well as household consumption. In general distribution is carried out by distribution firms in determined geographical areas and as stipulated in concessions.

2.3. The Regulatory Institutions

There are four relevant public institutions relevant in the regulation of the Chilean electric system. These are described briefly in this section.

National Energy Commission (CNE)

The CNE is in charge of studying and proposing electric regulations, it estimates regulated prices, provides technical assistance to the government and is concerned of the electric system development. It is important to notice that in spite of proposing regulatory modifications and assisting the government, this institution has no fiscalization faculties.

Center of Economic Dispatch and Charge (CDEC)

The principal purpose of a CDEC in operating the dispatch system is to ensure that only the most efficiently produced electricity reaches consumers. However, the CDEC also seeks to ensure that every generating company has enough installed capacity and can produce enough electricity to meet the demand of its customers.

The CDEC is in charge of the coordination and planning of the system operation and responsible of security of supply. The CDEC is made up of all generators with more than

2% of installed capacity of a particular system and transmission firms having more than 100 km of lines.

The CDEC must inform generators the supply and demand conditions, coordinate maintenance of generators and check operation regulations are fulfilled. Besides, the CEDC must determine the spot price at which transferences among generators are valued and has the faculty of dispatching generators to produce electricity.

Ministry of Economy

The Ministry of Economics approves the tariffs proposed by the CNE. Additionally, the Ministry has the faculty of implementing electricity restrictions under crisis conditions. Finally, it has a fundamental in solving divergence situations that might arise in CDEC.

Superintendence of Electricity and Fuels (SEC)

The SEC is a supervising agency that reports the President directly and checks the fulfillment of the regulations of the sector. Among its obligations is to check the achievement of the quality standards required by the law as well as to investigate the causes of blackouts.

2.4. The Electric Market

This section presents the tariff structures that make up the electric market as well as the system of generation prices.

2.4.1. Structure of Tariffs

The policy aims to represent real costs the real costs of generation promoting competition in the segment. This has resulted in the absence of scale economies in the generation segment which enable to set prices as the marginal cost of supply. The marginal cost is considered to have two main components: energy and power. The generated energy component corresponds to the price of energy and its estimation depends on which electric node injects the energy into electric net. On the other hand, nodal prices for capacity are calculated based on the annual cost of installing a new diesel fuel gas turbine generation facility.

The two components just defined originate the values of node price for energy and node price for power. These prices should reflect average spot prices. The determination of the node price establishes a fund to cover peak-hour generation costs. Distribution firms generate this fund according to the electricity provided by the generators and then distributes among the generators by the price mechanism.

The node price is the price at which generators sell their energy to trunk transmission firms which also charge a fee for this transportation (Trunk transmission fee). Trunk transmission firms then deliver the energy to sub transmission firms which also charge a fee for energy transportation (sub transmission fee). These firms deliver the energy to distribution firms which are the ones in charge of supplying energy to final consumers. Distribution firms charge a fee known as “Value Added of Distribution” (VAD). These fees vary according to the category of the final consumer[3]. Therefore and considering all the fees, the price the final consumer faces is defined by the following expression:

Final Consumer Price = Node Price + Transmission Fee + Sub transmission Fee + VAD

Nodal prices for energy are calculated based on the projected short term marginal cost of satisfying the demand for energy at a given point in the interconnected system, quarterly during the succeeding 48 months in the SIC and monthly during the succeeding months in the SING. In order to determine such marginal cost in the SIC, a formula is used that takes into account ten year projections of the principal variables in the cost of energy at each substation in the interconnected system over the 48month period. This includes projected

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[3] Final consumers belong to the household, industrial or service categories.

growth in demand; reservoir levels (which are important in determining the availability and price of hydroelectricity); fuel costs for thermal electric generation facilities; planned maintenance schedules or other factors that would affect the availability of existing generation capacity; and scheduled additions to generation capacity during such period. The same general principles are used to determine marginal cost in the SING.

2.4.2. The System of Generation Prices and Management of Waters

In the electric system three markets interact to make the delivery of electric energy possible. Generators, transmission and distribution firms meet in these markets to carry out the energy exchanges. These markets include (1) the spot market in which generators exchange energy among themselves, (2) the regulated market, where distributing firms buy through mid and long term contracts at node prices, and (3) the free market, where large users may negotiate and sign contracts with generators and distributors under free conditions of prices and quality of supply.

Each of these markets is described below:

- **The Spot Market**

  The spot price represents the instantaneous marginal costs of the system and is supposed to ensure the system operates at minimal cost. The CDEC dispatches generators according to operation costs increasingly. Thus, given a certain demand requirement, this is supplied by the all those generators which guarantee this supply and at lowest cost.

  The main advantage of using short-term marginal costs to determine dispatch is that it reduces the possibility of short-term strategic behavior on the part of generating companies, which is a real concern for spot markets with bidding and few participants. The danger of noncompetitive behavior would be high in Chile, which has few generating companies. On the downside, the use of marginal costs requires that pool operators play a prominent role in determining short-term marginal costs, especially in systems with an important hydroelectric component. Current generating technologies imply the first generators to be entering the system are run-of-the-river plants. Their operation costs are close to zero since water cannot be stored (thus, these waters do not have opportunity costs). Therefore, if the water is not used as it passes through the generator, this energy is lost.

If the energy provided by the run-of-the-river plants does not suffice, then thermal generators enter the system in increasing order of operation costs. Under the need of providing additional energy, reservoir hydroelectric generators enter the system and also according to operation costs.

If further demand requirements persist, thermal generators enter the system according to operation costs. Thermal generation costs depend mainly on the costs of the fuel requirements and on the efficiency of energy conversion.

The orders of CDEC are compulsory and independent of individual contracts of generating firms. Therefore, frequently generators buy and sell energy with each other in order to fulfill all these requirements. The energy traded by the generators is sold at the instantaneous marginal cost or spot price. The separation between energy delivery and contracts enables the system to minimize total production costs.

The level of thermoelectric energy produced will depend on the level of energy generated by stored water. The most important reservoir is the Laja Lake and is central in the price determination of the SIC. The water to be used in energy production must be such it minimizes present costs but considering the opportunity cost of not having it available in the future. By simulation models CDEC determines the amount of water to be used in each period so that marginal costs of operation equal opportunity cost of water. Therefore, the marginal costs of the system represent the opportunity costs of water.

It is important to consider the optimal use of water today depends on tomorrow's level of precipitations and thaws If precipitations are abundant then the costs of storing water are low as opposed to dry conditions under which water increases its value as thermal generators operate intensely and where there the probability of failure exists. It is impossible to predict with certainty future water disposals so simulation models are used.

When supply conditions are normal and no failures are expected, the opportunity cost of water equals the highest cost thermal generator operating. Nevertheless, as the probability of failure increases, so does the opportunity cost of water. In the extreme case, this opportunity cost reaches the marginal cost of failure. The cost of failure is the key price under scarcity conditions since it represents the opportunity cost of energy.

- **The Regulated Market**

The spot price is subject to strong variations continuously. The regulated market attempts to prevent consumers face strong price fluctuations. This goal results in the estimation of the node price considering a probability distribution of hydrology.

It is important to notice the node price is not a price designed to reflect current supply and demand conditions. Conversely, the effect of a current drought is diluted by the fact the price determination considers all hydrologies considered in the simulation model are equiprobable and independent of the situation of the present year.

Nodal prices for capacity and energy consumption are established every six months, in April and October, by a decree issued by the Ministry of Economy. Although nodal prices are quoted in Chilean pesos, the calculations used to determine nodal prices are mainly effected in U.S. dollars. Nodal prices so established become effective in May and November. Nodal prices are adjusted during a six-month period only if changes in the underlying variables in the formula used to project a nodal price then in effect would result in a variation in excess of 10%. In addition, the Chilean Electricity Law requires that the difference between nodal prices and the average price paid by unregulated customers in the six-month period prior to the date of nodal price calculation not exceed 10%. If nodal prices do not meet this requirement, they will be adjusted so that such difference will not exceed 10%.

In those episodes demand is impossible to be supplied at the node price, the system considers substitutes to contingent prices. These are compensations to unsupplied energy. For every KWh not supplied the pertinent generator must pay the user the difference between the cost of failure and the node price. In practice, it is impossible to determine the amount of unsupplied energy. Therefore, the compensation is defined as the difference between the amounts experienced during the same period the year before but corrected by the expected increase rate for consumption for this year.

- **Free Clients**

The third market of clients in the industry is that of free clients. In this market large users negotiate directly with generating or distributing firms the supply conditions and quality including the prices of energy and power.

2.5. The Current Legislation and The Recent “Ley Corta”

The current legislation assumes tariffs should represent the real costs of generation, transmission and distribution associated to efficient operation. This should result in optimal development of electric systems and in correct signals to consumers and electric firms. It was expected that high energy prices would give incentives for more investment in generation. This actually happened, and up to 1999 investments have been made ahead of the indicative plans prepared by the government. However Chile has suffered supply problems in extremely dry years basically due to regulatory failures, particularly enforcing outage cost payments. Recently, natural gas restrictions have deepened this issue.

Prices are not subject to regulation in those businesses where competitive conditions are observed. In practice, and previous to the ley corta, supplies to final users whose installed power is equal or smaller than 2.000 KW were considered to be sectors where markets have monopoly conditions and thus the law considers price regulations. Conversely, if energy supplies to final consumers were over 2.000 KW, the law admitted free prices, assuming negotiation abilities and the capacity of getting alternative supplies, such as self-generation or direct contracts with generating firms. This was what determines the regulated and free clients.

The “ley corta” or short law was approved recently and introduces modifications to the former law. Some of the most important changes are presented below:

- The regulation of the transmission system is modified in terms of resource assignment by all agents of the system. The procedures to determine transmission fees were modified enabling the development and payment of 100% of the system under efficient conditions.

- The law also changes the characterization of free clients lowering the bound from 2000KW to 500 KW. Users whose connected power is over 500 KW have the faculty to choose the price scheme over four consecutive years (free or regulated prices). The law introduces the market of complementary services. This establishes the transaction and valuation of technical resources that help to improve service quality and services.

- Moreover, the law contemplates scarcity signals to ensure efficient behavior from consumers. In fact, generators are allowed to agree increases or decreases in consumption with their regulated clients as a function of scarcity. As a means to strengthen the rights of consumers the law also establishes the possibility of negotiating compensations and economic incentives.

- An important modification and relevant for this project has to do with alternative technologies. In fact, the conditions to develop projects with small generators using non-conventional energies, especially renewable energies, are improved. To do this the market is open to this kind of technologies. To encourage investments, these energies are exempt from trunk transmission payments.

- To guarantee operators satisfy the demand, more clear responsibilities are established for operators of the system. In particular, gas restrictions that produce unsupply are no longer considered to be external failures. That is, operators are responsible to avoid failures or interruptions in cases of fuel restrictions.

3. The Security of Supply Problem

3.1. Understanding the Problem

Security of supply has been an important issue within the study of energy security. The discussion became relevant in 1965 after a famous “black-out” in New York. As a result, attention was given to the study of potential failures and weaknesses of the electric system. However, repeated general failures have continued to occur maintaining the relevance of the issue. Examples of these back-outs are those experienced in the United States East Coast in 1977 and 2003, California in 2001 and Europe in 2003.

There is no general definition of security of supply. Lovins (1982) classifies the causes of the failure of electric systems into four main categories.

- Natural Catastrophes: earthquakes, droughts, etc.
- Deliberate Action: Terrorist attacks, industrial sabotage, strikes, etc.
- Errors: human mistakes, system failure.
- Communication Interruptions, Command and Control: failures in coordination programs, failures in communication systems.

Each of these causes of failure may generate interruptions in electric supply. The importance of the problem lays in the fact reduced or interrupted electric supply results in social costs. These affect economic activity because of potential production reductions and increased costs. However, consumers also experience surplus loss when faced to the impossibility of carrying out their usual activities due to lack of energy[4].

The characteristics of an electric systems determine its degree of vulnerability before the risk factors just mentioned. To determine the electric system's nature, several attributes society value must be considered. Examples of these attributes are low cost, reliability, low failure rates, and independence. The point is that tradeoffs exist among attributes making the design of the system a complex private and public decision-making and implementation problem. That is, although supply restrictions or interruptions generate social costs the design of more trustful systems carries higher costs. This is especially true under the private scheme which does not necessarily guarantee responsibility over these attributes, unless the correct incentives are included.

In this context, security of supply should be understood as "the price level of energy consumers are willing to pay" (Helm, 2002). This is crucial given the fact consumers seek a stable price pattern since energy's consumption is complementary to the consumption of other durable goods.

This study will compare two alternative construction schedules of power plants . The attributes that will be considered are costs and failure rates. The idea is to establish how costly it is for society to reduce failures frequency under unexpected shocks such as fuel supply restrictions.

3.2. The International Experience

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[4] The economic impact in surplus is presented in the next Section.

Security of supply has been included in several studies by different institutions. However, the most important advances have taken place in the United States and Europe. The approaches these two economic groups have given the issue differ. In fact, the United States has focused on competition and protection of facilities. In contrast, the European approach has attempted to control energy demand encouraging energy saving and by promoting non-conventional renewable energies.

Although individual nations had concerned themselves about the security of supply, the issue began to be studied regionally in the European Community (EC) after the signature of the Kyoto Protocol. Security is treated as complementary to reducing energy dependence on fossil fuels as a means to decrease GHG emissions. To achieve the latter objective, the EC has encouraged the use of non-renewable energies resulting in reduced demand and greater independence of fossil fuels. The European Community has established mechanisms that enable collaboration among participant countries.

The European Community seeks to balance and diversify the supply sources. Moreover, it stresses security of supply policy must not be understood merely as reduced fuel imports, but it requires political and economic initiatives which result in diversification of sources and technologies.

The EC signals the purpose of security of supply policy is to warrantee short and long term energy availability for all types of consumers (industrial, services, domestic) at reasonable prices and simultaneously considering seriously environmental conservation. In particular, renewable energies are expected to double their 1995 participation in the system by 2010. The investment required to reach the target are estimated in E$165 billion for the entire 1997-2010 period. Other objectives include to increase 18% energy efficiency in the same 1995-2010 period and to maintain appropriate security of supply levels.

In order to fulfill the different objectives, the EC has defined principles considered to be fundamental. The most important principles include efficiency, competition and supply security. The supply security principle refers to maintain an adequate level of reliability in the system but considering efficiency and competition issues.

Two major approaches have been considered to deal with the security of supply issue in the USA. The first approach has to do with market conditions which ensure competition and the development of the electric sector. The second deals with technical issues especially those related to protection of terrorist attacks.

During the last decade, the American electric system has experienced deep changes. In fact, today twenty-four states and the District of Columbia have open and competitive markets. Besides, since the year 2000 five states include in their electric portfolios non-conventional renewable energies in competitive conditions. These changes have been subject to constant analysis. In particular, it is of interest to determine the levels of reliability of the system under competitive conditions.

From the technical point of the concept of energy security is made up of two fundamental concepts: reliability and critical infrastructure protection. Reliability requires “adequacy” of supply which means the system must be able to provide all the electricity demanded at all times. Reliability also requires security as the system’s ability to resist unexpected perturbations. The critical infrastructure problem deals with the installations key to the United States and the protection required to keep these reasonably safe from attacks of any kind.

3.3. Security of Supply in Chile

Chile has applied a sector view of the problem of security of supply. That is, internal factors of the sector have been subject to study and evaluation. This is consequence of the legal framework existing in Chile. The concepts directly related to the quality of supply that are considered in this framework are the following:

- Theoretical Reserve Margin: Minimum excess generation capacity which enables to supply peak power of an electric system or subsystem given the characteristics of the generation units and transmission systems. This concepts is related to level of required redundancy.
- Reliability: attribute of an electric system determined simultaneously by sufficiency, security and service quality. This term relates energy availability to final users.
- Sufficiency: attribute of an electric system which determines whether the installed capacity suffices to supply the demand associated to the system.
- Security of Service: response capacity of a system, or part of it, to face contingencies and minimize consumption losses through backup and complementary services. This concept is related to the number of expected failures of the system.
- Service Quality: Attribute of a system determined simultaneously by quality of product, quality of supply and quality of commercial service. This is a broad concept used to evaluate the sales of a product or service to final clients.
- Quality of Product: component of the quality of service attribute that enables to qualify the product obtained by the delivered by the different agents that make up the system. It is characterized by the frequency, magnitude, and contamination of instantaneous supply tension.
- Quality of Supply: component of the quality of service attribute that enables to qualify the supply given by the different agents of the system. It is characterized by the frequency, duration and magnitude of supply interruptions. This component not only values energy availability but also its quality in terms of its similitude to an ideal voltage wave.
- Complementary Services: Technical resources present in the generation, transmission and distribution facilities an electric system should count for the appropriate coordination of the system. It is understood by complementary services at least those services that enable to carry out and adequate control of frequency, tension control, and recovery of service under both normal and contingency conditions.

- About Energy Transfers: Energy transfers produced in a center of dispatch, resulting from a restriction decree are also valued at instantaneous marginal cost and is applicable to energy transactions in the system. In hours of energy interruption this value is equal to the cost of failure.
- Cost of Failure: Distinction between cost of failure for power and energy. If supply is insufficient to satisfy a given demand, then there is a bar restriction. The magnitude of the failure is established in comparison to the latest demand projection available. Under restriction conditions, the marginal cost in the bar equals the cost of failure associated to the magnitude of the failure.

Having clear the concepts present in the legal framework and based on the international experience it is possible to determine what should be understood by security of supply in Chile. This has not yet been defined for Chile. A first step would be defining the scope in which the security of supply is to be considered. The authorities must then propose what is their understanding of the subject. However, to start the discussion two relatively similar definitions are presented:

- Security of supply refers to the feasibility of an electric system to face reasonable negative scenarios in the future, associated to a low probability of permanent scarcity, at reasonable prices.
- Security of supply relates to a performance metric of an electric sector referring to the certainty the final consumer has of disposing of electric energy at a price level coherent to the country’s competitiveness.

It is important to consider that competitive markets reach an equilibrium when supply equals demand. However, long-term planning does not incorporate explicitly a payment to reduce failure risks. The Chilean law does include the payment for power as a means to encourage stock formation; however, the type of energy source used to generate this power is not considered. Consequently, these stocks may all use the same type of fuel. The “ley corta” has included additional incentives to incorporate other types of energy. In fact, as already mentioned, non-conventional renewable sources are exempt from certain payments.

Nevertheless, it is not clear how encouraging this benefit may result since this incentive is limited only 5% of installed capacity of the electric system.

4. Methodology for Establishing Security of Supply and Scenario Costs

This chapter presents a conceptual model that enables to evaluate and analyze the inclusion of renewable energies in the energy matrix. The model considers monitoring of the electric system in terms of failure as well as comparing costs and benefits in different development scenarios of the sector.

4.1. Conceptual Framework to Estimate the Social Cost of Failure

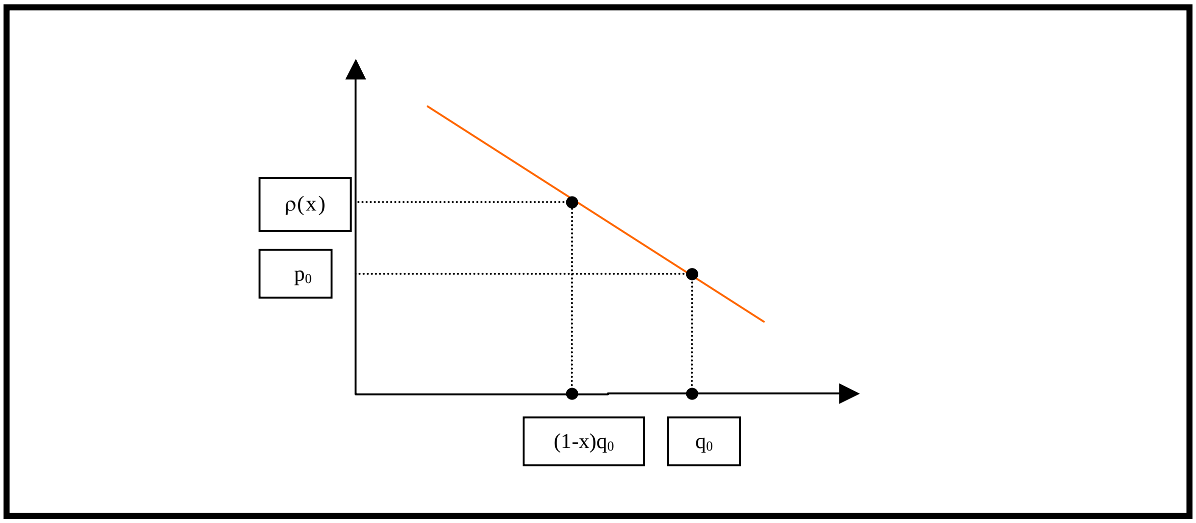
The social cost of failure (commonly known as failure cost) is defined as the cost users pay on average for not disposing of one KWh. This cost attempts to measure the social costs associated to electricity supply restrictions.

There are several methodologies to value the impact of a failure in electric supply. According to Serra, Galetovic and Sanhueza (2002), the costs must consider different kinds of consumers: household consumers, service sector consumers and industrial sector consumers.

Household Cost of Failure

Let q_0 represent the electric consumption of a representative family and $(1-x)q_0$ the consumption under a supply restriction of x%. This restriction is shown in the figure below:

Figure 3 Representation of x% Supply Restriction



Then the gross marginal cost of failure associated to this x% restriction is given by:

$$mc_h(x) = \rho(x)$$

where, ρ(x) is the price that would drop family consumption to (1-x)q_0 without the need of a restriction. That is this price represents the maximum value a family is willing to pay for the last undelivered KWh.

Therefore, the net cost of failure is defined as:

$$nmc_h(x) = \rho(x) - p_0$$

where p_0 is the price for a demand of q_0, that is, under normal supply condition.

To estimate the gross cost of failure, Serra et al use consumer surplus arguments. Therefore, the total gross cost of failure is given by:

$$C_h(x) = \int_{(1-x)q_0}^{q_0} p(q)dq$$

where p(q) represents the inverse demand for household energy consumption.

Average costs depend on whether the restrictions are programmed or not. For an expected or programmed restriction of x% the average cost of failure is given by:

$$C_h(x) = \frac{1}{xq_0} \int_{(1-x)q_0}^{q_0} p(q)dq$$

However, under unexpected restrictions, families cannot choose what energy uses to modify or eliminate. That is, short-term average costs reach the average failure cost of total restriction,

$$C_h(x) = \frac{1}{q_0} \int_{0}^{q_0} p(q)dq$$

Service Sector Cost of Failure

To estimate this cost the same procedure used for household consumption is used. The only difference is all functions and values apply to the service sector. This way, the gross failure cost is:

$$C_s(x) = \int_{(1-x)q_0}^{q_0} p(q)dq$$

The average cost of expected failure is:

$$C_s(x) = \frac{1}{xq_0} \int_{(1-x)q_0}^{q_0} p(q)dq$$

and the failure cost of unexpected restrictions is:

$$C_h(x) = \frac{1}{q_0} \int_{0}^{q_0} p(q)dq$$

Industrial Sector Cost of Failure

The industrial failure cost may be estimated using different methodologies. The first uses input-output matrices and assumes a constant relationship between electric consumption and aggregate value. This value is a lower bound for the failure cost since firms have different options to face electric restrictions. Demand elasticities for each sector may also be used to estimate this cost of failure.

Average Social Cost of the System

The average social cost to society for a programmed (or long term) and equiproportional restriction is estimated as the weighted average of the three costs of failures previously defined. The factors represent the participation of each sector in total electric consumption.

Based on Serra, et al (2002) the CNE provides unit cost of failures according to the percentage of unsupplied energy. These values are shown in the table below:

Table 2 Unit Costs of Failure as a Function of Percentage Unsupplied Demand

Unit Cost of Failure	**0-10%**	**10-20%**	**Over 20%**
(US$/MWh)	227,4	318,1	334,9

Source: CNE (2004)

4.2. Conceptual Framework to Evaluate Costs and Benefits of Security of Security

The general methodology to monitor and evaluate costs and benefits related to security of supply considers the comparison of two alternative scenarios. The first scenario is a base or business as usual scenario considering the development schedule of the system as proposed by CNE. A second scenario contemplates a mix of energy sources which include non-conventional renewable resources.

To make reasonable comparisons among different scenarios it is necessary to consider scenarios with equivalent capacities. To do this effective capacities are considered, that is, the installed power is corrected by generation factors associated to each technological alternative.

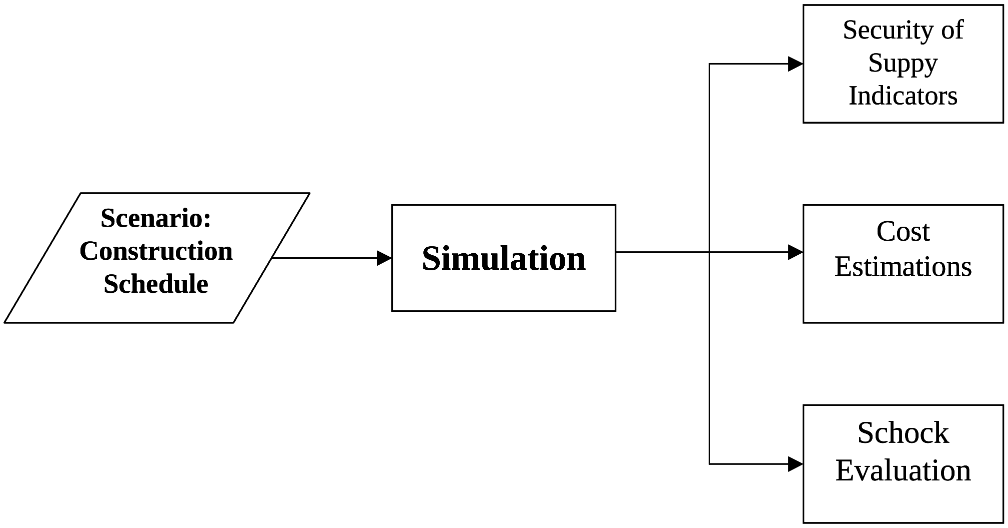
The development scheme of the electric sector for a period is required as an input for the simulation model which evaluates the system's performance and development. The values obtained by the simulation are the input for the evaluation of the indicators and costs of each of the scenarios considered. This enables the comparison of the different scenarios.

To evaluate the scenarios two main types of indicators are defined. The first set of indicators refer to monitoring of the system and security of supply (non-monetary indicators). For example, these indicators include generation per type of energy and number of failures under each scenario. A second set of monetary indicators is defined. For example, these include node price and operation costs of the system under each scenario. A complete description of the indicators is given in section 4.4.

The following figure presents the main characteristics of the methodology proposed for the evaluation of different electric systems scenarios.

Figure 4 Methodology of Scenario Evaluation

The stages of the methodology are described briefly below:



1. Development Scheme: The development scheme of the electric sector considers the future generators considered to enter the system for the next ten years. The considered plan defines the scenario under study and is an input of the simulation system.

2. Simulation: The simulation model GOL (Optimal Laja Management) is used to represent the performance of different electric scenarios. The output of the simulation are values of the generated energy, the marginal costs of generation and the node price of the electric system for a ten-year period.

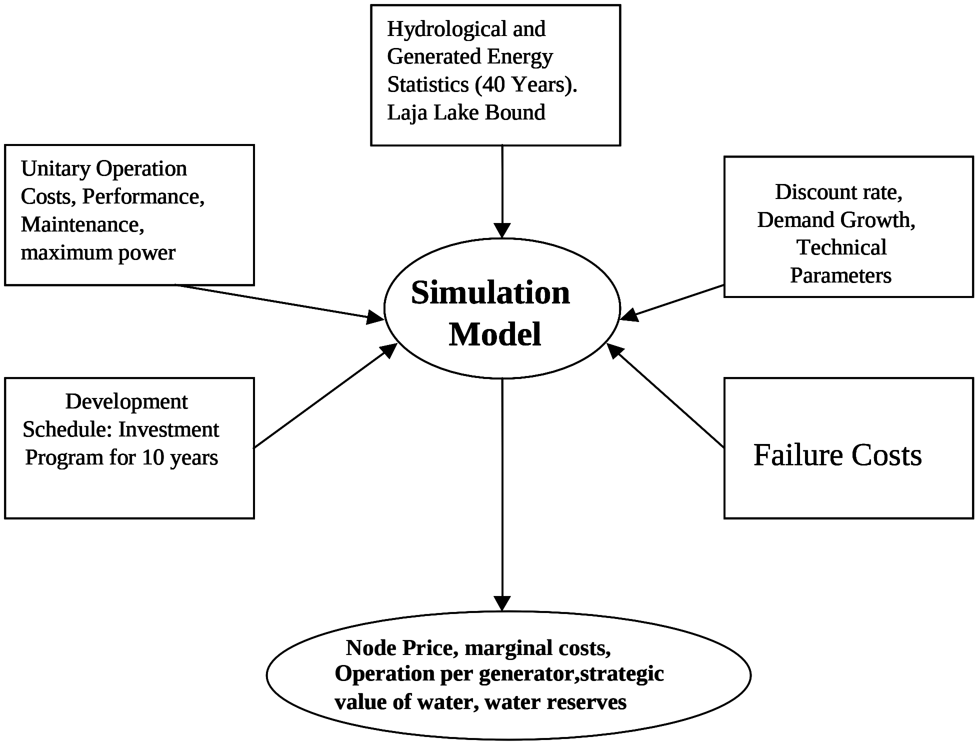
3. Security of Supply Indicator Estimation: The values estimated by the simulation are used to estimate different security of supply indicators for each year considered by the simulation.

4. Cost Estimation: Investment and Operation Costs are estimated for each considered in the simulation. This enables policymakers to have a first estimation of the costs necessary to reach different security of supply targets.

5. Shock Evaluation: The last stage of the methodology consists of determining the degree of reliability of the system, shocks are examined. In particular, it is possible to examine restrictions on natural gas availability which is a current problem of the sector. This enables to estimate the costs for different shocks and under different scenarios including failures costs.

The simulation model GOL used to estimate the node price is vital to be able to estimate and analyze security of supply indicators and scenario costs. Therefore, the main characteristics of the model are illustrated in the following figure:

Figure 5: Inputs and Outputs of GOL Simulation Model



4.3. Scenario Definition

The general methodology described above is applied to the particular case of the Central Interconnected System. The period considered is 10 years (2005-1014).

As explained above simulations are carried out assuming a specific development schedule of the electric system. Two major scenarios are considered and compared. The first scenario takes the development schedule proposed by the electric regulator and its energy matrix is made up mainly of conventional energy sources (hydroelectric energy and natural gas). This scenario will be referred to as baseline scenario.

A second scenario considers an alternative development schedule of the electric sector. The alternative scenario also takes the development schedule proposed by the regulator but includes about 26% of non-conventional renewable energies in the energy matrix. The renewable energies replace conventional sources in the original plan with equivalent power. This scenario is the “alternative scenario”.

The electric system considers a nominal power capacity. However, power plants require maintenance and their operation is variable throughout the year. Efficiency factors are considered in order to capture the effects non-operation and reduced efficiency have on the effective power capacity of the system.

Therefore, both scenarios differ in the components of their energy matrices. However , overall effective power is maintained. That is, two scenarios having equivalent energy production capacities will be compared. This makes the comparison of the scenarios possible in terms of security of supply and costs as will be explained.

The efficiency factors represent average operation conditions for each type of energy and are commonly known as generation factors. Factors for both conventional energy sources (CES) and non-conventional renewable energies (NCRE) are considered. These are presented in the table below:

Table 3 Generation Factors for each Kind of Energy

	Kind of Energy	**Average**
CES	Hydroelectric Energy	0,80
	Natural Gas	0,80
	Diesel	0,85
	Coal	0,75
	Others	0,60
NCRE	Mini Hydro	0,60
	Eolic	0,40
	Geothermal	0,95
	Biomass	0,55

Source: Department of Electric Engineering, University of Chile (2005)

The table below shows the main energy sources for the baseline scenario. The baseline scenario is made up mainly of hydroelectric energy and natural gas both reaching 76% of total power. The baseline also includes 7% geothermal energy in the period considered. Other energy sources basically refer to direct energy transmission from Argentina. The following table presents the power associated to generating plants that are expected to be added to the system according to type of energy. This corresponds to the indicative plan developed by CNE for the Central Electric System in 2004.

Table 4 Development Schedule of Baseline Scenario (Mega Watts)

Año	Hydro	Natural Gas	Other	Geothermal	Total Year	Effective Power
2005	25	0	0	0	**25**	**20**
2006	65	385	0	0	**450**	**360**
2007	155	385	0	0	**540**	**432**
2008	0	381	0	100	**481**	**365**
2009	155	0	250	100	**505**	**334**
2010	400	381	0	100	**881**	**685**
2011	0	0	400	0	**400**	**240**
2012	0	758	0	0	**758**	**606**
2013	0	0	0	0	**0**	**0**
2014	0	0	0	0	**0**	**0**
Total	**800**	**2290**	**650**	**300**	**4040**	**3042**

The development schedule associated to the alternative scenario includes a more important participation of non-conventional renewable energies. Geothermal capacity is increased and eolic, mini hydro, biomass plants are incorporated in the energy matrix. This schedule is presented in the table below.

Table 5 Development Schedule of Alternative Scenario (Mega Watts)

Year	Hydro	Natural Gas	Mini Hydro	Eolic	Geothermal	Biomass	Other	Total Year	Effective Power
2005	25	0	25	0	38	0	0	**88**	**71**
2006	65	385	25	0	38	0	0	**513**	**411**
2007	155	385	25	18	101	25	0	**709**	**564**
2008	0	381	25	18	101	25	0	**550**	**437**
2009	155	0	25	18	101	25	250	**574**	**406**
2010	400	381	25	18	38	25	0	**887**	**697**
2011	0	0	25	18	38	25	400	**506**	**312**
2012	0	0	25	18	38	25	0	**106**	**72**
2013	0	0	25	20	38	25	0	**108**	**73**
2014	0	0	0	0	0	0	0	**0**	**0**
Total	**800**	**1532**	**225**	**128**	**531**	**175**	**650**	**4041**	**3043**

As can be seen, the main difference between the two scenarios is that the alternative scenario replaces the inclusion of natural gas power in 2012 (758MW) by renewable energy. However, this power is distributed from the beginning of the period in the alternative scenario. This makes an important difference as will be seen when shocks occur.

Four additional scenarios are also studied. Given the recent gas supply crisis, natural gas supply restrictions of 30% and 50% are considered for the fourth and ninth years of evaluation and for both the baseline and alternative scenarios. These shocks enable examining how the system reacts before shocks in terms of supply and cost of failure.

4.4. Definition of Indicators

Different performance indicators are required to compare the different scenarios. These are evaluated using the results obtained from the simulations. As discussed previously, there are two main types of indicators: Non-monetary and monetary indicators.

Non-monetary indicators attempt o quantify the nature of each scenario in terms of number and frequency of failures as well as providing complementary information such as energy generation per type of source.

The following non-monetary indicators are defined for each scenario:

- **Generated Energy by each type of technology** (or source) Q_t . The simulations deliver the average energy each of the power plants provide to system for the different scenarios. Therefore, it is possible to aggregate energy generation according to the kind of energy. The figures are obtained for a trimester and can thus be used to obtain yearly data. For example, t may be hydroelectric or natural gas.
- **Energy Supply.** This indicator provides total energy supply (Q_s) and is obtained as the aggregation of energy supplies associated to all technologies. Let T be the set of energies considered in each construction schedule, then:

$$Q_S = \sum_{t \in T} Q_t$$

- **Unsupplied Demand.** The CNE provides annual projections of future energy demand. Therefore, it is possible to estimate directly the difference between the average supply (Q_S) and demand for each (Q_D) year considered. This estimation can also be calculated on a trimester basis using demand disaggregation factors[5]. Thus, the unsupplied energy for each period Q_D^U is given by:

$$Q_D^U = Q_D - Q_S$$

- **Number of Failures**. Each simulation consists of 1,440 runs which provide energy supplies and its associated marginal costs. When the costs correspond to failure costs a failure is present. Therefore, it is possible to establish in each simulation (one for each scenario) the number of failures.

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[5] These factor just decompose a year's demand consumption in each of the four trimesters.

- **Percentage of Failures** Thus, a first set of failure indicators is the number of failures present in each scenario and the percentage of failure defined the quotient between the runs with failure and total runs (1,440). This indicator reveals the frequency of failures of each construction scenario.

Monetary indicators are also defined. These indicators are useful to compare price levels, benefits and costs associated to the different scenarios:

- **Node Price (NP).** This indicator reflects average marginal operation costs under each scenario. It is calculated as the average marginal costs of the 1,440 runs.

$$NP = \frac{\sum_{I=1}^{1440} MC_i}{1,440}$$

- **Failure Price (FP).** Additionally, an indicator reflecting the average failure price (FP) is defined. Let F be the set of runs that present failure and f its cardinality (f = # F). Then the failure price is

$$FP = \frac{\sum_{i \in F} cmg_i}{f}$$

- **Social Cost of Failure (SC).** Finally, to establish the social cost of failure (SC) the unsupplied energy (Q_D^U) is valued at failure price. Thus this cost is estimated as

$$SC = FP \cdot Q_D^U$$

- **Investment and Operation Costs**. To evaluate the investment and operation costs of generation, unitary costs are considered for each type of technology. Therefore, for each technology investment and operation unitary costs are required. These are available in dollars per kWh. The investment costs are independent of the simulations and just require the construction schedule. Conversely, operation costs are estimated using the generated energy provided by the simulations in each scenario and for each technology.

5. Estimation of Environmental Benefits

The inclusion of renewable energies into the energy matrix accounts for environmental benefits. This research considers the estimation of health and agriculture benefits associated to ozone concentration reductions and health benefits for PM10 concentration reductions.

To estimate these impacts it is necessary to know the location of each generating plant and its surrounding topography, and atmospheric and weather conditions. These will determine the area affected and the corresponding concentration of each pollutant in each point. Subsequently, these concentrations can be used to estimate both health and agricultural impacts. Finally, these impacts can be valued.

However, to estimate concentrations is a difficult task. In the case of ozone complex models are required to represent the chemical processes involved in its formation. This analysis would consider ozone formation from the emissions of NOx and VOC emissions. The case of particulate matter is not so different since the main impact of thermal generating plants is due to secondary particulate matter. Thus, it is not feasible to model the pollution dispersion and formation in the short run. This fact is complicated even more by the lack of information about pollutants.

This problem implies existing models have to be used and only Santiago has models available. Thus, a hypothetical and simple case will be examined and independent from the security of supply scenarios. In fact, it will be supposed two existing plants in Santiago (Renca and Nueva Renca) will be removed from the system since it is feasible to establish the resulting environmental impact. However, the energy these generators contribute to the system must be replaced elsewhere in the system.

5.1. The Damage Function Approach Methodology

The dose response approach[6] for estimating environmental benefits is included in the indirect and non-demand methodologies. This means no willingness to pay estimates are obtained for a change in environmental quality. The damage function approach estimates the effects changes in pollution have on a variable of interest (health, agriculture, ecosystem, materials). These effects are captured in damage functions and the effects are subsequently valued.

The damage function approach quantifies physical effects of changes in pollution that are subsequently valued. One of the main advantages of this methodology is it makes the disaggregation of information possible in a useful way to design public policy. In fact, by disaggregating the effects, the decision-maker gets aware of relative costs and benefits making it feasible to focus limited resources.

This methodology requires the definition of two alternative scenarios. The first is the base scenario and the second an alternative scenario associated to a certain project. The comparison of both enables to determine the effects that are consequence of changes in the environmental variable. By assigning a monetary value to each effect it is possible to estimate the costs of benefits of the policy considered. In the case, environmental quality the number of adverse effects is reduced. It is this difference which is valued and considered as a benefit in terms of saved costs.

To evaluate benefits using the damage function approach a series of steps must be followed. The first consists in estimating the change in emissions (in this ozone of PM10) associated to the policy under study. That is an estimation of $\Delta E = E_C - E_B$ is obtained, where E stands for emissions, sub index c denotes the scenario with policy and b represents the baseline (case without policy).

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[6] This methodology is also known as dose response, or impact pathway approach.

This variation implies a change in air quality (concentrations). That is, the next step consists in estimating concentration variations as a result of changes in emissions. Let C represent concentrations, then this variation is represented by:

$$\Delta C = C(E_C) - C(E_B)$$

Subsequently, using concentration response functions the variation of effects is established.. This is so since these functions relate changes in air quality to health or agriculture impacts. For example, the reduction in concentrations of a given pollutant, the use of a mortality function provides the number of deaths that are avoided as a consequence of improved air quality. Thus, a function associated to endpoint i provides the variation of related cases (ΔH_i).

$$\Delta H_i = f(risk, population, incidence, \Delta C)$$

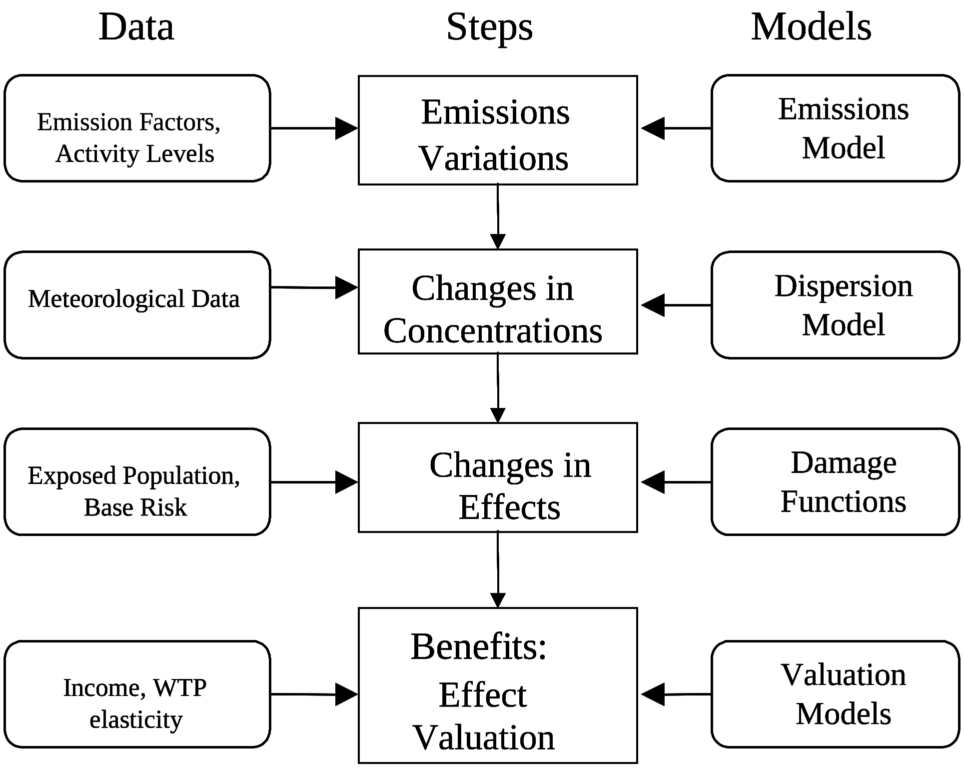
Finally, each effect is associated to a unit value (V_i) which is used to evaluate the benefits from the reduced number of cases. For example, if two death cases are avoided and each is valued at US$ 1 million then the benefits associated to the death endpoint are US$ 2 million. Finally, monetary benefits associated to each endpoint are aggregated. Thus, total health benefits associated to the air quality improvement (ΔT) in the case N endpoints are considered is given by:

$$\Delta T = \sum_{i=1}^{N} V_i \cdot \Delta H_i$$

5.2. Valuation of Health Benefits

The following figure summarizes the damage function approach and includes the data necessary for its application as well as the model associated to each stage.

Figure 1 Steps in the Damage Function Approach, Data Requirements and Models



5.2.1. Estimating Changes in Health Effects: Damage Functions

Damage functions are used to estimate changes in health effects. The health literature provides different functions which have different functional forms. The two most used functional forms of damage functions are linear and log-linear relations.

A linear relation between the incidence rate and concentrations is given by:

$$y = \alpha + \beta x$$

Where α incorporates all other independent variables in the regression used to estimate the parameters. The relation between the base incidence rate y_o and control incidence rate y_c associated to a change in concentrations from x_o to x_c is given by:

$$\Delta y = y_c - y_0 = \beta(x_c - x_0) = \beta\Delta x$$

A log-linear relation is defined as the incidence rate (y) as $y = Be^{\beta x}$ or equivalently $\ln(y) = \alpha + \beta x$, where B represents the incidence of y when concentrations of x are null, β is the coefficient associated to x and α=ln(B).

Then, the relation between Δx and Δy is expressed as follows:

$$\Delta y = y_c - y_0 = Be^{\beta x_c} - Be^{\beta x_0}$$

This implies:

$$\Delta y = Be^{\beta x_0}(e^{\beta(x_c - x_0)} - 1) = y_0(e^{\beta\Delta x} - 1)$$

Where y_o is the initial or base incidence.

Finally, the change in effects is estimated as the product between the incidence rate

5.2.2. Application of the Methodology to the Case Under Study

Santiago is divided into cells that make up a grid to carry out benefit estimation. The grids associated for ozone and PM10 are different. That is concentrations for both pollutants under study are estimated for the cells that make up the grid. Considering the spatial differenciation, the health models associated to each pollutant require to incorporate this issue.

In particular, the damage functions are modified. For the linear case, the change in effects associated to endpoint i in cell j (ΔH_{ij}) are:

$$\Delta H_{ij} = \beta_i \cdot \Delta x \cdot POP_{ij}$$

Where β_i represents the parameter associated to the damage function of the endpoint i and POP_{ij} represents the population in cell j exposed to the risk i.

Similarly, log-linear functions are expressed as:

$$\Delta H_{ij} = -\left[y_0 \cdot \left(e^{\beta\Delta x} - 1\right)\right] \cdot POP_{ij}$$

After having chosen a damage function for each endpoint, benefits can be estimated using unitary values as explained previously. The benefits of improved air quality associated to effect i in cell j (ΔT_{ij}) are expressed as:

$$\Delta T_{ij} = V_i \cdot \Delta H_{ij}$$

Then, the overall benefits associated to cell i are given by:

$$\Delta T_i = \sum_j \Delta T_{ij}$$

Finally, the aggregation of benefits over all endpoints results in total benefits:

$$\Delta T = \sum_i \Delta T_i$$

5.3. Valuation of Effects in Agriculture

The valuation of effects in agriculture is similar to that of health impacts. Agricultural production is highly affected by environmental conditions. In fact, air pollution has a negative impact in several agricultural species.

The damage generated by pollution depends on the concentration levels, the species under consideration and other production factors. The damage implies decreased producer and consumer surpluses due to supply contractions and quality consequences.

Agricultural crops are affected negatively mainly by three pollutants: ozone (O_3), sulfur dioxide (SO_2), and Nitrogen dioxide (NO_2). Cancino and Donoso (2003) point out ozone is the most critical pollutant. Only the impact of ozone (and its precursors) will be analyzed in order to establish its impact on agriculture.

According to Heck (1990), valuation of agricultural production requires several input data:

- Dose-response functions which relate changes in production to changes in air quality.

- Air quality information as detailed as possible.
- Performance of each of the species under consideration.
- Number of hectares used for each species
- Prices for each species

5.3.1. Dose-response Functions in Agriculture

The absence of national dose-response functions results in the need of using international information. The most recent studies have attempted to measure the cumulative damage experienced by the species (Centre for Ecology and Hydrology 2002, Wang and Mauzerall 2004). However, former studies will be used since the choice of these functions depends mainly on the similarities of the region where the study was made with those of the region to which these relations are to be transferred. Fortunately, most agricultural damage functions studies have been carried out in California, USA since the climatic conditions of this region are quite similar to those in Santiago.

From all species cultivated in the Metropolitan Region, it was possible to find dose-response functions for 18 of them, representing 64.6% of total agricultural fields. These are different kinds of onions, corn, lettuce, lemons, wheat, beans for internal consumption, export beans and other beans, fresh-consumption tomatoes, industrial tomatoes, white wheat, grapes, wine yards.

Those crops for which no relations were found were classified according to their level of sensitivity in: resistant, tolerant and sensitive. Then, a dose-response relation was assigned to these species by using a function for other crop with similar sensitivity. This assumption increases the coverage of agricultural lands to 72.8%. The remaining species could not be related to another and will not be included in the analysis. The following table includes those species to which another dose-response function is related.

Table 6 Species that use another's dose-response (D-R) function

Species	**Sensitivity**	**Associated D-R Function**
Peas	Sensitive	Tomato, lettuce, spinach
Oat	Sensitive	Tomato, lettuce, spinach
Cauliflower	Tolerant	Wheat, corn, beans
Melon	Sensitive	Tomato, lettuce, spinach
Nuts	Resistant	Soy
Potato	Sensitive	Tomato, lettuce, spinach
Carrot	Resistant	SOY

The lack of dose-response functions for some of the species, which are grown in the Metropolitan Region, results in underestimation of productive changes as a consequence of ozone variations. However, the information of the lands used for crops was obtained from the 1996-1997 agricultural census. Evidence suggests lands available for crops have diminished slightly due to agricultural parcelation (Cancino and Donoso, 2001). This results in an overestimation of effects. Unfortunately, it is not feasible to predict which of the two counter effects prevails.

Dose-response functions used in agriculture may have different functional forms. The forms that will be applied for the current study are polynomial and exponential. The polynomial and exponential functions may be expressed as:

$$Y = \alpha + \beta * C + \gamma C^2$$
$$Y_n = \exp\left(-\frac{C}{\delta}\right)^{\varepsilon}$$

Where "Y" represents the performance of the species under study, "Y_n" normal performance, and "α", "β", "δ", "ε", and "χ" are parameters.

5.3.2. Methodology

The procedure employed to estimate benefits or costs associated to NOx and VOC emission reductions or increases is explained below. First, scenarios must be compared to obtain emission reductions of NOx and VOC. Then, the photochemical model CADM uses these emissions to provide ozone concentrations. Then, concentration variations are used with dose-response functions to obtain the changes in the production levels of each species.

When working with not normalized production levels, the normalized production difference between the reduction and base scenarios is obtained by the following equation:

$$\Delta Yn_{ij} = Y_n(reduction)_{ij} - Y_n(base)_{ij}$$

When production levels associated to both scenarios are already normalized, the normalized production difference is given by:

$$\Delta Yn_{ij} = Y_n(reduction)_{ij} - Y_n(base)_{ij}$$

Where "Ybase_{ij}" and "Yn(base)_{ij} are measures of production level of species i in cell j under the base scenario, "Yreduction_{ij}" and "$\text{Yn(reduction)}_{ij}$ are measures of production level of species i in cell j under the reduction scenario, and ΔYn_{ij} represents the normalized change in production of species i in cell j. Finally, values are assigned to these changes using information of prices and performance for each of the species.

The literature generally proposes prices that consider the changes in supply that are consequence of adverse pollution effects (Center for Ecology and Hydrology 2002, Wang and Mauzerall 2004). However, this procedure is quite complex due to the need of estimating supply elasticities for each of the species considered. There are several studies, which just use market prices. The argument to support this approach is the production percentage affected is relatively small; thus, price markets are not modified.

The change in income associated to species i in cell j, "ΔI_{ij}" is obtained by the product of the price of the species "P_i", its performance "R_i", the number of hectares of species i in cell j "H_{ij}", and the production change related to species i in cell j "ΔY_{ij}".

$$\Delta I_{ij} = P_i \cdot R_i \cdot H_{ij} \cdot \Delta Y_{ij}$$

Then, the total change in income associated to species is obtained by the aggregation of income variations of all cells (J) in the grid:

$$\Delta I_i = \sum_{j=1}^{J} \Delta I_{ij}$$

Finally, total benefits for agriculture are obtained by adding the changes in income for each species.

$$\Delta I = \sum_{i=1}^{n} \Delta I_i$$

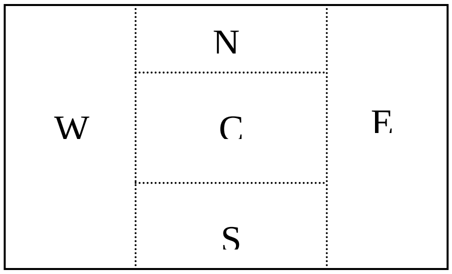
5.4. Grid and Dispersion Factors

As explained before, to estimate concentrations Santiago is divided into a grid. The methodology for estimating PM10 concentrations is being modified and will be presented in the next report. Thus, only the grid and dispersion factors related to ozone are presented.

To estimate ozone concentrations, the model CADM is used. The CADM is a photochemical model that estimates ozone concentrations from NOx and VOC emissions. The grid consists of 72*72 or 5184 cells. Thus, benefits are aggregated over these cells. This requires to estimate the population in each cell and the crops in each cell.

The CADM was used to estimate dispersion factors (Lemus 2005). To do so zones were defined in Santiago. These zones are: North (N), South (S), East (E), West (W) and Center (C).

Figure 6 Influence Zones



Most NOx and VOC emissions are generated in the center of Santiago. Thus, dispersion factors establish the impact changes in emissions in the zone C have on concentrations in all zones (N, S , E, W, C). This relation is expressed as:

$$\Delta C(Ozone)_i = \alpha_{i-C} \cdot \Delta E(VOC, NOx)_C$$

Where the index i represents any of the zones (N, S , E, W, C), $\Delta C(\text{Ozone})_i$ represents the change in concentrations in zone i, and $\Delta E(VOC, NOx)_C$ stands for the change on NOx and VOC emissions in zone C.

The emission concentration factors (or dispersion factors) for NOx and VOC are presented below. The units of these factors are $\left(\frac{\mu g / m^3}{kg / h / km^2}\right)$ and is interpreted as the change in ozone (ug/m^3) when reducing emissions in kg/h/km^2.

These factors were obtained for 20%, 40%, and 60% emission reductions (for both NOx and VOC). As can be seen in the tables below, there are positive and negative coefficients. This means ozone concentrations can increase (positive coefficients) or decrease (negative coefficients) with emissions reductions.

Table 7 Emission-Concentration Coefficients for NOx

	% EMISSION REDUCTIONS		
Zone	**20%**	**40%**	**60%**
E	1.8E-05	4.0E-06	8.1E-06
N	5.6E-06	3.7E-06	3.7E-06
C	(1.2E-05)	(2.0E-05)	(1.3E-05)
S	(9.6E-06)	2.6E-06	(1.0E-06)
W	(4.2E-05)	1.6E-05	(3.2E-06)

Table 8 Emission-Concentration Coefficients for VOC

	% EMISSION REDUCTIONS		
Zone	**20%**	**40%**	**60%**
E	8.6E-06	1.9E-06	3.7E-06
N	3.4E-06	1.6E-06	2.0E-06
C	5.9E-06	5.5E-07	5.2E-06
S	(1.5E-06)	2.0E-06	9.9E-07
W	(1.1E-05)	6.0E-09	1.1E-06

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