Integrated Environmental Strategies

Global and Local Environmental and Energy Security Benefits of the Development of the Renewable Energy Sector in Chile

O'Ryan and Febré Ingenieros Consultores

April 2006

National Renewable Energy Laboratory

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Project "Technical Support to IES Program in Chile"

Final Report

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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 Febre Ingenieros Consultores, USEPA and NREL. The objective of this phase is to assist the Chilean government with further developing clean energy strategies. The work was carried out by Raúl 0'Ryan (PhD) as head of the project and Jacques Clerc as assistant economist.

This work is in support of the IES program that 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 is the final of four reports considered in the project to examine the impact of the introduction of non conventional renewable resources into the Chilean energy matrix. It presents and analyzes the results obtained using the methodological framework defined to evaluate the costs and benefits of security of supply as well as local and global environmental benefits .

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.

In this report the impacts of introducing non-conventional renewable energies into the Chilean energy matrix are analyzed. The basic objectives are to present a comprehensive methodology to examine the issue of introducing NCRE's into the matrix, and to generate numbers that could allow examining whether NCRE's are an interesting option for the future development of the Chilean electric system.

Specifically, the evaluation considers two major tiers: the impacts on security of supply and the local and global environmental benefits. The local environmental analysis considers both human health benefits and benefits on agriculture. In agreement with the contracting party of the project, and due to lack of models and base information, the tiers are examined separately. Only Santiago has models that enable the estimation of environmental quality variations as a result of changes in the energy matrix. For this reason, the terms of reference state that tropospheric ozone and PM-10 concentration reductions in Santiago would be evaluated associated to the reductions in emissions of a gas-powered plant in the city. However, the availability of air quality measurements associated to changes in operation in thermal power plants of the Quillota Valley in the Region of Valparaiso, allowed complementing this analysis. Additionally, the reductions in global pollutants have been estimated.

The evaluation of the security of supply issue does not present the problem of lack of models. The most recent schedule plan for the entire Central Electric System of the country has been modeled as the baseline case. A second scenario considering alternative technologies is then compared to this baseline, considering both monetary and non-monetary indicators. Finally, the impact of gas supply shocks and different fuel prices are also compared for both scenarios.

As a result, the environmental analysis has been undertaken for two relevant –but different- settings, while the security of supply evaluation has been carried out considering the entire system of central Chile. Both evaluations allow establishing and comparing the magnitude of the impacts and serve as benchmarks for analysis of similar cases. This work is very timely given the recent passage of a Law that in part attempts to promote small suppliers to enter the system (Ley Corta) and the continual threat of natural gas shortages caused by Chile's primary supplier.

To obtain the proposed objective, the main activities of the project have been:

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 case.

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.

The second chapter describes the Chilean electric system particularly the regulatory institutions, the electric market and the legal regulatory framework. The third chapter introduces the security of supply concept and shows the international and Chilean experience on this issue. In the fourth chapter the methodological framework to establish costs associated to different energy-matrix scenarios is presented. The fifth Chapter presents the main monetary and non-monetary indicators associated to the introduction of non-conventional renewable energies into the chilean energy matrix. In the sixth chapter the environmental costs or benefits associated to the emission reduction of a thermal plant are established to get an idea of the impact substituting conventional energies for non-conventional renewable energies (NCRE). The seventh chapter presents potential benefits from greenhouse gas emission reductions if a typical thermal power plant is replaced by NCRE equivalent power. Finally, in chapter eight conclusions are drawn regarding the potential benefits of including NCRE into the Chilean energy matrix.

2. The Chilean Electric System

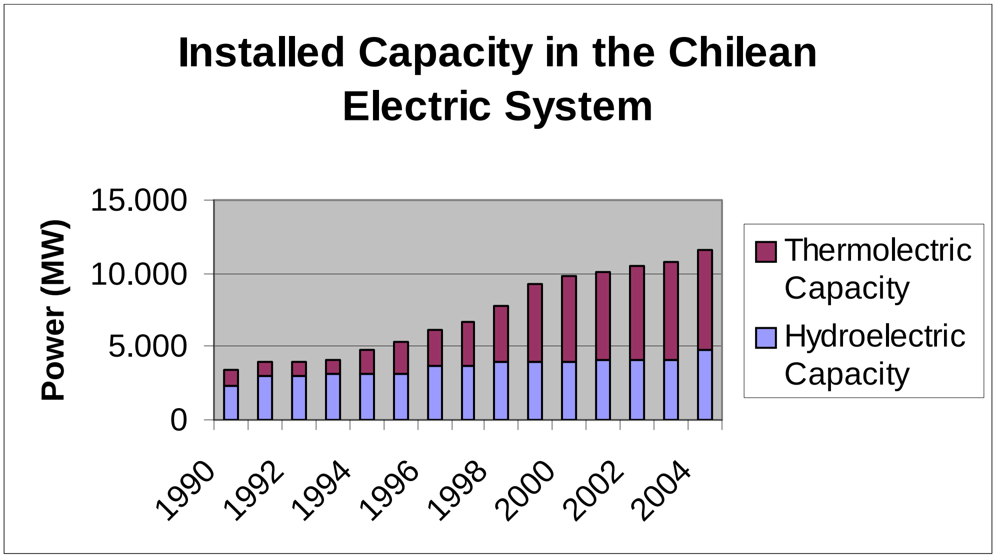
Chile was the first country in the world to deregulate and liberalize the electric sector. Up to 1980, electric regulation in Chile followed the usual pattern of contemporary electric systems: state-owned firms that were vertically integrated and subject to rate of return regulation. The operation of 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.

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 shows that in ten years installed capacity doubled, increasing from less than 4,000 MW in 1990 to almost 10,000 MW in 2000. In 2004, total installed capacity is 11,561 MW, 41% corresponds to hydroelectricity and 59% to thermal generation.

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

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



Source: Own elaboration based on public information obtained from CDEC.

Total country energy generation increased from 18,000 GWh in 1990 to more than 40,000 GWh in 2000, an annual growth rate of 8.5% over that decade. Total generation in 2004 reached almost 49,000 GWh.

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 over 70% of total energy is generated by thermoelectric power plants, basically gas 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%

Source: Own elaboration based on public information obtained from CDEC.

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 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

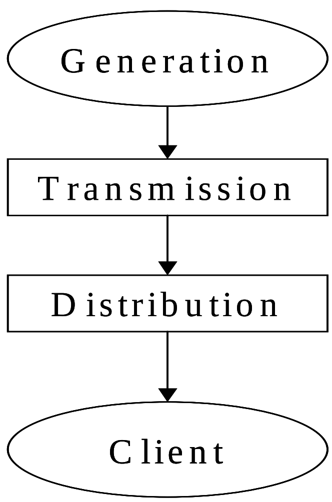
Electric System of Magallanes

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. Thermoelectric generators produce all the energy generated in this system. 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



Source: Own elaboration.

Generation Business

As discussed, generation of electricity is done mainly through 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 of energy.

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

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

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 Market for Electricity

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 price of electricity is set based on the real costs of electricity. Marginal generation cost is a first component. This 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 power 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 distribute it among the generators by the price mechanism.

The node price is the price at which generators sell their energy to trunk transmission firms which charge a fee for transportation of the energy (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 48 month period. This includes projected 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.

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

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 that 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 has been opened to this type 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].

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

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 that 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 compares 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

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 sectoral approach to the problem of security of supply. That is, internal factors of the sector have been subject to study and evaluation as stipulated by the legal Chilean framework. The following concepts are related to quality of supply and are considered in the Chilean legal framework:

- 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 concept 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.

What should be understood as security of supply has not been defined for Chile. A first step in this direction requires defining the scope in which the security of supply is to be considered. Two relatively similar definitions have been recently proposed[5]:

- 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 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 recently 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.

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[5] See Final report "Desarrollo de una Metodología para la Evaluación Económica y Social del Impacto de Energías Renovables No Convencionales", 2004.

4.1. Conceptual Framework to Estimate the Social Cost of Failure

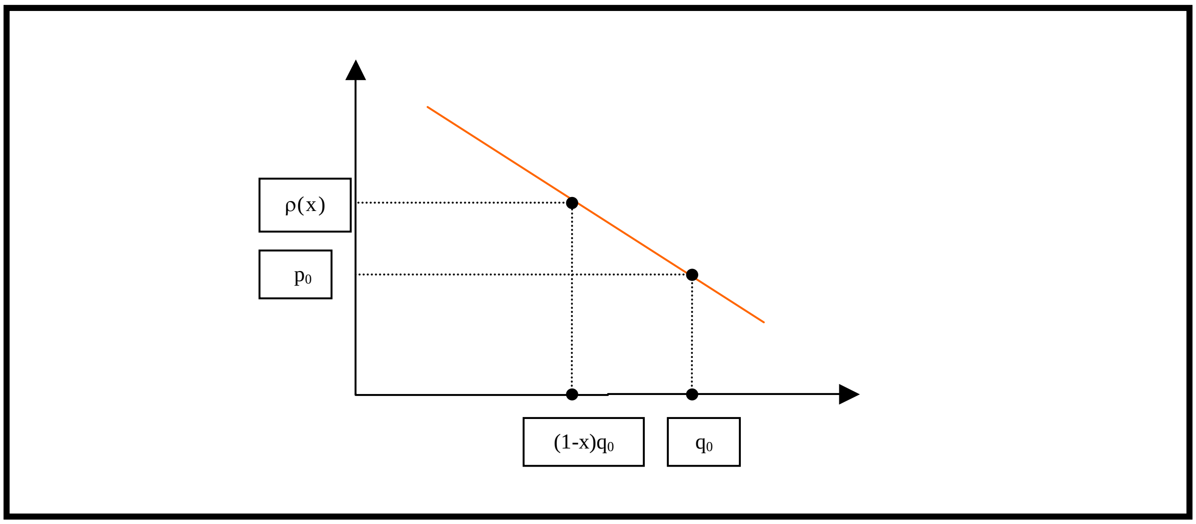
The social cost of failure (commonly known as failure cost) is defined as the cost users pay on average for not disposing of one KWh. This cost attempts to measure the social costs associated to electricity supply restrictions.

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 the average (unit) cost of failures according to the percentage of unsupplied energy[6]. Specifically, average costs of failure are determined for supply restrictions of 5, 10, 20 and 30%, and associated to periods of 1, 2 and 10 months. To weigh the occurrence of the three scenarios (1, 2 and 10 months) only 1 and 2 month scenarios are considered to be feasible and the costs of these scenarios are averaged.

The following table presents social costs of failure as function of unsupplied demand as determined by the last CNE estimation.

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

Unit Cost of Failure	Type I 0-5%	Type II 5-10%	Type III 10-20%	Type IV Over 20%
(US$/MWh)	306.2	338.7	432.8	453.4

Source: CNE (October, 2005)

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

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.

[6] Twice each year the CNE provides a technical report which explains how nodal prices are estimated . These reports include cost of failure estimations that are necessary for this price determination.

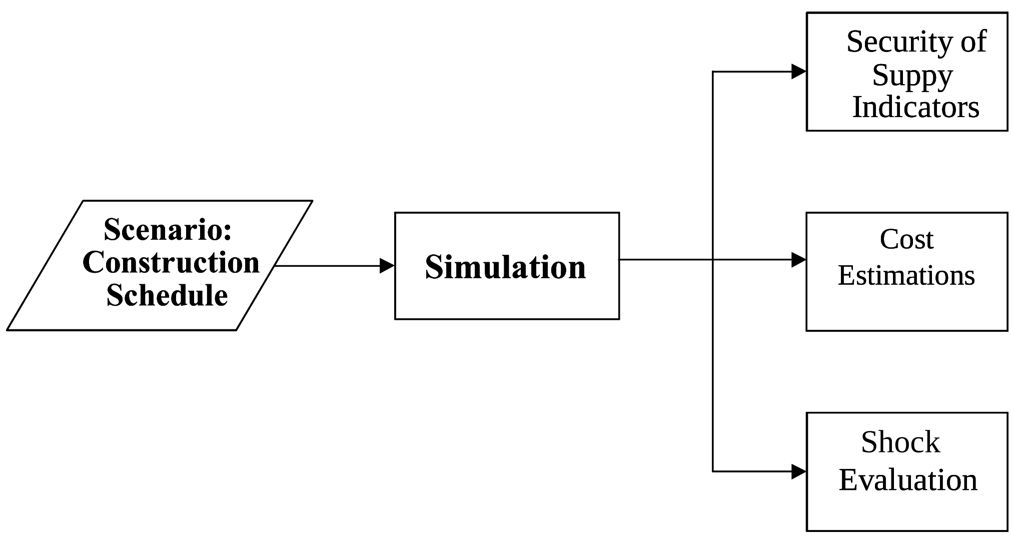
The development scheme of the electric sector for a period is required as an input for the simulation model which evaluates the system's performance and development. The values obtained by the simulation are the input for the evaluation of the indicators and costs of each of the scenarios considered.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

To evaluate the scenarios two main types of indicators are defined. The first set of indicators refers 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 4.5.

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:



Source: Own elaboration.

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 outputs 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.

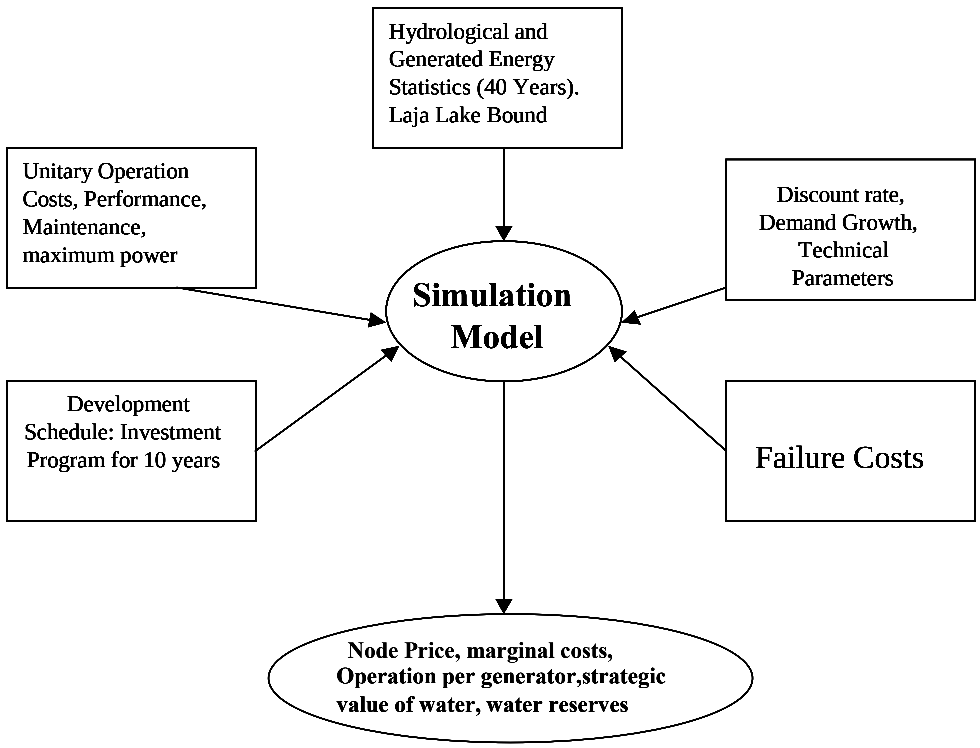
4. Cost Estimation: Investment and Operation Costs are estimated for each considered in the simulation. This enables policymakers to have a first estimation of the costs necessary to reach different security of supply targets.

5. Shock and Input Price Scenario Evaluation: The last stage of the methodology consists of determining the degree of reliability of the system. For this purpose shocks are examined. In particular, it is possible to examine restrictions on natural gas availability or input price variations which are current issues of the sector. The simulation of shocks enables to quantify the impacts of undesired scenarios over different construction schedules.

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:

This general methodology is applied to the particular case of the Central Interconnected System. The period considered is 10 years (2006-2015).

Figure 5: Inputs and Outputs of GOL Simulation Model



Source: Own elaboration based on public information obtained from CDEC.

4.3. Scenario Definition

As explained above simulations are carried out assuming a specific development or construction schedule of the electric system. Two major scenarios are considered and compared for two different construction schedules. 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). It only considers 3% of NCRE's. This scenario will be referred to as the *baseline scenario*.

A second major scenario considers an alternative construction schedule of the electric sector that includes more NCRE's than the baseline scenario. The renewable energies replace conventional sources in the original plan with equivalent power. In this scenario almost 22% of total new power corresponds to non-conventional renewable energies. As a result, the energy matrix would have 9% renewable energy installed power by the end of the period. 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 main 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	0.7
	Natural Gas	0.965
	Compressed Natural Gas (CNG)	0.965
	Diesel	0.950
	Coal	0.950
	Others	0.6
NCRE	Mini Hydro	0.6
	Small wind	0.550
	Geothermal	0.95
	Biomass	0.9

Source: Department of Electric Engineering, University of Chile (2006)

The table below shows the main new energy sources for the baseline scenario. The baseline scenario is made up mainly of coal and CNG that correspond to 43% and 34% of the new nominal capacity. The baseline also includes 5% geothermal energy in the period considered. The 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 October 2005.

Table 4 Development Schedule of Baseline Scenario (Mega Watts)

Year	Hydro	CNG	Coal	NG	Geo	Total	Effective Power
2006	25					25	17.5
2007	157	350		125		632	568.0
2008	155					155	108.5
2009	145	420	400			965	895.4
2010		510	400		100	1010	975.7
2011		125	400		100	625	604.4
2012	403	125			100	628	497.7
2013		125	400			525	509.4
2014		125	400			525	509.4
2015		125	400			525	509.4
Total	**885**	**1905**	**2400**	**125**	**300**	**5615**	**5195.2**

Source: Own elaboration based on CNE (2005).

The development schedule associated to the alternative scenario includes a more important participation of non-conventional renewable energies. Geothermal capacity is increased and small wind, 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	CNG	Coal	NG	Mini Hydro	Small wind	Geo	Biomass	Total	Effective Power
2006	25	0	0	0	20		0	10	**55**	**38.5**
2007	157	350	0	125	30	21	0	15	**698**	**611.1**
2008	155	0	0	0	30	30	0	15	**230**	**156.5**
2009	145	35	400	0	30	30	0	15	**655**	**563.3**
2010	0	510	400	0	30	30	100	15	**1085**	**1014.9**
2011	0	0	400	0	30	30	100	15	**575**	**523.0**
2012	403	125	0	0	30	30	100	15	**703**	**545.7**
2013	0	0	400	0	30	30	100	15	**575**	**523.0**
2014	0	125	400	0	30	30	100	15	**700**	**643.6**
2015	0	0	400	0	30	30	100	15	**575**	**523.0**
Total	**885**	**1145**	**2400**	**125**	**290**	**261**	**600**	**145**	**5851**	**5142.5**

Source: Own elaboration.

As can be seen, the main difference between the two scenarios is that the alternative scenario replaces 760 MW of CNG by renewable energy. The power replaced is distributed from the beginning of the period in the alternative scenario. This makes an important difference as will be seen when shocks occur.

Additional to the two main scenarios, other scenarios are also examined. First, a shock to natural gas supply is considered. Given the recent gas supply crisis, natural gas supply restrictions of 50% are considered in 2008 and 2012 for both the base and alternative scenarios. In 2008 it is assumed 50% of restricted natural gas can be replaced by diesel, and in 2012 the assumption is 80% of restricted natural gas can be replaced by CNG[7].

Two additional scenarios are also evaluated to study how each construction schedule responds to input price changes. These scenarios consider different price scenarios for CNG and coal from the ones assumed by CNE. The CNE uses a price of 4 US$/Mbtu for CNG and 60 US$/Ton in the case of coal throughout the period. The scenarios proposed for both the base and alternative scenarios consists in increasing the CNG price in 100% and coal price in 33%.

[7] These assumptions were suggested by experts from Electric Engineering Department, University of Chile.

4.4 Scenario Analysis

The simulations of the operation of the Chilean Interconnected Central Electric System allow analyzing the costs and security of supply under the different construction schedules and for different scenarios within each construction schedule. To be coherent with the simulation model, the analysis considers demand for electricity is inelastic[8].

Comparison Within a Given Construction Schedule

The presence of a shock due to natural gas restrictions or a change in fuel prices modifies the costs of the system in each construction schedule. The following analysis attempts to capture the welfare implications of shocks within a given scenario.

A shock has impacts on the operation of the system. Let P_b be the initial price of the system in a given scenario and is represented by the intersection of marginal cost and demand curves. A shock modifies the costs of the system. Generally, the initial part of the marginal cost curve does not change since the most economical technology is hydro generation. Given the shocks presented, this curve changes in the thermal segment of the curve which determines the marginal cost of the system.The change in the marginal cost curve implies that equilibrium marginal cost –and consequently price- rises to P_c.

In some cases, supply may only reach a value of $q_s < q$ that does not suffice to satisfy demand requirements. There will be an amount of $(q-q_s)$ of unsupplied demand, therefore the system will present failures. This is the case of natural gas restrictions where the restricted input may be replaced but only partially by another input substitute such as diesel.

To estimate welfare implications, changes in the associated benefits to producers, consumers and failure costs must be quantified. Producers modify their benefits due to the

[8] In fact, demand predictions for the ten-year period are used.

changes in marginal cost and subsequent price change. This variation is the change in income minus the change in operation costs (CO) presented in the following equation[9]:

$$\Delta B_p = P_c q_s - P_b q - (CO^c(q_s) - CO\ (q))$$

Consumer expenditure is used to represent changes in consumer benefits. The variation in expenditure consumers experience as a result of the corresponding price increase (and possible change in quantity) is:

$$\Delta B_{con} = -(P_c q_s - P_b q)$$

This change in income $P_c q_s - P_b q$ is a transfer from consumers to producers and will have no impact on overall benefits.

However, to obtain the aggregate change in benefits due to the shock, it is necessary to add the social costs of failure (CF) to the sum of the changes in producer and consumer benefits. Thus, costs of failure are considered as an external cost. As a result:

$$\Delta B = \Delta B_p + \Delta B_{con} + \Delta B_{ext} = -(CO_b^c(q_s) - CO_b(q)) - \Delta CF = -\Delta CO - \Delta CF$$

Consequently, changes in benefits due to a shock (input restriction or price increase) are a loss in welfare. This loss is obtained as the sum between variation in operation and failure costs. The other costs are transferes among consumers and producers.

Comparison Between Alternative Construction Schedules

When comparing different construction or development schedules, a similar approach is followed. The main difference is investment costs are considered. That is, investment is also included in the benefit analysis and might be key in the ex ante decision of choice of the construction plan.

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9 CO^c represents total operation costs in the presence of shocks and CO the base costs (or without shocks).

The analysis consists of determining the relative costs of both scenarios and may or not consider shocks or price scenarios. Assuming a base (b) scenario is compared to an alternative (a) scenario, changes in producer benefits include relative income, operation costs (CO) and investment (CI):

$$\Delta B_p = (P_a q_a - P_b q_b) - (C_a(q_a) - C_b(q_b)) - (CI_a - CI_b)$$

Similarly, relative consumer benefits are:

$$\Delta B_{con} = -(P_a q_a - P_b q_b)$$

Finally, relative external benefits are considered. In this section, only cost of failure is included in the external cost category. Yet, a complete analysis including environmental benefits should be included[10].

Thus, relative benefits between two scenarios are $\Delta B = -\Delta CO - \Delta CI - \Delta CF$.

4.5 Definition of Indicators

Different performance indicators are required to help compare the different scenarios. As discussed previously, there are two main types of indicators: Non-monetary and monetary indicators.

Non-monetary indicators attempt to 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:

[10] As explained later, there is not enough information and models to incorporate this analysis in the entire SIC.

- **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. It is an indicator of expected supply. 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 disaggregating factors[11]. Thus, the unsupplied energy for each period Q_D^U is given by:

$$Q_D^U = Q_D - Q_S$$

- **Probability of Failure.**

  Each simulation consists of 1,440 runs that provide energy supplies and its associated marginal costs. When the costs correspond to failure costs a failure is present and visible in the results of the simulation. Thus, these costs show the presence of failures or the existence of unsupplied demand. However, the simulation model does not show the amount of this unsupply[12].

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[11] These factor just decompose a year’s demand consumption in each of the four trimesters.
[12] These amounts are delivered as expected values and not for each case.

The good thing is the model directly delivers two different probabilities of failure: The probability of having a failure of more than 1GWh, and the probability of having a failure of more than 10% demand.

The model estimates these probabilities by the following formulas:

$$\Pr ob[\,failure > 1GWh] = \frac{number \;\; of \;\; simulations \;\; with\, failures \;\; > 1GWh}{1440}$$

$$\Pr ob[\,failure > 10\% Demand] = \frac{number \;\; of \;\; simulations \;\; with\, failures \;\; > 10\% Demand}{1440}$$

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 an estimator of expected average marginal cost or node price[13]. It is calculated as the average marginal costs of the 1,440 runs.

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

- **Social Cost of Failure (SC).**

  The social cost of failure is used to value unsupplied demand. To carry out this task would require knowing how the resulting unsupplied demand derived from the simulations is distributed among the different types of failure. The model delivers the value of expected cost of failure.

[13] This indicator neglects price regulation regarding the relation between node price and free contract prices.

$$SC = \frac{\sum_{i \in F} CF_i \cdot Q_D^U}{1400}$$

- **Investment and Operation Costs**.

The CNE has costs for each of the existing plants which currently operate in the SIC and project operation costs for those included in the official construction schedule. These costs are incorporated in the simulation model that is used to determine prices and predict efficient operation of the system. These costs mainly consist of fuel costs for thermal plants. Hydro, mini-hydro, and small wind plants are assumed to have null operation costs since these require of no fuels.

The following table shows the costs of existing and officially projected plants according to CNE and as included in the simulation model.

Table 6 Operation (Variable) Costs of Plants in the Base Scenario [US$/MWh]

Name Of Plant	Identifier	Technology	Total Variable Costs [US$/MWh]
Arauco 1	arau	Biomass	45.94
Celco 2	cbv2	Biomass	6.26
Celco 4	cel4	Biomass	20.57
Celco 5	cel5	Biomass	30.85
licanten0	lic0	Biomass	20.57
licanten1	lisg	Biomass	119.08
valdivia3	val3	Biomass	44.34
valdivia4	val4	Biomass	49.06
valdivia5	val5	Biomass	60.38
valdivia6	v63c	Biomass	79.25
Celco 6	cel6	Biomass	154.25
Nueva Aldea 1	nal1	Biomass	13.54

cholguan0	cho1	Biomass	10.05
cholguan1	cho2	Biomass	58.07
Nehuenco I Diesel	n1ds	Diesel	111.25
Petropower	petr	Diesel	3.92
Renca	renc	Diesel	214.08
Nueva Renca Diesel	nrds	Diesel	102.24
San Isidro Diesel	sids	Diesel	118.10
Diego Almago TG	dalm	Diesel	198.46
Huasco TG	hctg	Diesel	131.89
Laguna Verde TG	lvtg	Diesel	150.33
Taltal2 Diesel	tald	Diesel	170.78
Nehuenco 9B Diesel I	n9d1	Diesel	193.99
Nehuenco 9B Diesel II	n9d2	Diesel	219.09
EV25	ev25	Diesel	153.43
Turbina Cenelca	tce1	Diesel	153.22
Candelaria CA Diesel I	cad1	Diesel	177.77
Campanario CA Diesel	camd	Diesel	70.28
Turbina Cenelca II	tce2	Diesel	153.22
Ancud	chle	Diesel	152.23
Nueva Aldea 2 Diesel	na2d	Diesel	0.00
Candelaria CA Diesel II	ca2d	Diesel	177.56
Bocamina	boca	Coal	33.21
Guacolda I	guac	Coal	19.95
Huasco TV	hcov	Coal	110.03
Laguna Verde	lver	Coal	81.25
Ventana I	vent	Coal	35.02
Generación Carbón	ccbn	Coal	23.35
Horcones TG	horc	Natural Gas	76.02
Nehuenco I	neh1	Natural Gas	23.56
Nueva Renca	nren	Natural Gas	16.60
San Isidro	sisi	Natural Gas	20.98
San Isidro FA CNG	sifl	Natural Gas	56.74
Taltal1	tal1	Natural Gas	24.65
Nehuenco 9B CNG I	n9gl	Natural Gas	53.52
Nehuenco II	neh2	Natural Gas	17.55
Turbina PSEG	pseg	Natural Gas	23.64
Campanario CA	camp	Natural Gas	19.76
Nueva Aldea 2 Gas	na2g	Natural Gas	58.04
Geothermal	geo	Geothermal	2.2
Nehuenco I FA CNG	n1fl	CNG	39.54
Nehuenco I CNG	n1gl	CNG	33.96
Nueva Renca Int CNG	nril	CNG	36.96
Nueva Renca CNG	nrgl	CNG	30.98
San Isidro CNG	sigl	CNG	34.41

Candelaria CA CNG	cagl	CNG	45.14
Campanario CA CNG	caml	CNG	45.91
Generación CNG	cgnl	CNG	28.83
Generación CNG FA	cglf	CNG	37.94
Nehuenco 9B CNG II	n92g	CNG	77.49

Source: CNE (2005)

To evaluate the investment costs of generation, the CNE also has available values for the plants considered in the base scenario. In the alternative, unitary costs are considered for renewable-energy investments. The investment costs are independent of the simulations and just require the construction schedule.

Table 7 Investments by Type of Technology (US$/KW)

Hydro	950.76
Natural Gas	651.88
Diesel	934.21
Coal	1200
Mini Hydro	1000
Small wind	1400
Geothermal	1420
Biomass	2000

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

5. Security of Supply Monetary and Non Monetary Indicators Associated to the Introduction of NCRE's into the Chilean Energy Matrix.

This section presents the results obtained from the simulations of the different scenarios and the corresponding monetary and non monetary indicators. These are used to examine the impact of the introduction of NCRE's on security of supply. Although the analysis was made using trimester data from the simulations, the results are shown annually for simplicity.

5.1 Non-monetary Indicators

- **Generated Energy by each type of technology and Energy Supply**

These results are obtained directly from the simulations and trimester data were aggregated to annual data considering the hydrological year[14]. The table below shows the annual generated energy for each type of energy under the base scenario.

Table 8 Generated Energy for Each Type of Fuel under the Base Scenario (GWh)

Technology	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Hydro	25,000	25,626	27,233	27,304	26,988	27,143	27,844	28,572	28,256	27,512
Natural Gas	7,976	8,500	8,212	11,375	11,412	11,377	11,365	11,362	11,352	11,407
CNG	0	1,503	2,576	4,990	7,078	7,338	8,132	8,702	9,730	11,398
Coal	4,809	4,949	5,029	6,899	8,346	11,061	12,586	15,171	18,745	22,414
Oil	2,506	2,870	3,912	535	485	468	460	458	459	456
Geo	0	0	0	0	423	1,235	2,046	2,436	2,436	2,436
Biomass	959	971	1,020	657	634	616	614	612	609	617
Total	**41,250**	**44,418**	**47,981**	**51,761**	**55,365**	**59,238**	**63,048**	**67,314**	**71,586**	**76,240**

Source: Own elaboration.

These results represent average generated energy of the system considering fluctuations of water availability. The table shows total generation (supply) grows on average 7% every year. This is a consequence of the increase in energy demand and in installed capacity.

It can also be seen hydroelectric generation grows about 10% during the ten-year period but on average it grows around 1% a year. This together with the fact of more steeper growth of other fuel generations explain why hydroelectric energy's participation in total energy generation falls from 61% to 36% in the entire evaluation period. The opposite occurs with thermal generation which increases from 39% to 64%[15].

The table below shows the generated energy under the alternative scenario. These energies include both conventional and non-conventional sources.

[14] The hydrological year 2006 starts in April 2006 and ends in March 2007.
[15] This figures include geothermal and biomass generation.

Table 9 Generation in the Alternative Scenario (GWh)

Technology	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Hydro	25,012	25,638	27,352	27,447	27,087	27,170	28,054	28,992	29,241	28,352
Natural Gas	7,946	8,397	8,115	11,161	11,256	11,218	11,186	10,937	10,877	11,029
CNG	0	1,451	2,318	4,129	5,622	5,618	5,726	5,423	4,962	6,040
Coal	4,780	4,824	4,846	6,411	7,980	10,595	12,004	14,261	17,569	20,963
Oil	2,382	2,540	3,340	485	464	457	456	456	456	456
Geo	0	0	0	0	423	1,235	2,256	3,457	4,269	4,872
Biomass	992	1,137	1,299	1,082	1,182	1,293	1,410	1,531	1,651	1,743
Mini Hydro	118	302	459	617	775	932	1,090	1,248	1,406	1,524
Small wind	26	142	289	431	578	720	867	1,009	1,156	1,262
Total	**41,256**	**44,429**	**48,017**	**51,763**	**55,367**	**59,238**	**63,049**	**67,312**	**71,586**	**76,240**

Source: Own elaboration.

Thermal generation in the alternative scenario increases but at a lower rate than the one observed in the base scenario (recall the main difference between the two scenarios is CNG plants being replaced for renewable energies). On average, in the alternative scenario both coal and oil generation descreases 5% On the other hand, the replacement of CNG increases hydro generation on about 1% in the alternative scenario. The table below shows the participation of conventional and NCRE in annual generation under the alternative scenario.

Table 10 Generation of Conventional versus Renewable Energies in the Alternative Scenario (GWh)

Year	Conventional	% Conventional	Renewable	% Renewable	Supply
2006	40,120	97.2%	1,136	2.8%	41,256
2007	42,849	96.4%	1,581	3.6%	44,429
2008	45,970	95.7%	2,047	4.3%	48,017
2009	49,633	95.9%	2,130	4.1%	51,763
2010	52,410	94.7%	2,957	5.3%	55,367
2011	55,057	92.9%	4,180	7.1%	59,238
2012	57,426	91.1%	5,623	8.9%	63,049
2013	60,068	89.2%	7,244	10.8%	67,312
2014	63,105	88.2%	8,481	11.8%	71,586
2015	66,840	87.7%	9,400	12.3%	76,240

Source: Own elaboration.

The results show participation of renewable energies grows steadily in resulting total supply in the alternative scenario. In fact, the participation of renewable energies in total supply grows from less than 3% in 2006 to more than 12% in 2015.

The results also show geothermal energy provides most of the energy generated from these type of fuels. In fact, geothermal generation represents on average 38% of renewable supply every year (considering 2010 onwards). In fact, in 2005 geothermal participation of renewable supply represents 14% and reaches more than 50% in 2015.

On the other hand, small wind energy shows the smallest participation in renewable energy generation representing on average almost 14%,

- **Unsupplied Demand**

As explained previously, the CNE provides projections of future energy demand. This indicator is used to estimate expected energy unsupply. Considering demand a deterministic variable and the average of total supply, it is possible to estimate average unsupply as the difference between both.

This indicator is presented in table below for the base and alternative scenarios. The shocks (natural gas restrictions considered in 2008 and 2012) and increased input price scenarios are also included.

Table 11 Demand and Percentage Unsupply for Each Year

		Base Scenario			Alternative Scenario		
Year	**Demand**	**Base**	**50% Shock**	**Price**	**Alternative**	**50% Shock**	**Price**
2006	41,273	0.06%	0.05%	0.06%	0.04%	0.04%	0.04%
2007	44,446	0.07%	0.10%	0.07%	0.04%	0.07%	0.04%
2008	48,065	0.20%	0.37%	0.20%	0.12%	0.25%	0.12%
2009	51,762	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%
2010	55,366	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
2011	59,238	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

2012	63,048	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
2013	67,313	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
2014	71,586	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
2015	76,239	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Source: Own elaboration.

Average unsupply in both the base scenario is 0.03% and 0.02% in the alternative scenario in the entire ten-year period. These figures are maintained in the high price scenarios since there are just price adjustments and no new failures.

In the presence of gas shocks differences arise. In fact, under the 50% shock case, the alternative scenario has a lower percentage of 0.040% while the base scenario 0.050% average unsupply.

The results also reveal the 2008 gas restriction increases unsupplied demand and thus increases expected failures since diesel is capable of replacing only 50% of missing required natural gas. However, the 2012 shock does not have impacts on unsupply or failures implying CNG replacing 80% of restricted natural gas suffices to maintain the level of reliability of the system.

- **Probability of Failure Indicators**

The following table presents the probability of having a failure larger than 1GWh.

Table 12 Probability of Presenting a Failure larger than 1 GWh (%)

Year	Base Scenario			Alternative Scenario		
	Base	**50% Shock**	**Price**	**Alternative**	**50% Shock**	**Price**
2006	6.7	6.7	6.7	4.8	4.8	4.8
2007	4.7	6.5	4.7	3.8	5.3	3.8
2008	6.9	9	6.8	5.7	7.6	5.7
2009	1.5	1.7	1.5	0.2	0.2	0.2
2010	0.6	0.6	0.8	0.1	0.1	0.1
2011	0.2	0.2	0.2	0	0	0

2012	0	0	0	0	0	0
2013	0	0	0	0	0	0
2014	0	0	0	0	0	0
2015	0	0	0	0	0	0

Source: Own elaboration.

The base scenario presents a probability of failure slightly higher than the alternative scenario. Results coincide with unsupply results and as expected input price increases do not change these probabilities. Also as expected, the gas shock is only significant in 2008.

The indicator of the probability of failure greater than 10% demand is null in all cases and years except for the 50% shock scenario in 2008. In this case, the probability is 0.5% in the base scenario and 0.1% in the alternative scenario.

5.2 Monetary Indicators

- **Node Price**

The 1440 simulations also show marginal costs of operation for each trimester. The average of the 1140 simulations under each scenario is the node price of the system. The node price reveals average marginal costs of energy generation. The average node prices[16] for each hydrological year are presented in the table below.

Table 13 Node Price for Each Scenario (US$/kWh)

Year	Base Scenario			Alternative Scenario		
	Base	50% Shock	Price	Alternative	50% Shock	Price
2006	82.7	83.3	83.2	79.8	80.6	80.5
2007	85.4	91.3	87.6	79.3	85.3	81.7
2008	99.5	116.9	103.6	89.3	105.6	93.2
2009	39.3	40.4	55.2	34.8	35.5	49.2
2010	34.7	35	53.9	31.6	31.8	48.4
2011	31.9	32.8	51.5	29.7	30.5	45.9
2012	31.4	33.1	51.2	28.7	30.4	45.4

[16] Annual average is obtained as the mean of the node prices for the four trimesters in each year.

2013	31	31.1	50.4	28	28	43.9
2014	30.8	30.8	50	27.3	27.3	43
2015	32.1	32.1	52.4	27.4	27.4	44

Source: Own elaboration.

The table shows the highest values of the expected node price are found in the presence of shocks. In fact the average node price in 2008 reaches US$117 under the base scenario and US$106 in the alternative scenario with 50% shock. It can also be observed, the node price is lower under the alternative scenario than in the base case. Finally, the price scenarios reveal marginal costs are lower under the alternative scenarios.

- **Social Cost Of Failure**

The social cost of failure provides an estimation of the expected value of failure. This indicator is presented in the figure below:

Table 14 Social Cost of Failure (Million US $)

Year	Base Scenario			Alternative Scenario		
	Base	50% Shock	Price	Alternative	50% Shock	Price
2006	7	7	7	5	5	5
2007	9	13	8	5	9	5
2008	25	47	25	14	31	14
2009	1	1	1	0	0	0
2010	0	1	0	0	0	0
2011	0	0	0	0	0	0
2012	0	0	0	0	0	0
2013	0	0	0	0	0	0
2014	0	0	0	0	0	0
2015	0	0	0	0	0	0
NPV	**37**	**60**	**36**	**22**	**40**	**22**

Source: Own elaboration.

The table shows the NPV of costs associated to the base scenario is higher than the one associated to the alternative scenario. In fact, in the absence of shocks, the base scenario's associated NPV is 15 million higher. The difference grows in the presence of shocks reaching 20 million in the 50% shock case.

It can also be observed, the highest expected costs of unsupply are found in the cases and years that present shocks due to the high number of failures. The year 2007 presents relatively high values as expected since the period includes relatively a high frequency of failure. Finally, and as expected, price scenarios do not change failure costs.

- **Investment and Operating Costs**

The construction schedules defined previously make it possible to establish investment costs in the base and alternative scenarios. These are presented in the tables below as well as the present value of these investments for the year 2006 using 8% discount rate as proposed by the regulator.

Table 15 Investment Costs in Baseline Scenario (MillionUS $)

Year	Hydro	CNG	Diesel	Coal	NatGas	Geoth	Total
2006	31						**31**
2007	170	232			68		**470**
2008	170						**170**
2009	144	268		490			**902**
2010		315		490		**142**	**947**
2011		68		490		**142**	**700**
2012	430	68				**142**	**640**
2013		68		490			**558**
2014		68		490			**558**
2015		68		490			**558**
NPV	**765**	**910**	**0**	**2265**	**63**	**366**	**3810**

Source: Own elaboration.

Table 16 Investment Costs in Alternative Scenario (MillionUS $)

Year	Hydro.	CNG	Diesel	Coal	NatGas	Mini Hydro	Small wind	Geo	Biomass	Total
2006	31					20			20	**71**
2007	170	232			68	30	29		30	**559**
2008	170					30	42		30	**272**
2009	144	22		490		30	42		30	**758**
2010		315		490		30	42	142	30	**1049**
2011		0		490		30	42	142	30	**734**
2012	430	68				30	42	142	30	**742**
2013		0		490		30	42	142	30	**734**
2014		68		490		30	42	142	30	**802**
2015		0		490		30	42	142	30	**734**
NPV	**765**	**570**	**0**	**2265**	**63**	**207**	**251**	**656**	**207**	**4391**

Source: Own elaboration.

As can be observed alternative scenario considers significantly lower investments in CNG plants, replacing them by non-conventional technologies. However, the higher investment costs of renewable energies make the alternative scenario investments US$581 million higher than in the alternative scenario.

The results of generated energy per type of technology can be used to obtain operating costs in each scenario. The following tables present these costs for the base and alternative scenarios.

Table 17 Operation Costs in the Base Scenario (Million US $)

	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Biomass	27	28	32	8	6	5	5	5	4	5
Oil	256	287	421	15	6	4	2	2	2	2
Coal	140	145	148	167	196	257	292	352	435	525
Natural Gas	159	174	171	227	227	225	224	224	224	225
CNG	0	43	74	154	213	217	239	256	284	335
Geo	0	0	0	0	1	3	4	5	5	5
Hydro	0	0	0	0	0	0	0	0	0	0
Total	**583**	**676**	**847**	**570**	**649**	**710**	**768**	**844**	**956**	**1,097**

Source: Own elaboration.

The present value of operation costs in this scenario is US $5,390 million using an 8% discount rate.

Table 18 Operation Costs in the alternative Scenario (Million US $)

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Biomass	26	25	29	7	5	4	4	4	4	4
Oil	239	246	345	6	3	2	2	2	2	2
Coal	139	140	141	151	185	244	276	327	403	482
Natural Gas	159	171	168	221	222	221	220	214	212	216
CNG	0	42	67	126	168	165	167	158	144	175
Hydro	0	0	0	0	0	0	0	0	0	0
Geo	0	0	0	0	1	3	5	8	10	12
Mini Hydro	0	0	0	0	0	0	0	0	0	0
Small wind	0	0	0	0	0	0	0	0	0	0
Total	**563**	**624**	**750**	**511**	**584**	**639**	**674**	**713**	**775**	**890**

Source: Own elaboration.

The present value of this scenario is US $4,759 million using an 8% discount rate.

As can be seen, the present value of operating costs is lower in the alternative scenario. In fact, the base scenario is more than US$600 million more expensive than the alternative scenario. This is because, in spite of high investment costs, operating costs associated to renewable energies are quite lower than the ones associated to conventional technologies.

5.3 Comparison of Scenarios

The following table summarizes the present value of total private costs and social costs of failure. A first comparison is between the base scenario and the alternative one that includes NCRE's. The results show that the present value of total private costs is 0.5% *lower* under the alternative scenario. The reason for this is that operating costs are 12% lower in this latter scenario. These lower costs more than compensate the 15% higher investment costs. It can be concluded that private considerations dominate the decision making process, i.e. determine that the alternative scenario is less costly than the base scenario.

This result is strengthened when social failure costs are included. Even though they are not determinant in the final result, expected failure costs are about 40% lower in the alternative scenario, approximately US$15 million in the period. As a result, total private and social failure costs are 0.7% lower in the alternative scenario.

Table 19 Present Value of Costs for Each Scenario (Million US $)

Year	Base Scenario			Alternative Scenario		
	Base	50% Shock	Price	Alternative	50% Shock	Price
Investment Costs	3,810	3,810	3,810	4,391	4,391	4,391
Operation Costs	5,390	5,647	6,421	4,759	4,995	5,566
Total Private Costs	**9,200**	**9,457**	**10,231**	**9,150**	**9,386**	**9,957**
Social Cost of Failure	37	60	36	22	40	22
Total	**9,237**	**9,517**	**10,267**	**9,172**	**9,426**	**9,979**

Source: Own elaboration.

Two other relevant comparisons relate to a shock in gas supply and a different fuel price schedule discussed above. In both cases the main conclusion that a scenario that includes NCRE's is economically attractive, is strengthened. In the presence of natural gas supply shocks, total costs associated to the alternative scenario (column 6) are almost 1% lower than those associated to the base scenario (column 3). Under a scenario of higher fuel prices a larger cost difference is observed, that reaches almost 3%. Clearly, as prices of fuels increase, the positive economic impact of introducing NCRE's becomes greater.

5.4 Construction Schedule Comparison

The uncertainties introduced by shortages in gas supply from Argentina have made it necessary to change the construction schedule significantly from April 2004 to October 2005. The second report of this study evaluated NCRE's for Chile considering the first schedule (that was the one available at the time of the report) and concluded that a different schedule based on renewable energies was more costly. However, given the current gas shortages and the changes in the construction schedule, the costs of the renewable scenarios are lower than the proposed construction schedule as discussed in the previous section. Given the importance of this change in this section the main differences are examined in more detail[17].

[17] There are some minor differences between the costs for the 2004 schedule between this report and report 2, because more realistic assumptions have been included in this final analysis. Better operation and investment

Responding to natural gas supply shortages, the official construction power plant schedule proposed by the CNE has led to a change in the structure and size of the projected energy matrix as can be observed in the table below. In the schedule proposed in April 2004, natural gas represented almost 57% of the nominal power to be installed in the next decade. In the current construction schedule this fuel's participation is reduced to only 2%. This gas is almost completely replaced by compressed natural gas (CNG).

Table 20 Comparison of Official Construction Schedules as Proposed by CNE (Nominal MW to be included in the system in ten year period)

	April 2004	October 2005
Hydro	800	885
CNG	0	1,905
Coal	0	2,400
NG	2,290	125
Geo	300	300
Other	650	0
Total	**4,040**	**5,615**

Source: Own elaboration.

Additionally, the 2005 construction plan increases total capacity significantly –by 39%- as compared to the 2004 plan. This increase in nominal power is obtained basically through new CNG and coal-powered plants[18]. As a result, coal will be the most important new energy source representing almost 43% of future additional capacity, followed by CNG representing almost 34%.

The change to more expensive fuels implies expected marginal costs increase resulting in higher prices as a result of increases in operation costs[19]. The following table shows that the marginal costs between both base numbers almost double from the 2004 plan to the 2005

costs are now available and the discount rate has been reduced from 10% to 8% to make it comparable to the exercise in the previous section.

[18] The 650 MW considered in the 2004 schedule were direct electricity imports from Argentina that have now also been replaced.

[19] The main change in prices are due to the introduction of more expensive coal power plants and the use of CNG.

plan. Average marginal costs in the alternative scenario are also significantly more expensive in the 2005 schedule.

Table 21 Average Marginal Costs in Each Construction Schedule and Scenario (Us$/KWh)

	April 2004		October 2005	
Year	**Base**	**Alternative**	**Base**	**Alternative**
Average	**28**	**25**	**50**	**46**

Source: Own elaboration.

Finally, the following table presents the present value of the private costs of each construction schedule, both considering the base case and the alternative scenario based on NCRE. As can be seen, in the April 2004 plan, the base case is less costly than the alternative scenario so the base case is preferable to the introduction of renewable energies. This conclusion holds even if the social failure costs are considered.

However, these conclusions are reversed when the more costly October 2005 plan is considered. Under the new conditions, the NCRE scenario is less costly than the base scenario, under the expected price of the different fuels, as projected by CNE. Thus, these new conditions make the introduction of NCRE economically attractive from a private perspective. These results are even stronger when shocks are considered as discussed in the previous section.

Table 22 Comparison of Total Private Costs of the Different Constructions Schedules (In US$ Millions)

	April 2004		October 2005	
Cost	**Base**	**Alternative**	**Base**	**Alternative**
Investment Costs	2,214	2,722	3,810	4,391
Operation Costs	4,152	3,780	5,390	4,759
Total Private Costs	**6,366**	**6,502**	**9,200**	**9,150**
Social Cost of Failure	99	79	37	22
Total	**6,465**	**6,581**	**9,237**	**9,172**

Source: Own elaboration.

Consequently the comparison of both construction schedules reveals that NCRE's become more attractive economically as the energy matrix changes towards fuels that are more expensive. In particular for Chile, the matrix and prices considered in 2004 made a plan with NCRE's more costly than one that considered significant expansion based on natural gas. However, the change in the matrix towards coal and CNG in 2005 reversed this situation.

6. Estimation of Local Environmental Benefits of Introducing NCRE into the Energy Matrix

6.1 General approach.

Chile's electric system has experienced accelerated growth during the last fifteen years and demand is expected to grow at an average of 7% per year in the following 10 years. As discussed in Chapter 4, much of this expansion will be based on conventional thermal power plants, which will add more than 4400 MW by 2015. The environmental impacts associated to the operation of new thermal plants, specifically on human health and agricultural production, associated to ozone and PM-10 emissions, have not been evaluated. In this section we explore the change in health and agricultural effects that can be expected from introducing NCRE to the grid, substituting part of the energy generated by thermal plants.

To undertake this evaluation the impact pathway or damage function approach discussed in the following section is followed. The ideal case would be to take a future thermal plant and evaluate its environmental impacts on the surrounding area based on the change in ozone and PM-10 concentrations. However, there is no ozone formation model, nor PM-10 dispersion or formation model to estimate the impacts of reduced emissions from replacing a thermal power plant by energy generated through NCRE. This restricts the possibilities to carry out evaluations using the dose response approach[20].

To solve this problem, a simplified approach is followed, that allows obtaining an approximate value or order of magnitude for environmental costs associated to the replacement of a typical thermal plant of approximately 350 MW. For this, two specific cases are examined, that make use of available information, which allow approximating the

[20] Even though the original idea was to develop a specific ozone model, this was finally not possible due to lack of sufficient resources, so a simplified approach was proposed and accepted.

desired results. In each case a plant similar to the one that would be replaced by NCRE is considered.

The first case evaluates the impacts on air quality of the recent introduction of the gas plant Nehuenco II (370 MW) located in the Quillota Province of the Valparaiso Region, using *measured* changes in ozone concentrations. Unfortunately in this case there is insufficient air quality data and no calibrated models. However comparing existing air quality data with and without the project allows estimating the potential benefits replacing a similar plant by NCRE. It is interesting because the Construction Schedule of Power Plants includes similar thermal plants being constructed in this Region.

The second case considers the removal of Renca (100 MW) and Nueva Renca (370 MW) plants in Santiago. Of particular interest in this case is the fact that a complex model to determine ozone formation was available, together with a simplified primary PM-10 dispersion model. This allows evaluating the benefits and is a good example of how the impact pathway approach should be applied[21]. Unfortunately, these benefits cannot be considered as representative of what can be expected in other Regions because the plant is located in a highly populated urban setting. Future plants will not be located in such settings and consequently, the estimated benefits –particularly associated to PM-10 reductions- probably overstate what can be expected in these cases.

As a result the local environmental effects of eliminating a typical gas powered plant from the system will be approximated, establishing the importance of each pollutant in the total value. Each section will detail the models used to estimate concentration reductions.

The removed plants are natural gas powered plants that in terms of capacity and operation resemble one of the GNL plants removed in the base line[22] for establishing operation and social costs of failure. Thus to get an approximation of the impact the exclusion of this

[21] This exercise was the only one contemplated in the formulation of the project, however the Nehuenco case was added to include a case that is similar to what is expected in the near future, following a suggestion by Chile's National Energy Commission.
[22] This plant is Concepción I.

plant, other similar plants are studied. The excluded plant resulted to produce about 1800 GWh in 2007. On the other hand Nehuenco's production fell a similar amount of about 1200 GWh from 2004 and 2005. There are air quality measurements for these years in locations next to the plant, which enable to quantify grossly ozone changes as a result of this decrease in operation.

For Santiago, Renca and Nueva Renca produced almost 1800 GWh during 2004, also very similar to the gas power plant eliminated form the system in the previous exercise. In this case, there are daily measurements of ozone precursors and also PM10 emissions. A model is available for Santiago that allows establishing changes in ozone concentrations from eliminating this large power plant. Besides, a simplified model to estimate primary particulate concentrations is also available. Consequently, it is possible to estimate the effects derived from changes in ozone and PM-10 concentrations resulting from the removal of the plant.

6. 2. Methodology: The Impact Pathway or Damage Function Approach

The impact pathway approach[23] for estimating environmental benefits is an indirect and non-demand methodology[24]. 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 or dose response functions, and the effects 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 becomes aware of the relative costs and benefits of each policy, making it feasible to focus limited resources.

This methodology requires the definition of two scenarios. The first is the base (or without project) scenario and the second an alternative scenario associated to a specific project. The

[23] This methodology is also known as dose response, concentration response or damage function approach.
[24] Consequently, the final results for benefits cannot be considered as the ideal willingness to pay estimates for a change in environmental quality.

comparison of both scenarios allows establishing the changes in physical effects as a result of changes in the base scenario. In the case environmental quality improves, the number of adverse effects (on health or agricultures) is reduced. The difference in effects is then valued. Therefore, this method interprets these saved costs as benefits.

To evaluate benefits using the damage function approach a series of steps must be followed. First, the change in emissions (in this study changes in ozone and PM10 emissions) associated to the policy under study must be estimated. 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).

The next step requires estimating concentration variations as a result of the changes in emissions. Let C represent concentrations, then this variation is represented by:

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

The third step requires using concentration response functions to establish the change in effects. In particular, these functions relate changes in air quality to health or agriculture impacts. Thus, a function associated to effect i provides the variation of related cases (ΔH_i).

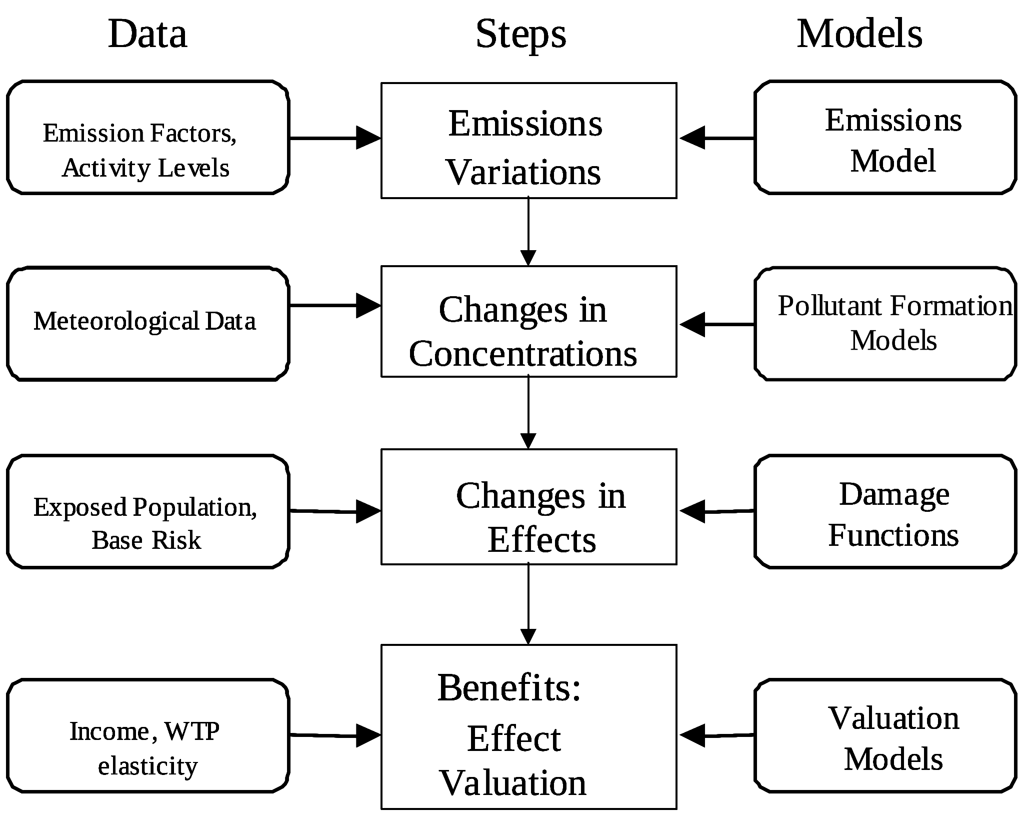
$$\Delta H_i = f(risk, population, incidence, \Delta C)$$

The last step puts a unit monetary value on each effect (V_i), which is used to evaluate the benefits from the reduced number of adverse cases. Finally, monetary benefits associated to each effect are aggregated. Thus, total health benefits associated to the air quality improvement (ΔT) in the case N effects are considered is given by:

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

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 6 Steps in the Damage Function Approach, Data Requirements and Models



6.2.1 The Health Model

This section specifies the model that is used to evaluate health benefits derived from PM10 and ozone concentration reductions. The concentration response functions and values used to carry out this evaluation are presented as well as other complementary data required.

a) Dose Response Functions

Two categories of health effects are usually considered associated to air pollution. The first deals with the *duration of the exposure* leading to an effect. Effects caused by short-term exposure (in the order of days or hours) are described as 'acute effects'. Those caused by long-term exposure (in the order of months or years) are identified as 'chronic effects'. The second category deals with the general *type of effect*, which distinguishes between mortality and morbidity. Impacts on mortality relate to people dying earlier than they would in the absence of air pollution. Morbidity relates instead to illness, ranging from minor effects such as coughing to life threatening conditions that require hospitalization. Mortality and morbidity are commonly used, and increasingly long term effects are being incorporated into effects/benefit evaluations.

In Chile the PPDA (1997) considers only short-term mortality. Other studies (O'Ryan el al. 2005) include long-term mortality. The dose response functions used to establish changes in each selected endpoint due to variations in ozone and PM10 concentrations should be internationally accepted functions when peer reviewed local functions are not available. In the case of Chile, there have only been a few studies that develop local parameters only for PM-10 and they have not been subject to intense scrutiny. For this reason, in this study transferred dose response functions are used.

The following table presents the endpoints considered, the age groups and the pollutant(s) to which they apply. Most endpoints relate to hospital admissions (HA) for different respiratory or heart diseases. The rest of the endpoints with available functions include short and long-term mortality, emergency room visits for asthma, respiratory symptoms[25] and minor restricted activity days (MRAD).

Table 23: Endpoints Considered for Ozone and PM-10 in Chile

Endpoint	**Age Group**	**Pollutant C-R**
Short-term Mortality	All ages	PM10, O_3
Long-term Mortality	Adults	PM10
HA, Respiratory Disease	All ages	O_3
HA, Respiratory Disease	Age 65 and older	O_3
HA, Asthma	All ages	PM10, O_3
HA, Pneumonia	Age 65 and older	PM10, O_3
HA, COPD	Age 65 and older	PM10, O_3
HA, Congestive Heart Failure	Age 65 and older	PM10
HA, Ischemic Heart Disease	Age 65 and older	PM10
HA, All Cardiovascular+65	Age 65 and older	PM10, O_3
ERV Asthma	All ages	PM10, O_3
Asthma Attack	All ages	O_3
MRAD	All ages	O_3
Symptoms	All ages	PM10, O_3

Source: Own elaboration based on PPDA (1997) and EPA (2003)

The following table presents the specific concentration-response functions applied to quantify health impacts derived from ozone concentration variations. Relevant characteristics of each function, such as functional form and parameter value, are also presented. The following table presents the specific damage functions for PM10 used.

[25] Symptoms account any of 19 acute respiratory symptoms including runny or stuffy nose, wet cough, cough, chest pain, and wheeze.

Table 24 Concentration Response Functions for Ozone

Endpoint	Functional Form	Parameter	Change in ozone Concentration	Incidence Rate	Population	Source
HA, Asthma	Log-Linear	0.00000475	Daily (24-hour) average	Daily Rate of HA for Asthma	All ages	Burnett et al. 1999
HA, COPD +65	Log-Linear	0.00274	Daily (24-hour) average	Daily Rate of HA for CODP	Age 65 and older	Moolgavkar et al 1997
HA, Respiratory Disease	Linear	0.0077	One-hour max	No rate necessary	All ages	Thuston et al.1992, Burnett et al. 1995
HA, Respiratory Disease +65	Log-Linear	0.00265	Daily (24-hour) average	Daily Rate of Respiratory HA	Age 65 and older	Schwartz. 1995
HA, Pneumonia +65	Log-Linear	0.0037	Daily (24-hour) average	Daily Rate of Respiratory HA for Pneumonia	Age 65 and older	Moolgavkar et al 1997
Asthma Attack	Linear	68.44	One-hour max	No rate necessary	Asthmatic-All ages	Whittemore and Korn. 1980, Stock et al. 1988
Mortality	Log-Linear	0.000936	Daily (24-hour) average	Base Mortality rate	All ages	Samet et al. 1997
MRAD	Linear	34	One-hour max	No rate necessary	All ages	Portney and Mullahy. 1986
Symptoms	Linear	54.75	One-hour max	No rate necessary	All ages	Krupnick et al. 1990
ERV Asthma	Linear	2.8E-08	One-hour max	No rate necessary	All ages	Stieb et al. 1996

Source: Table constructed from information obtained in Lemus (2005)

Table 25 Concentration Response Functions for PM10

Endpoint	Functional Form	Parameter	Change in PM10 Concentration	Incidence Rate	Population	Source
Mortality	Log-Linear	0.0002	Annual Average	Base Mortality Rate	All ages	Schwartz 2003
Long Term Mortality	Log-Linear	0,002257	Annual Average	Base Mortality Rate	Age 30 and Older	Pope et al 2002
HA, All Cardiovalscular+65	Log-Linear	2,23E-04	Daily Average	Daily Rate of all Cardiovascular HA	Age 65 and older	Schwartz 2000
HA, Pneumonia +65	Log-Linear	0,000498	Daily Average	Daily Rate of Pneumonia HA	Age 65 and older	Moolgavkar et al. 1997
HA, Ischemic Heart Disease+65	Log-Linear	0,000496	Daily Average	Daily Rate of Ischemic-Heart Disease HA	Age 65 and older	Schwartz and Morris 1995
HA, Congestive Heart Failure +65	Log-Linear	0,000741	Daily Average	Daily Rate of Congestive Heart Failure HA	Age 65 and older	Schwartz and Morris 1995
ERV Asthma	Log-Linear	0,00367	Daily Average	Daily Rate of ERV Asthma	Ages under 65	Schwartz 1993
COPD +65	Log-Linear	0,000877	Daily Average	Daily Rate of COPD HA	Age 65 and older	Moolgavkar et al. 1997
Symptoms	Linear	0,000461	Daily Average	No Rate Required	Ages 18-65	Krupnick et al. 1990

Source: Own Elaboration based on information obtained from EPA

b) Benefit Values

The valuation of change in the number of cases for each endpoint considered requires a value for each endpoint. Ideally, it is best to use local values for each endpoint. However in Chile these values are not generally available, and when a local value has been estimated, there is no consensus about it. For this reason to put a value on each endpoint, two sets of values have been used. The first set of values used is the one applied in the evaluation Prevention and Atmospheric Decontamination Plan (1997). A second set of values is obtained transferring values from the BENMAP database. The basic goal of benefit transfer is to estimate benefits for one context by adapting an estimate of benefits from some other context. Benefit transfer is often used when it is too expensive and/or there is too little time available to conduct an original valuation study, yet some measure of benefits is needed, as in the case of this report[26].

The PPDA employs in the economic evaluation the values estimated by Eskeland (1994). These values were estimated following a cost of illness and human capital approach for both mortality and morbidity endpoints. These values are applied directly as in the PPDA evaluation, updated to dollars of year 2000[27]. Table 26 presents these values below.

BenMAP is the result of years of research and development, and reflects methods based on the peer-reviewed health and benefits analysis literature. BenMAP is a tool for estimating health and welfare benefits associated with air pollution regulations proposed or finalized by the U.S. Environmental Protection Agency. The basis of BenMAP is a damage function approach to estimating changes in the incidence of health effects and valuing those changes and thus provides for both damage functions and unitary values for each endpoint.

The Benmap set of values included the most recent estimations and values are transferred using a simple methodology that is common practice. Preferences are assumed the same across countries. Consequently, differences in the willingness to pay for a good across countries can be explained by differences in income. The adjustment usually incorporates income elasticity of willingness to pay (WTP) by the following relation:

$$WTP_t = WTP_s \left(\frac{Y_t}{Y_s} \right)^{\eta}$$

[26] It is important to note that benefit transfers can only be as accurate as the initial study.
[27] To update these values, annual economic growth and inflation rates are used.

The index t is associated to the receptor country carrying out the transfer and s the source country. Y represents income in terms of purchasing power parity an η income elasticity of WTP.

This income elasticity represents the change in WTP across the two countries, associated to a 1% change in income. For example, if η= 0.5, the receptor country will increase its spending in reducing risks only half as much as the source country would for every 1% increase in income. When considering a unitary elasticity, it is assumed the willingness to pay of the receptor country only varies proportionally to the relative income between these countries[28]. In this report, and given different studies show a wide range of elasticity values[29], a unitary elasticity is employed[30].

To characterize income, local prices must be used, however measured in terms of purchasing power. Consequently income in both countries must be measured using purchasing power parity (PPP) or a similar correction. In this report, per capita PPP income for the year 2000 for both Chile (the receptor) and the United States (source) is used. These are US$ 10.127 and US $ 35.056 and were obtained from the World Bank (2004).

Table 26 presents the values transferred for Chile that are applied in the benefit estimation undertaken in the following sections.

Table 26: Unit Benefit Values for Chile, BENMAP and PPDA.

Endpoint	PPDA	Benmap	
	Value	Transferred Values	Type of Estimation
Statistical Life	69,497	1,826,910	WTP
HA, Respiratory Disease	784	4,402	COI

[28] When transferring human capital or Cost of illness values, the elasticity is not considered since only differences in income and not preferences explain expenditure differences.
[29] WTP studies have estimated elasticities from 0.2 to greater than 2. (Albertini, Cropper et al. 1997; Bowland and Beghin 2001). If variations in personal income and health benefits are valued at par between both countries, the value of e is one. However, Ardila, Quiroga and Vaugham (1998) made specific estimate of η for Latin American and Caribbean countries based on contingent valuation studies of sanitation programs which generated a value equal to 0.54.
[30] For example Health Canada (2002) suggests using a value of 1.

HA, Respiratory Disease +65	784	5,313	COI
HA, Asthma	784	2,449	COI
HA, Pneumonia +65	784	5,155	COI
HA, Congestive Heart Failure	784	4,396	COI
HA, COPD +65	784	3,943	COI
HA, Ischemic Heart Disease+65	784	7,475	COI
HA, All Cardiovalscular+65	784	6,122	COI
ERV Asthma	50	75	COI
Symptoms	2	7	WTP
MRAD	10	15	WTP
Asthma Attack	8	12	WTP

Source: Own Elaboration using data from PPDA evaluation (1997) and Benmap Database.

6.2.2 The Agricultural Model

This section specifies the model that is used to evaluate agricultural costs or benefits derived from ozone concentration variations. A first necessary step to undertake such an evaluation is establishing the area affected by these variations, and the specific crops planted in this area. This section specifies common damage functions and values to be applied to each crop in central Chile.

The absence of national dose-response functions makes it necessary to transfer international functions. Fortunately, most agricultural damage functions studies have been carried out in California, USA and this makes the transfer reasonable since the climatic conditions of this region are quite similar to those in central Chile.

Those crops for which no dose response 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 crops with similar sensitivity. Finally, dose response functions were selected for oat, different kinds of onions, corn and maize, cauliflower, lettuce, lemon, nuts, potatoes, different kinds of beans, different types of tomatoes, wheat, carrot, grapes and wines. In total, twenty-six species of crops were considered. This assumption increases the coverage of agricultural lands with dose response functions to 73%[31]. For the Quillota Province, the total of agricultural lands impacted, with dose response functions, is 91%.

The source of the dose response functions selected are presented in the following table and detailed in appendix 2.

Table 27 Dose Response Functions for Agriculture

Species	**Source**
Onion	Temple et al. 1986
Fodder	Somerville et al. 1989
Bean	Temple et al. 1986
Bean	Temple et al. 1986
Bean	Temple et al. 1987
Lettuce	Temple et al. 1988
Lettuce	Fuhrer et al. 1989
Lemon	Thompson y Taylor. 1969
Maize	Kress y Miller. 1985
Maize	Somerville et al. 1989
Soy	Somerville et al. 1989
Tomato	Fuhrer et al. 1989
Wheat	Kress et al. 1985
Wheat	Heck et al. 1984
Wheat	Somerville et al. 1989
Grapes	Thompson et al. 1970
Wine Yard	Brewer et al. 1988

The producer prices[32] for each crop as well as the surface performance (production by hectare) data were obtained from Food and Agriculture Organization (2004) that has values for Chile. These are presented in the table below:

[31] The rest are assumed not to be affected by pollution.
[32] It is important to use producer prices and not the prices paid by the consumer.

Table 28 Performance and Producer Price for Species Considered in the Evaluation

Species	Performance (Kg/Ha)	Producer Price US$/kg
Dry Vetch	787	0.33
Green Vetch	6226	0.38
Dry Grain Vetch	4665	0.10
Onion	47155	0.15
Early Onion	47155	0.15
Corn	15152	0.18
Cauliflower	15294	0.13
Annual Fodder	25647	0.32
Permanent Fodder	25647	0.32
Lettuce	13810	0.30
Lemon	18750	0.16
Maize	12265	0.13
Melon	15476	0.13
Nuts	1692	0.27
Potato	19531	0.12
Internal Consumption Bean	6182	0.30
Export Bean	6182	0.30
Summer Bean	6182	0.30
Green Bean	6182	0.30
Fresh Tomato	65000	0.31
Industrial Tomato	65000	0.31
White Wheat	4320	0.17
Wheat	4320	0.17
Table Grapes	10417	0.29
Wines	10417	0.29
Carrots	25385	0.13

Source: FAO (2004)

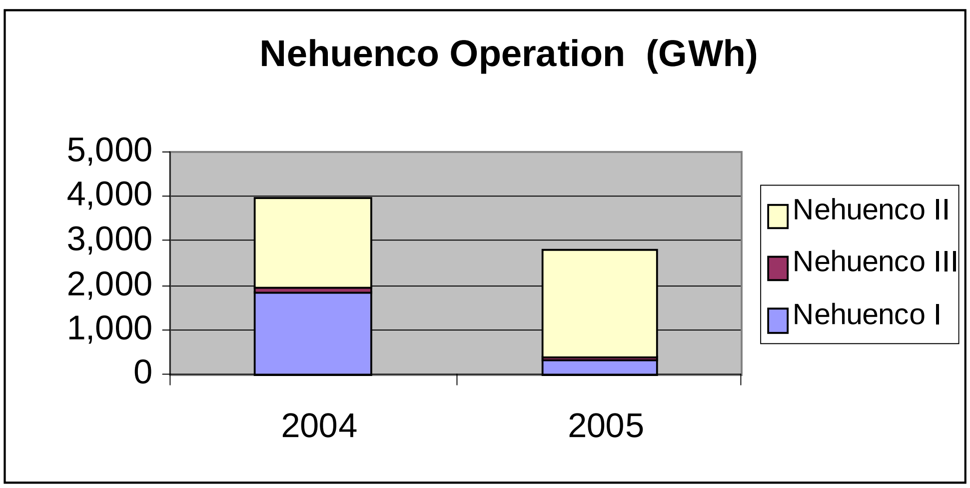
6.3 Case 1: Reducing emissions from Nehuenco.

In the Valparaiso Region there are currently several thermal power plants and at least four are expected to be constructed in the Region according to the latest construction schedule by 2015. To study the effect of relocating a plant projected to be installed in the Valparaiso Region a simplified analysis is followed: basically the effect of the replaced plant will be considered similar to the effect that reductions in emissions by Nehuenco has had in the Region[33].

This comparison makes sense because a typical 350 MW combined cycle power plant (Concepción I) would produce 1800 GWh in 2007 in the baseline. Nehuenco's production fell a similar amount of about 1200 GWh from 2004 and 2005. i.e. they are similar in terms of energy generation.

Nehuenco is located in the Quillota Province and consists of three thermal power plants: Nehuenco I built in 1998, Nehuenco III in 2001 and Nehuenco II by the end of 2003. In 2005, Nehuenco I, with a nominal capacity of 350 MW, reduced significantly its generation as can be seen in the following graph.

Figure 7 Operation of Nehuenco Plants



Source: Own Elaboration based on CDEC (2005)

6.3.1 Effects on Air Quality

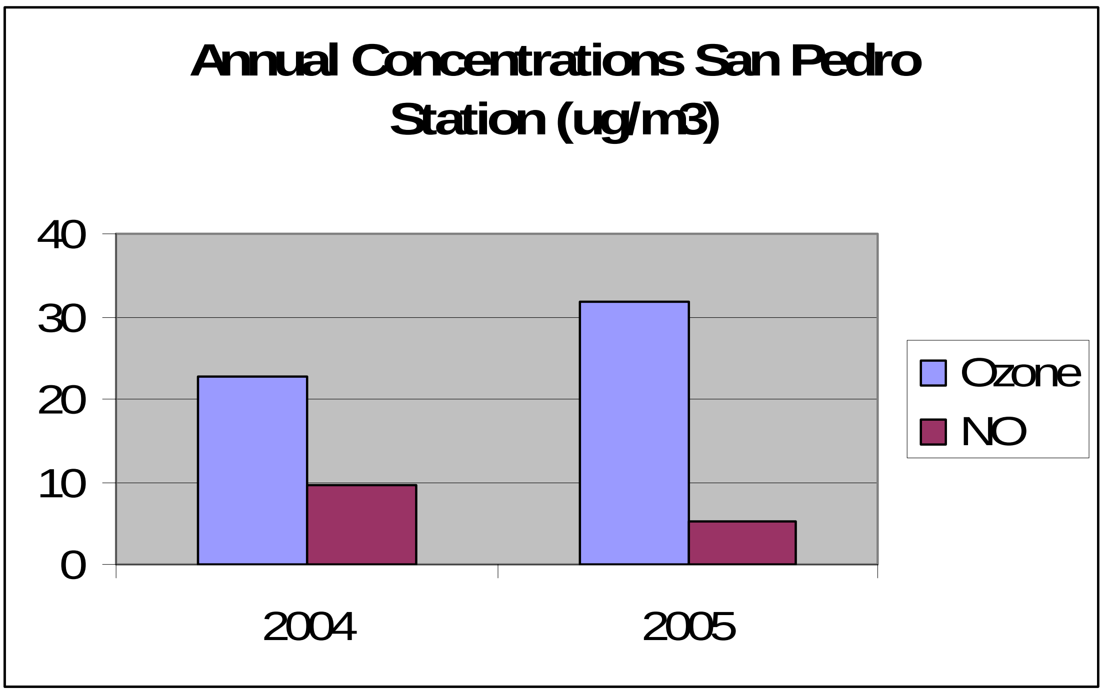
Changes in operation have affected emissions and air quality in the nearby areas, as measured in three monitoring stations that capture the main effects. These stations are San

33

Pedro, UCV and Bomberos. For these stations, there is hourly information for each day of the year for NOx and ozone concentrations among other pollutants. Unfortunately the information for PM-10 is not sufficient to obtain any conclusions about potential effects on these pollutants concentrations.

The following figures present the annual changes in ozone and NO for each of the monitoring sites. The first station presented is San Pedro which is the station located closest to the Nehuenco plants.

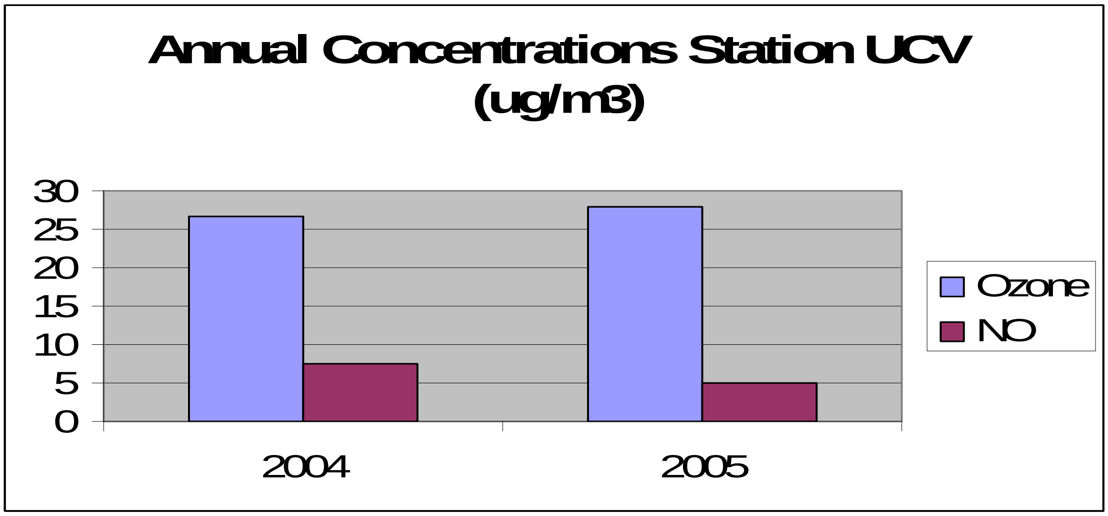
Figure 8 Annual Average Concentrations in San Pedro Station



Source: Own Elaboration based on information provided by CONAMA Region Valparaiso.

The next station is UCV and the annual concentrations for ozone and NO are presented in the following graph.

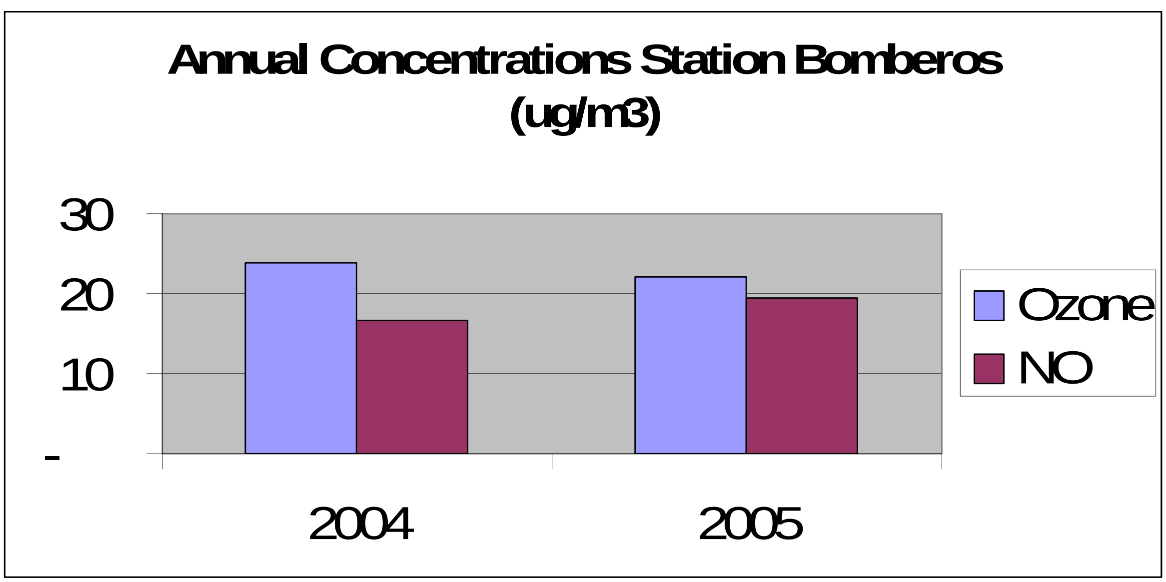
Figure 9 Annual Average Concentrations in UCV Station



Source: Own Elaboration based on information provided by CONAMA Region Valparaiso.

The third and last station is Bombero. This station is located in the city of Quillota which is the largest urban center in the Quillota Province. The figure presented below shows annual concentrations registered in this station for ozone and NO.

Figure 10 Annual Average Concentrations in San Pedro Station



Source: Own Elaboration based on information provided by CONAMA Region Valparaiso.

The graphs for San Pedro and UCV are very illustrative of the effects of reducing operation in the Nehuenco plant in 2005 compared to 2004. This is a period short enough to assume that emissions from other significant sources are constant. i.e. that any observed effect is due to changes in Nehuenco's operations[34]. NO concentrations fall from 2004 to 2005, due to reduced operations and correspondingly lower emissions of this pollutant. However, ozone concentrations actually *increase*, a counterintuitive result. Additionally, no relation is observed between the Bombero station and electricity production indicating that the urban characteristics of pollution dominate the possible impacts of the power plant on air quality.

To explain why NO concentration reductions may lead to increases in ozone concentrations it is necessary to understand the chemical process of ozone formation. Ozone is formed in interaction of NOx and VOCs in the presence of sunlight. Ozone formation is a highly non-linear process implying NOx and VOC reductions do not necessarily result in ozone concentration reductions. The following set of basic reactions describes ozone formation:

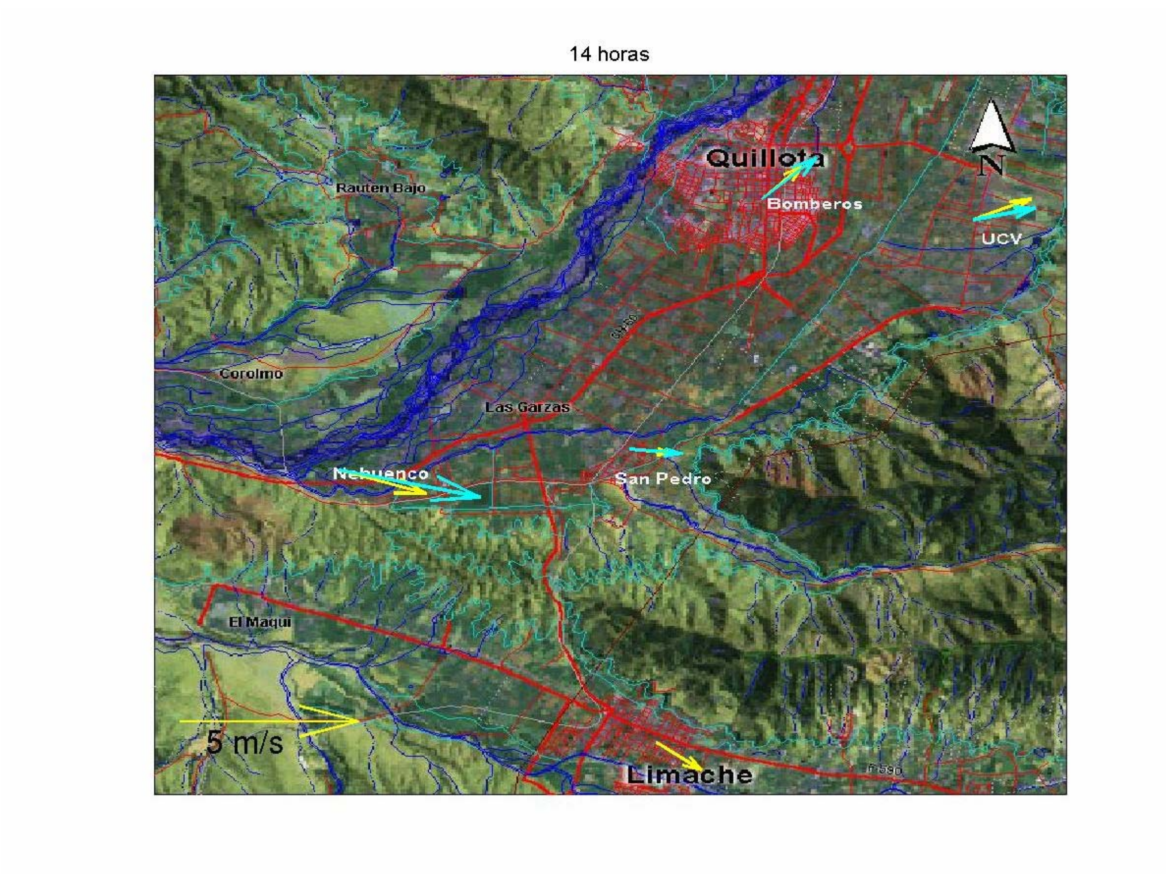
$$NO_2 + Radiation \rightarrow NO + O$$
$$O + O_2 \rightarrow O_3$$
$$O_3 + NO \rightarrow NO_2 + O_2$$

Under given levels of radiation, the system of reactions presented above comes to an equilibrium among species O_3, NO and NO_2. However, when disturbing the system the equilibrium changes. For example and as appreciated in the last reaction, when NO concentrations increase (e.g. by emissions), ozone concentrations are reduced. On the other hand in the presence of VOCs the ratio of NO and NO_2 is shifted towards NO_2 with the result of increased ozone levels. Whether ozone levels increase or decrease in the presence of both NO emissions and VOCs depends on the reactivity of the VOCs and the ratio between NOx and VOC[35].

[34] No significant project was developed in this area in this period.
[35] The CADM model explained in section 6.4.1 takes into consideration these complex interrelations fro the Santiago Basin. Unfortunately no similar model is available for the Quillota Region.

To determine the area impacted by Nehuenco´s emissions it is necessary to take into account the wind fields in the area, presented in the following figure. The yellow arrows indicate average wind speeds and directions as measured in the respective sites at 14:00 hours (local time). The green arrows indicate average wind speeds and directions at those days where the Chilean norm for ozone (160 µg/m3 for 1 hour) were exceeded. It can be observed that there is only a slight difference in wind speed but wind directions seem to be rather constant. Furthermore, according to the observed wind directions that, in a first approximation, the whole valley downwind of the power plant can be considered as area of impact. Without additional information (for example by the application of models) this measured data has to be taken as representative for certain areas in order to carry out a cost-benefit analysis. In the case of the Valle de Quillota the area selection for each monitoring station is partly done on a scientific basis, partly through expert opinion.

Figure 11 Wind Fields in Monitoring Stations at 14:00 hours



Due to the kinetics of air chemistry, monitoring stations at a given distance represent different chemical regimes. In this respect, the stations UCV and San Pedro exhibit the required distance in order to be considered different from a chemical perspective. On the other hand, it is also well known that stations located in an urban area represent very different conditions to rural sites, i.e. the air quality measurements depend on many other variables than emissions from a mega plant. Consequently, the station Bombero located within the town of Quillota, represents only the urban environment, in which local emissions outweigh by far those from a remote power plant. Based on these considerations the following three areas for the cost-benefit analysis have been identified:

1) Area Quillota represented by the station Bomberos. This area covers the town of Quillota only and is not affected by changes in the Mega plants emissions.
2) Area 1. This area ranges from the thermal electric power station Nehuenco towards the west of the monitoring station to halfway between the two monitoring stations San Pedro and UCV towards the east. Furthermore this area is restricted by the mountains towards the north and the south.
3) Area 2. This area ranges from halfway between the two monitoring stations San Pedro and UCV towards the west. In order to be at the center of the area we choose the same distance towards the east. Again this area is restricted by mountains towards the north and south.

Even though the choice of area is rather arbitrary, it seems to be reasonable from a chemical point of view and expert opinion supports this choice[36].

Thus, areas 1 and 2 are considered to represent how ozone concentrations change as a consequence of power plant operation variations. Area 1 concentrations are assumed to be uniform and equal to San Pedro concentrations while Area 2 concentrations are considered to be uniform and equal to those observed in the UCV station.

[36] Rainer Schmitz from the Geophysics Department of the Universidad de Chile.

6.3.2 Exposure

After defining the areas affected by ozone variations as a consequence of power plant operation changes, it is necessary to define the exposed population and crops to obtain health and agriculture costs or benefits. To estimate the exposed population the CENSO 2002 was used while the CENSO AGROPECUARIO (1996-1997) was used to obtain information of plantations in the region. In both cases, data from the Quillota Province were considered to provide the information for areas 1 and 2 as defined above. The following table summarizes the total exposed population and the total has of crops exposed.

Table 29 Exposed Population and Crops

Exposed Population	96,448
Area of Crops (hectares)	9,192

Source: own elaboration

6.3.3 Benefits of reducing Power Plant Operation

The case under study shows that reduced power plant operation *increases* ozone concentrations in the two sites where effects are observed. Thus, surprisingly, the removal or relocation of a power plant would produce health and agriculture *costs* as a result of increased ozone pollution.

The total change in health and agriculture cases is presented in appendix 3, based on the dose response functions presented in the previous section. When applying the different dose response functions, different temporal ozone averages were used. For example, in evaluating health, daily effects were obtained and depending on the damage function, the daily maximum of 1-hour concentration or 24-hour average was required. Finally, effects were aggregated to obtain the change in annual effects.

Finally, it is possible to establish the annual costs of reducing operations (increasing ozone). For this, the changes in health and agriculture effects are multiplied by the unitary cost of each effect. The health results are presented in the following table:

Table 30 Annual Ozone Health Costs (Negative Benefits) for Both PPDA and Benmap Values (Year 2000 US $)

Endpoint	Costs BENMAP	Costs PPDA
Mortality	5,032,668	191,446
Morbidity	912,625	268,098
Total Health Costs	**5,945,293**	**459,544**

Source: own elaboration

The results show health costs are extremely sensitive to the set of values applied. These range from about US$500 thousand to almost US$6 million. Differences are especially considerable in the mortality case where the Benmap values result in costs over 26 times larger than when using PPDA values.

Costs in agriculture are presented in the table below. The results show annual costs are quite small as compared to health benefits.

Table 31 Annual Agriculture Costs (US $)

Agriculture Costs	85,408

Source: own elaboration

6.4 Case 2: Removing Renca from Santiago

The case examined assumes the generators Renca and Nueva Renca located in Santiago are removed and replaced elsewhere by equivalent power plants. Ideally, these plants would not produce pollution, or else pollution is emitted in areas with no agriculture or health impacts. Thus, the base scenario considers all the emissions as available in the inventory. For the case scenario, Renca and Nueva Renca’s emissions are removed.

The Metropolitan Region of Santiago covers a 15,403.2 km^2, and is divided administratively into six provinces: Chacabuco, Cordillera, Maipo, Melipilla, Santiago, and

Talagante. Each province is divided into "comunas[37]". The entire Metropolitan Region is divided into 54 comunas.

The process of estimating benefits in Santiago requires a series of steps. The first consists in defining the area of influence. In this case, the entire region will be considered in establishing ozone concentrations. This is because the photochemical processes involved in ozone formation are far from being local.

The next step, requires estimating ozone and PM-10 concentrations. For ozone, a photochemical model is used to estimate concentrations given primary emissions. For PM-10 a simplified linear approach is used. A third step requires defining the relevant population and crops exposed in different zones of the Region. Finally the environmental impacts and their values must be established. These steps are discussed for ozone and PM-10 in the following sections.

6.4.1 Methodology to Estimate Pollutant Concentration Variations in Santiago

In this section, the methodological approach used to estimate ozone and PM-10 concetrations from variations in emissions is discussed for the Santiago, given the available data and models for each pollutant.

a) Estimating Ozone Concentrations

To estimate ozone concentrations in Santiago, the model CADM is used. The CADM is a photochemical model that estimates ozone concentrations using a simulation model from NOx and VOC emissions. CADM is a comprehensive, three dimensional, multi-layer, Eulerian atmospheric chemical transport model, designed to simulate relevant physical and chemical processes in the troposphere. Although it is not restricted to any particular region, the model has been developed focusing on the Metropolitan Region around Santiago de Chile. The model consists of two main modules, the mesoscale meteorological model PSU-NCAR MM5 that provides all the meteorological input, and the chemistry-transport module (CTM). The MM5 provides the time dependent three dimensional wind,

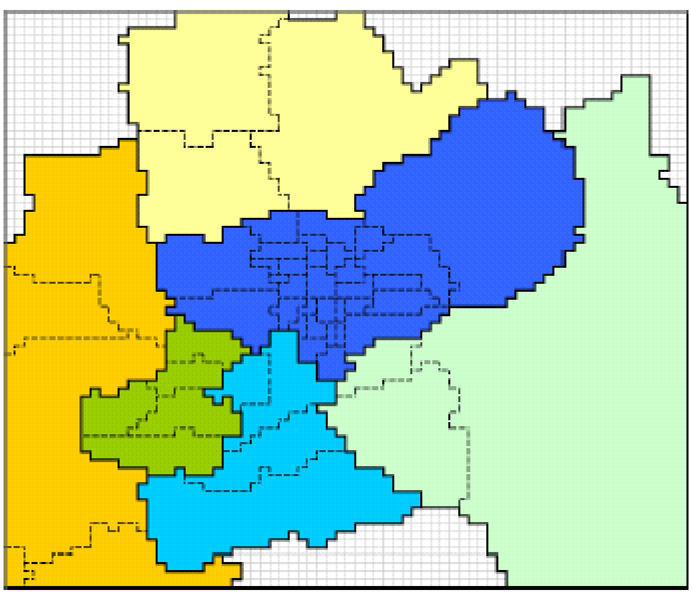
[37] The smallest administrative unit in Chile is called "comuna" and is headed by a mayor.

temperature, pressure, and specific humidity fields. The CTM is driven off-line by the meteorological output of the MM5 and predicts the time-varying trace gas concentrations by solving numerically a species continuity equation that includes advection, diffusion, deposition, gas and aqueous phase conversion.

To visualize ozone concentrations spatially, the Metropolitan Region containing Santiago is divided into a grid with 72*72 or 5184 cells. The territory covered by the grid is between 32,938º ◦and 34,000º South latitude, and 69,968º and 71,264º◦◦◦ West longitude.

The following figure shows the distribution of cells per commune. As mentioned before, The Metropolitan Region is divided into six provinces that appear in the figure in different colors: Cordillera (light green), Chacabuco (yellow), Maipo (light blue), Melipilla (orange), Santiago (blue) and Talagante (dark green). The white cells are not included in the Metropolitan Region.

Figure 12 Distribution of Cells by Commune



Source: Lemus (2005

The CADM model estimates air quality in each of the cells, requiring emissions of at least one the them, wind fields, and the thermal inversion height.

Emissions Inventory

The 2000 emission inventory is used by CADM to provide ozone concentrations. This is the latest official record of emissions available for Santiago. The inventory is required because concentrations of precursors are relevant in resulting ozone concentrations. This inventory includes PM10 emissions as well as emissions of nitrogen oxides (NOx), sulfur oxides (SOx), and volatile organic compounds (VOC). Annual emissions for both stationary and mobile sources are presented in the figure below:

Table 32 Emissions in 2000

SOURCE	**PM10**	**CO**	**NOx**	**VOC**	**SO2**	**NH3**
	ton/year	**ton/year**	**ton/year**	**Ton/year**	**Ton/year**	**ton/year**
Total Stationary	1905	11715	9877	55363	6855	28415
Total Mobile Sources	2467	175725	47045	24728	3135	933
TOTAL	4372	187440	56921	80091	9990	29348

Source: CONAMA

In ozone concentration estimation NOx and VOC concentrations are required. According to the inventory, total NOx emissions are 56,921 tons/year and VOC emissions 80,091 tons/year[38]. The transport sector (mobile sources) is responsible of 83% NOx emissions and 31% VOC emissions. Stationary sources represent 17% of NOx emissions and 69% of VOC emissions.

Results Delivered by CADM Model

Ozone concentrations for each scenario are estimated according to the following criteria as required by the different concentration response functions:

- Average ozone concentrations for 7 hours (9:00-16:00hrs)
- Average ozone concentrations for 12 hours (7:00-19:00hrs)
- Average ozone concentrations for 24 hours
- Average ozone concentrations for maximum daily hourly values.

[38] National Commission of Environment (2004).

Estimation of Annual Concentrations

Ozone concentrations provided by CADM are available only for the period December 2001 through January 2002. However, to estimate many health and agricultural effects annual concentrations are required. Lemus (2005) generated expansion factors for ozone using data provided by SESMA (2004).

In particular, concentration data from monitoring stations of the MACAM net in the period 1997-2001 were used to estimate monthly average concentrations in each of the years considered. Then, a monthly average was estimated for the entire period and for each station. The next step is to divide the concentrations for each station and month by average January emissions. This month generally presents the highest average concentrations. The factors are averaged across stations for each month resulting in the expansion factors presented in the table below.

Table 33 Monthly Expansion Factors for Ozone Concentrations

Month	Expansion Factor	Number of Days
January	1.00000	31
February	0.96029	28
March	0.91431	31
April	0.68037	30
May	0.47658	31
June	0.32487	30
July	0.3894	31
August	0.51145	31
September	0.64694	30
October	0.84919	31
November	0.93034	30
December	0.99008	31

Source Lemus (2005)

b) Estimation of PM10 Concentrations

Particulate matter (PM) includes solid or liquid particles dispersed into the atmosphere. These particles include among others dust, ashes, metallic particles, and pollen. Particulate matter is classified according to the size of the particulate. PM10 corresponds to particulate matter with a diameter equal or lower than 10 µm (10 micrometers). PM10 is made up mainly by particles with basic ph emitted by combustion. PM 2.5 corresponds to the smaller fraction of particulates, with a diameter smaller than 2.5 micrometers. These particles include mainly acidic particles and are the most harmful for human health.

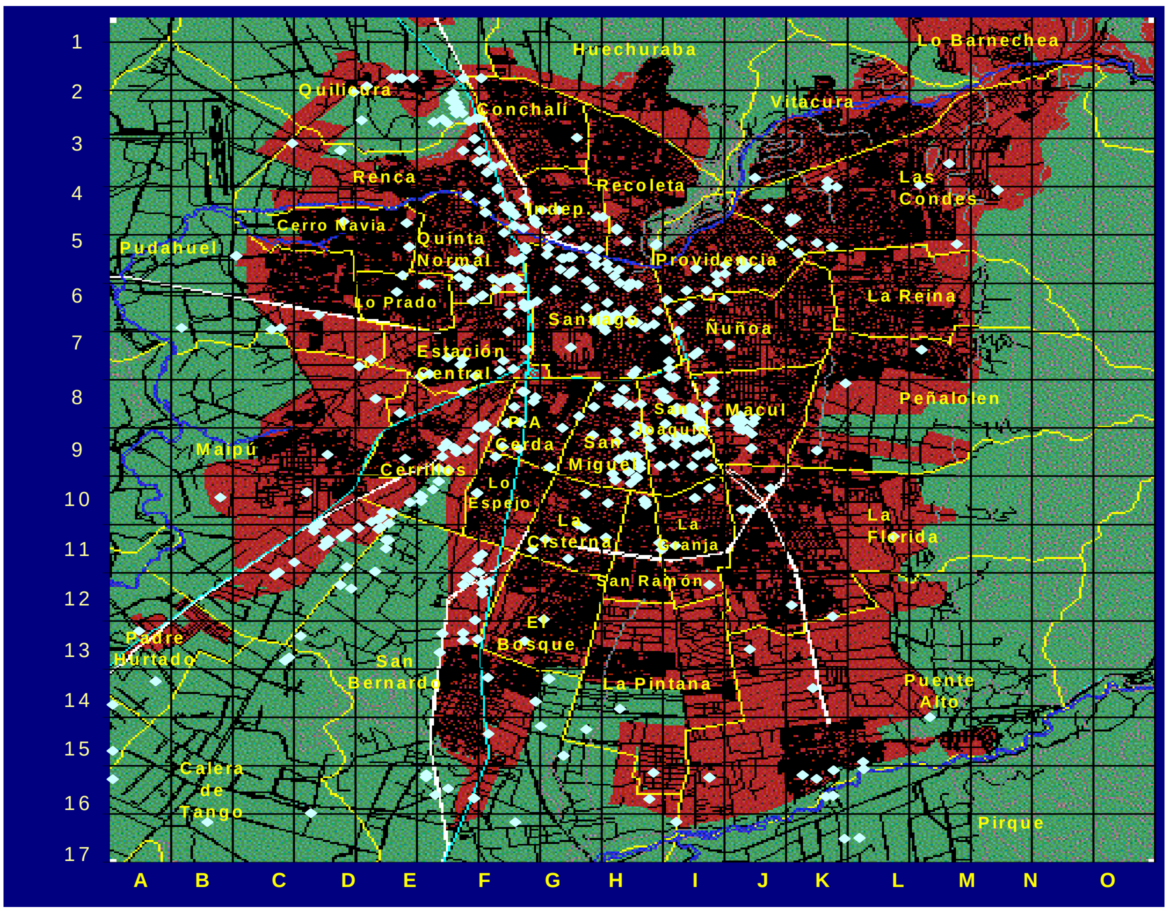
The PM 2.5 fraction corresponds to approximately 50% of total PM10 in Santiago. Almost half of PM2.5 corresponds to secondary particles[39]. These are compounds not emitted directly, but produced by chemical reactions that take place in the atmosphere among substances like NOx, sulfur dioxide (SO2) and ammonia (NH3).

Unfortunately only primary emissions (from combustion) are available in Santiago and there are no chemical models predicting the formation of secondary particles. For this reason, a simple model characterizing only PM10 dispersion of primary emissions is used.

To estimate PM10 concentrations Santiago is divided into a 17x17 grid. Each cell of the grid is four square kilometers. This grid is presented in the figure below and covers the whole city of Santiago

[39] www.conama.cl

Figure 13 Grid Used to Estimate PM10 Concentrations



Methodology to Estimate Concentrations

One common method used to estimate concentrations in a certain point due to the emissions generated in another point corresponds to a linear model, which can be expressed according to the following expression:

$$Q_k = B_k + \alpha_{1k}e_1 + \alpha_{2k}e_2 + \alpha_{3k}e_3 + \dots\dots\dots\dots + \alpha_{nk}e_n$$

Where, Q_k represents the environmental quality level in zone k, due to the effect of the emissions of the "n" sources, measured in units of concentration. B_k is the base level of concentrations in zone k. The term α_{ik} is the dispersion coefficient, which relate emissions of source i, with concentrations in zone k. This coefficient depends on the characteristics of the emission source, as well as the meteorological conditions and the distance between the source i and the receptor k. The emissions of the source i are represented by e_i.

To obtain the dispersion factors for Santiago, the model developed by Muñoz (1993) was used. In that paper, a multiple cell model was developed, with one layer, and one height corresponding to the height of the mix (up to the base of the layer of thermal inversion). The height of the mix was considered variable in time.

The coefficients obtained reflect the impact of one unit of emission in the levels of concentration of each cell in the matrix, for an episode condition, i.e. very negative meteorological conditions. During episodes the most highest particulate matter concentrations are obtained. The coefficients are presented, relative to the impact on the central cell, in the following figure.

These factors where estimated for an emission of 10 g/s during 12 hours for episode days in Santiago. Cell 100% corresponds to a concentration of 30.9 μg/m3 . Only values greater than 5% are included.

Figure 14 Relative Transfer Coefficients for Santiago

(values in percentage, referred to cell 100)

					6.16		
				5.39	12.71	5.93	
5.10	7.93	12.41	20.50	34.96	100.00	14.14	7.13
5.84	8.01	11.18	15.49	20.37	26.88	7.65	5.25
5.06	6.35	7.96	9.90	11.06	11.86	5.83	
		5.07	5.79	5.94	5.89		

Source: O'Ryan (1996).

Estimation of Annual Concentrations

The episode conditions considered to estimate the dispersion factors discussed, are obtained for the 28 worst days in terms of weather conditions for dispersion in winter. During other seasons, dispersion conditions are much more favorable and as a consequence, similar emissions result in significantly lower concentrations of PM-10. Health benefits from reducing emissions in summer months can thus be expected to be significantly lower than in winter.

To estimate annual average concentrations the following simplified procedure is used. Jorquera (2002a and 2002b) estimated a factor that represents average dispersion conditions for each month in Santiago at four different receptor locations. His results show that these factors do not vary much between locations, hence we have used the average results from the four locations. As can be seen in the next table, average dispersion conditions in the worst winter month (June) are more than four times worse than in January.

Table 34: Relative dispersion factors for each month

Month	Relative Dispersion Factor	Number of days
January	0.239	31
February	0.279	28
March	0.366	31
April	0.579	30
May	0.805	31
June	1.000	30
July	0.859	31
August	0.646	31
September	0.431	30
October	0.279	31
November	0.251	30
December	0.251	31

Source: Personal elaboration based on Jorquera (2002a and 2002b)

To estimate the concentrations resulting from emissions each day, it is assumed that these factors represent the average dispersion conditions each month relative to the episode conditions (that has a factor of 1). Consequently, the concentrations in a day of November, for example, of reducing emissions will only be one fourth of those obtained in a day in June. As a result, total monthly concentrations are obtained multiplying the daily concentration obtained form the model by the number of days in the month and by the relative dispersion factor. The yearly concentrations are the sum of the concentrations obtained for each month. Aggregate annual concentrations are equivalent to the sum of 182 winter-day concentrations. Then, average annual concentrations are given by:

$$\langle C \rangle_{annual} = \frac{182}{365} C_{episode}$$

6.4.2 Results: Variations in Concentrations

Renca and Nueva Renca are located together in North Western Santiago, specifically their coordinates are UTM X: 343,692 and UTM Y: 6,301,403. It is important to recall that the grid defined to establish ozone impacts covers all the Metropolitan Region. This is not the case for PM10 where only the Santiago province is considered. The following sections present the initial emissions from Renca for PM-10 and ozone precursors and the changes in concentrations due to a relocation of Renca outside the Metropolitan Region.

6.4.2.1 Renca Emissions

To estimate primary PM10 concentrations, daily average PM10 emissions are required as an input for the available estimation procedure discussed in the previous section. Similarly for ozone, daily emissions of precursors are required.

According to the official inventory (2000), Renca and Nueva Renca are responsible for the annual emissions presented in Table 35. Unfortunately there is no estimate of daily emissions, so it is necessary to obtain an approximate value. Using a simple procedure that considers activity by Renca in different months of the year, the average daily emissions are obtained. These are also presented in Table 35.

Table 35 Renca and Nueva Renca: Annual and Daily Emissions

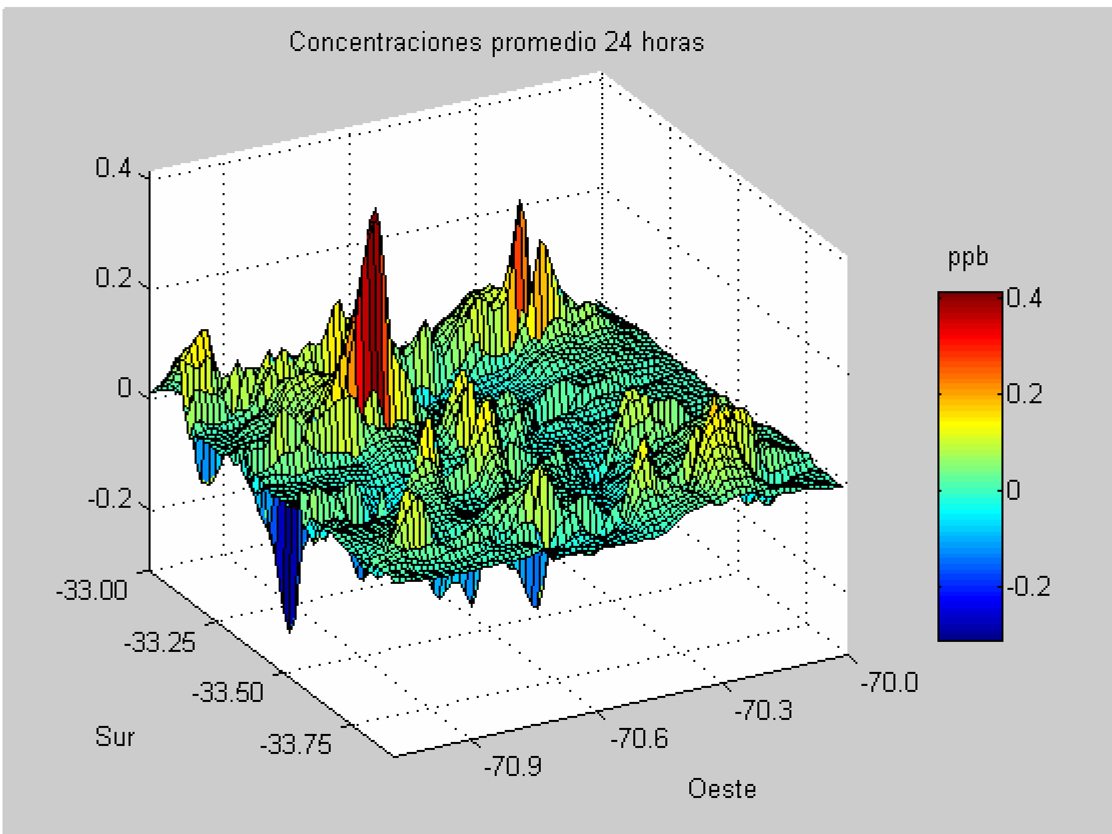
Pollutant	Annual (tons/year)	Daily (kg/day)
PM10	90	250
NOx	6713	18647
VOC	352	978

Source: SESMA (2000)

6.4.2.2 Variations in Ozone Concentrations

Concentration reductions are very small for ozone. The reason for this is the removal for Renca on average represents less than 1% change in emissions. For example, in January these plants emit 508 NOx tons. This figure expressed as kilograms per second would be about 0.19 kg/s. Considering base NOx emissions in the cell including Renca reach 80 kg/s, a small impact on ozone concentrations is reasonable. The following table presents the average 24-hour change in concentrations:

Figure 15 Change in 24-hour Average Ozone Concentrations

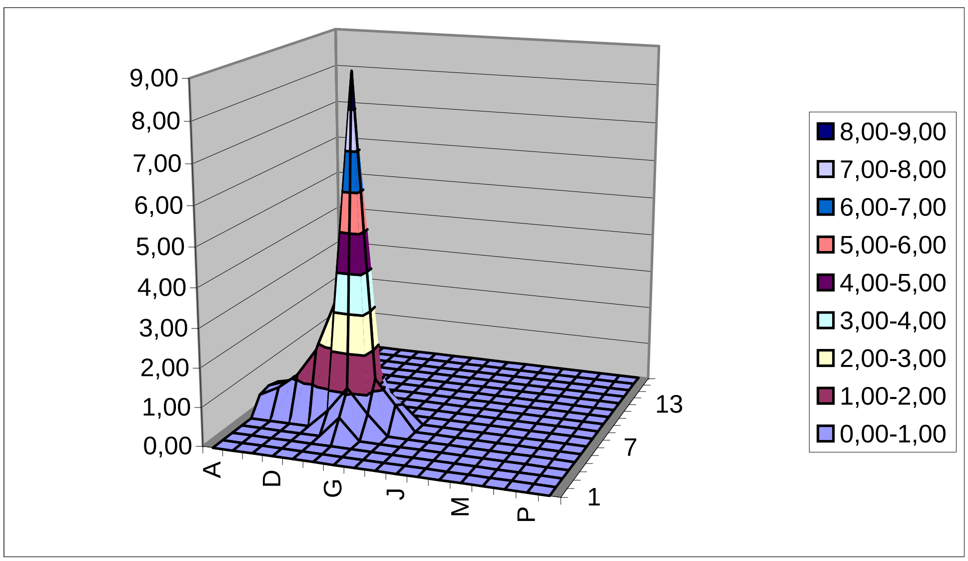


Source: own elaboration

6.4.2.3 Variations in PM10 Concentrations

The following figure shows the variation of PM10 concentrations for each of the cells affected by the removal of Renca and Nueva Renca. As can be seen, the effect of the removal is restricted to the northwestern area of the city where the plant is located.

Figure 16 Reduction in Annual Average PM10 Concentrations (μg/m^3)



Source: own elaboration

It is important to notice changes in concentrations are positive in some cells and negative in others. The positive case represents a decrease in concentrations while the negative an increase in concentrations. Then, in the ozone case it is not clear a priori if benefits or costs will be obtained.

6.4.3 Results: Estimation of Health Benefits

The removal of Renca and Nueva Renca results in the ozone and PM10 concentration reductions presented. As a consequence, health impacts and benefits are expected. These impacts and values are estimated using the health model for Santiago already defined.

Each pollutant has specific concentration levels in each cell of the grid used for each pollutant. In order to quantify the health impacts, it is necessary to establish the population in each cell. For this purpose, the last census 2002 was used and population was disaggregated for each cell of the grids.

The following table shows health benefits disaggregated by mortality and morbidity.

Table 36 Annual Health Impacts and Benefits derived from Ozone Concentration Reductions (US$)

Benefits	PPDA	Benmap
Mortality	9,688	254,671
Morbidity	47,492	164,644
Total	**57,180**	**419,316**

Source: own elaboration

As can be observed, total benefits are quite low. The main reason for the low benefits is the small impact of Renca and Nueva Renca on aggregate emissions and consequently concentration variations. Another reason is the emission reduction is produced in only one cell having a limited spatial impact throughout the city, This means a few people in the city experiment changes in concentrations.

The endpoints that present highest variations in terms of cases avoided are respiratory symptoms, MRAD and asthma attacks. However, it is the mortality endpoint that provides the greatest source of benefits due to the high unit value of a statistical life and in spite of the small variation in mortality.

The same information for PM10 is also presented. The following table presents health benefits disaggregated by mortality and morbidity.

Table 37 Annual Health Impacts and Benefits derived from PM10 Concentration Reductions

	PPDA	BENMAP
Long Term Mortality	1,389,940	36,538,200
Short Term Mortality	443,391	11,655,686
Morbidity	521,197	1,862,293

Source: own elaboration

The endpoint that presents greatest variations in avoided cases is symptoms, just like in the case of ozone. Also mortality is the greatest source of benefits specially if considering long term mortality.

6.4.4 Estimation of Benefits in Agriculture

The reduction in ozone concentrations also results in changes in agriculture production. To carry out this evaluation the information of the lands used for crops was obtained from the 1996-1997 agricultural census.

Given crops are located in different areas the region being studied and the fact ozone concentrations rise and fall in different sectors implies some crops increase and others decrease their production. After quantifying the changes in production, these are valued using the prices chosen for each species. The results are presented in the table below:

Table 38 Agriculture Benefits per year

Species	Benefits (US$)
Total Agriculture Benefits	**9,503**

Source: own elaboration

The results show some species present negative benefits[40]. This is because production for these species is reduced like in the case of lemons or maize. However, aggregate agriculture benefits are positive implying production reductions for some species are compensated by increased production of others. Yet, agriculture benefits in this case are extremely low both individually for each species and as can be observed for aggregate benefits.

[40] See Appendix 4 for more detail.

7. Global Benefits

This section presents the methodology used to estimate potential global benefits of replacing a conventional thermal plant by a NCRE plant due to the reduction in greenhouse gases (GHG). For this purpose, the same assumptions made in the local benefit case are made. In particular, natural gas plants in Nehuenco (350 MW for Nehuenco I) and Renca (370 MW for Nueva Renca) are studied and assumed as representative concerning GHG emissions from this type of plants. It is important to note that no life cycle analysis is included in this evaluation[41].

The lack of GHG emissions data for the power plants under examination, makes it necessary to use emission factors to estimate emissions knowing the operation of the power plants Renca and Nehuenco. The emission factors employed are presented in the table below:

Table 39 Emission Factors for Power Plants according to fuel

	KJ/kWh	kgC/kWh	Oxidation Rate	kgCO2/kWh
Fuel	12,609.86	0.325	0.98	1.169
Coal	16,699.62	0.352	0.99	1.279
Diesel	16,323.69	0.33	0.99	1.197
Natural Gas	7,008.97	0.107	0.995	0.391

Source: Emission Factors provided by Mechanic Engineering Department, University of Chile, 2006

To estimate direct emissions the data of reduced operation from Nehuenco and Renca is required. To be coherent with the local evaluations already carried out in chapter 5, Nehuenco will have a partial operation reduction and only Nueva Renca is assumed to be removed. The following table presents the operation reductions considered to estimate emissions for both power plants.

[41] GHG emissions form the building of alternative power plants can be susbstantially different from those from gas powered plants. However a full life cycle analysis exceeds the scope of this report.

Table 40 Operation Reductions Considered for each Plant (GWh)

Nehuenco	1,174
Nueva Renca	1,207

Source: Own Elaboration based on information obtained from CDEC

The use of emission factors and the operation reductions of these plants enable to estimate CO_2 reductions. The following table presents the emission reductions obtained following this procedure.

Table 41 Annual CO_2 Emission Reductions from Each Plant (tons)

Nehuenco	458,943
Nueva Renca	471,937

Source: Own Elaboration

To put a value on GHG emission reductions it is necessary to know how much society values these reductions. The best approximation to this value is the price currently observed in the market for greenhouse gases as obtained through the Clean Development Mechanism (CDM). Typical values found in CDM transactions vary between US$ 5 and US$ 10 per ton of reduced GHG emissions. The following table presents the annual benefits derived from emission reduction by each plant:

Table 42 Benefits from reduced GHG emissions for each unitary value considered.

Plant/ Price per reduced CO_2 ton	US$ 5	US$ 10
Nehuenco	2,294,716	4,589,433
Nueva Renca	2,359,685	4,719,370

Source: Own Elaboration

The results show that in both cases benefits range from about US$ 2 million to almost US$ 5 million according to the unit value used.

8. Conclusions and Recommendations

The restrictions to low price natural gas supply from Argentina has changed the outlook for NCRE's in Chile in a very short period. Between April 2004 and October 2005, the power plant construction schedule (baseline scenario) that considers a ten year period, has moved away from an increase in power based almost exclusively on natural gas (57% of power increase in the period) to an increase based on coal and CNG (77% of power increase in the period).

This change has affected the future energy matrix increasing significantly the expected cost of energy. In particular, in this period the marginal cost of energy almost doubles on average under the current construction schedule as compared to the 2004 plan.

Given the future energy matrix associated to the October 2005 construction schedule, and fuel prices assumed by CNE in the period 2006 to 2015, an alternative scenario that includes NCRE's, is economically attractive considering a social evaluation that considers only investment and operation costs. In fact, the lower operational costs associated to the alternative scenario, more than compensate the additional investment costs required to introduce NCRE's. As a result, total investment and operation costs under this alternative are 0.5% lower than under the base case, approximately US$ 65 million.

The previous conclusion is based on conservative values of fuel prices, both for coal and CNG. If prices are higher, the positive economic impact of introducing NCRE's becomes greater. For example, considering an increase of 33% in the coal prices and 100% in CNG, total investments and operation costs of the alternative scenario become almost 3% lower than the base scenario.

The consideration of social costs of failure *strengthen* the positive impacts of introducing NCRE's. First, the alternative scenario has a lower failure cost of US$ 15 million in the period, than the base scenario. Additionally, if natural gas supply restrictions occur this difference increases to US$ 20 million.

The marginal costs –and consequently the prices to consumers- under the alternative NCRE scenario are significantly lower than the base scenario. The replacement of high operation cost CNG power plants by the gradual introduction of low operation cost geothermal, biomass, mini hydro and small wind energies results in an 8% reduction in average marginal costs in the period. This difference reaches 10% when a high fuel price schedule is considered.

A scenario with more renewable sources also has better performance when considering diverse non-monetary indicators. The indicator of unsupplied demand is on average (considering the ten-year period) 0.03% in the base case and only 0.02% in the alternative scenario. In both cases this percentage rises in the presence of natural gas shocks. In fact, in the case of a natural gas shock in 2008, this indicator reaches 0.37% in the base scenario compared to only 0.25% in the alternative scenario. Natural gas restrictions in 2012 do not impact unsupplied demand, due to the availability that year of CNG.

The probability indicators show the same behavior as the unsupply indicators. The presence of NCRE reduces the average probability of a failure larger than 1GWh from 5.7% in the base case to 4.3% in the alternative scenario. As expected, natural gas shocks in 2008 also increase these probabilities to 6.6%, higher than the 5% when NCRE's are included. The probability of having a failure larger than 10% of demand in 2008 is significantly higher in the presence of a supply shock in the base case than with NCRE's: 0.5% vs 0.1% .

The systemic impacts on air pollution associated to the introduction of NCRE's where beyond the scope of this study. However, two cases have been evaluated that shed light on the order of magnitude of the expected direct costs/benefits of a typical gas powered plant in Chile. If these plants are replaced by non-polluting NCRE plants in an alternative scenario, these values can serve as a benchmark of the expected benefits -or costs- of this removal.

A first case examines the impacts on ozone concentrations associated to reducing precursor emissions in an amount similar to what would be expected if a typical 350 MW gas powered plant were removed in the Quillota Valley (Valparaíso Region). For this, the actual measurements of the impact on ozone concentrations of a reduction in the annual operation of Nehuenco of almost 1200 GWh, was determined.

A, at first sight, surprising result, is that ozone concentrations actually increase due to the reduction in Nehuenco's operation in two of the three monitoring stations and is not affected in the third one located in an urban setting. In fact, concentrations increase by 40% in the San Pedro station where the effect is the largest. This result is due to the fact that reducing Nehuenco's operation reduces NO emissions that actually destroy ozone[42] .

As a result there are environmental *costs* associated to the removal of Nehuenco due to the increase in ozone concentration. These costs affect health and agriculture. To determine a value for the health effects, it is necessary to put a value on each health endpoint. However, there is no generally accepted value for these endpoints in Chile and for this reason a reasonable range of values is considered. First, those used in the PPDA and second, transferred BENMAP values. The former are significantly lower than the BENMAP values. In particular, mortality values in the PPDA, estimated using a cost of illness approach, can be considered a lower bound of these values.

It is estimated that the total population affected by this increase in emissions is about 120 thousand people. As a result, total health costs associated to ozone concentration increases are between US$ 0.5 and 6 million *per year* depending on the set of values used. Using PPDA values only 40% of the costs are due to mortality effects, whereas with BENMAP values more than 80% of the health costs are due to mortality.

The agricultural area affected by emissions is more than 9000 ha., and includes fruits, cereals, grapes and other crops. However, the costs on agriculture production are low, compared to the health or failure costs, reaching less than US$100,000 per year.

[42] This result is dependent on the reactivity of the VOCs and the ratio between NOx and VOC.

The second case considers the health and agriculture benefits of the removal of the Renca 370 MW power plant in Santiago. This case was chosen as a surrogate for the lack of adequate ozone and PM-10 modeling and monitoring data for this pollutant in Chile. In this case PM-10 reductions affect almost 1.2 million people. Ozone variations affect more than 5 million people, and 15,403.2 km^2 of land[43].

The availability of the CADM model for ozone formation, as well as simplified PM-10 dispersion coefficients, allowed evaluating the effects in more detail than in the Nehuenco case. The ozone model shows that in some specific cells ozone concentrations increase and that in others they decrease. PM-10 concentrations are reduced in every relevant cell[44].

Variations in ozone concentrations result in total net benefits, i.e. the zones where concentrations are reduced have higher benefits than the costs in zones with increase in concentrations. Total health benefits are estimated between US$60 and US$400 thousand per year, the first using PPDA values and the latter BENMAP values. For agriculture the total estimated benefits reach less than US$10 thousand per year. These are relatively low values.

The results for ozone are different for both of the cases examined. In the Nehuenco example, health effects are relatively interesting and associated to areas removed from the main city, whereas in the Renca case they are low and related to an urban setting. This difference can be explained precisely by the fact that Renca is in the middle of a very populated city with a host of activities. The modeling has allowed to quantify effects, but these are low in such a complex setting with high background concentrations of different pollutants that affect ozone. Similarly, in the case of Nehuenco, the monitoring station in the city did not register any significant difference when the power plant did not operate. This result highlights the need for better modeling of ozone to better understand the effects of replacing large power plants close to urban settings as in the case of Nehuenco and other future plants in Chile.

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[43] This lands do not necessarily include crops and include urban areas.
[44] Only primary reductions are considered. There is no available model for secondary particulate formation.

Health benefits from PM-10 emission reductions are however significant in the Renca case. Long-term mortality benefits range from US$1.4 million to US$36 million per year. Short-term mortality ranges from US$ 400 thousand to US$ 12 million per year. Finally, morbidity benefits vary from US$ 0.5 and 2 million per year depending on the set of values used. These are significant values. Again they highlight the need to adequately model the dispersion of PM-10 as well as the formation of secondary particulates, to obtain a better approximation to these apparently important benefit values. In this study, simplified coefficients were used due to lack of proper models.

Annual benefits from reducing GHG emission in Renca and Nehuenco range from about US$ 2 million to US $ 5 million for each plant according to the unit price used to carry out the benefit estimation. These benefits are comparable to the health benefits derived from PM10 reductions. They are however less debatable and less uncertain. First, they are not site specific, so do not depend on the specific characteristics of the location of the plant. The global effect is the same wherever the plant is located. Second, the value of the reduction is determined by the market and not by indirect estimations as in the case of health effects. These latter values are subject to diverse criticisms, there is no consensus about the values, and consequently it is difficult to propose specific policies –for example subsidies- based on them.

In conclusion, NRCE's are currently an attractive option from a social perspective even when only private investment and operation costs are considered. The current high prices of fuels and natural gas shortages that are expected to continue in the future have forced the new construction schedule to include more costly power plants. A construction schedule with more (and reasonable) NCRE's would actually be less costly for society. It is thus recommended that instruments that promote NCRE's be examined. Reductions in failure costs associated to an energy matrix with more NCRE's strengthen the previous result.

Although the environmental exercises carried out are not directly comparable to the security of supply evaluation, the results suggest these could imply a significant contribution especially when considering health benefits associated to PM10 reductions in locations with significant exposed population. The case of ozone is uncertain since precursor emission reductions are heavily dependant on background environmental conditions, and the replacemet of gas plants may result in benefits or costs. Results also show for the case of ozone that health benefits/costs dominate agriculture benefits/costs. Finally, GHG emission reductions could also result in important benefits, again strengthening the possibility of introducing NCRE's.

The analysis carried out has been based heavily on models that characterize the electric system and the environment. However, more elaborated models are required to reach final conclusions. Pollutant concentration models must be available in locations other than Santiago, which can predict the real effects of precursor emission changes for both ozone and PM-10. The important and most representative case of potential plants in Valpariaso Region (Nehuenco) could not be evaluated using models. On the other hand, the modeled case of Santiago is less interesting from the electric decision making perspective.

The determination and valuation of health and agricultural effects should also be improved. Regarding health, local sets of health values and especially for mortality should be obtained and agreed on, to avoid the extreme sensitivity of health results to the values used. The agricultural effects seem to be of less importance, however in some cases there may be products whose markets are sensitive to the pollution levels where they are produced. This was not examined in this report.

Even with the limitations discussed, the results of this study suggest that NCRE is a potentially attractive choice to be included in the Chilean electric system. A key question that needs to be addressed is how to encourage private firms to include NCRE's. Security of supply benefits, benefits due to reduction in particulate matter, potential sales of reductions in GHG emissions in the CDM market, and in a lesser degree benefits due to ozone reductions, can contribute to generating the required incentives.

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10. Appendices

Appendix 1: Functional Forms of Health 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) $y = Be^{\beta x}$ 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 difference in incidence rate (Δy) and the exposed population.

Appendix 2: Dose Response Functions applied for Agriculture

Dose-response functions used in agriculture may have different functional forms. The forms 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", and "ε" are parameters specific to the dose response functions. "C" represents the level of concentrations[45].

The performance of a species represents the amount (or weight) of crop obtained in a unit of cultivated surface (generally hectare). Thus, given increases in concentrations performance (or production) is reduced.

The following table presents the dose response functions selected for agriculture. In each case, parameter values and source are specified.

Table 43 Dose Response Functions for Agriculture

Species	Concentration (Units)	Exposure (hours)	α	β	δ	ε	Source
Onion	ppm	12	5034	-109.4			Temple et al. 1986
Forrajera	ppb	12			139	1.95	Somerville et al. 1989
Bean	ppm	12	163.6	-9.387			Temple et al. 1986
Bean	ppm	12	165.8	-13.57			Temple et al. 1986

[45] The unit of the concentrations differ across pollutant and crop. For example, in the case of ozone some functions require average daily concentrations while others require maximum hourly concentrations.

Bean	ppm	12	167.6	-13.98			Temple et al. 1987
Lettuce	ppm	7			122	8.837	Temple et al. 1988
Lettuce	ppb	7			117	1.523	Fuhrer et al. 1989
Lemon	ppm	12	0.5	-0.022			Thompson y Taylor. 1969
Maize	ppm	7			16	3.709	Kress y Miller. 1985
Maize	ppb	12			124	2.83	Somerville et al. 1989
Soy	ppb	12			107	1.58	Somerville et al. 1989
Tomato	ppb	7			142	2.369	Fuhrer et al. 1989
Wheat	ppm	7			14.5	3.326	Kress et al. 1985
Wheat	ppm	7			5.3	1	Heck et al. 1984
Wheat	ppb	7			136	2.56	Somerville et al. 1989
Grapes	ppm	12	9315	-647			Thompson et al. 1970
Grapes	ppm	12	1.121	-0.066			Brewer et al. 1988

Appendix 3: Results from Nehuenco Case: Local Benefits

The following table presents in detail the rise in number of health endpoints associated to the rise in ozone concentrations in the Quillota Valley as estimated from the concentration-response functions and the subsequent valuation of these cases.

Table 44 Health Costs Derived Derived from Ozone Concentration Increase

Endpoint	New Cases	PPDA (US$)	BENMAP (US$)
Mortality	3	5,032,668	191,446
HA, Asthma	0	1	0
HA, COPD +65	2	9,394	1,888
HA, Respiratory Disease	74	327,106	58,284
HA, Respiratory Disease +65	44	234,546	34,610
HA, Pneumonia +65	1	3,581	545
Asthma Attack	1,369	16,426	10,950
MRAD	12,240	183,600	122,400
Symptoms	19,710	137,970	39,420
ERV Asthma	0	1	1
Total Benefits		**5,945,292**	**459,545**

The following table presents the number of lost tons derived from the rise in ozone concentrations in the Quillota Valley as estimated from the concentration-response functions and the subsequent valuation of these cases.

Table 45 Agriculture Costs Derived from Ozone Concentration Increase

Species	Recovered Tons	Benefits (US $)
Dry Vetch	0	0
Green Vetch	0.250023529	462
Dry Grain Vetch	0.005	5
Onion	1.771304348	3,395
Early Onion	0.05979661	108
Corn	0.192709677	412
Cauliflower	2.40652	3,539
Annual F	1252.039024	4,688
Permanent F	5585.374431	20,930
Lettuce	812.7106599	2,859
Lemon	5.492578249	10,251
Maize	1.508192771	2,276
Melon	3.445756098	2,316
Nuts	0.590691099	2,969
Potato	0.159270833	99
Internal Consumption Bean	0.020727273	36
Export Bean	0.074	148
Summer Bean	2.72776	4,871
Green Bean	0.005287081	13
Fresh Tomato	563.1346445	2,023
Industrial Tomato	0.105494845	379
White Wheat	1.450453125	2,813
Wheat	0.968447458	1,892
Table Grapes	489.228361	1,684
Wines	0.102990276	355
Carrots	51.21783333	16,885
Total Benefits		**85,408**

Appendix 4: Results from Santiago Case Case: Local Benefits

The following tables present the number of cases avoided derived from ozone and PM10 concentrations in Santiago as estimated from the concentration-response functions and the subsequent valuation of these cases.

Table 46 Health Benefits Derived From Ozone Concentration Reductions (US $)

Endpoint	Cases Avoided	PPDA (US$)	BENMAP (US$)
Mortality	0	9,688	254,671
HA, Asthma	0	22	69
HA, COPD +65	1	747	3,758
HA, Respiratory Disease	2	1,396	7,836
HA, Respiratory Disease +65	18	13,947	94,513
HA, Pneumonia +65	0	3	20
Asthma Attack	1,056	8,452	12,677
MRAD	6	65	97
Symptoms	11,382	22,764	45,528
ERV Asthma	2	97	146
Total Benefits		**57,180**	**419,316**

Table 47 Health Benefits Derived From Ozone Concentration Reductions (US $)

Endpoint	Cases Avoided	PPDA (US$)	BENMAP (US$)
Long Term Mortality	20	1,389,940	36,538,200
Short Term Mortality	6	443,391	11,655,686
HA, All Cardiovascular +65	7	5,613	43,834
HA, Asthma	8	6,484	20,253
HA, Pneumonia +65	1	902	5,928
HA, Ischemic Heart Disease+65	2	1,686	16,071
HA, Congestive Heart Failure	2	1,474	8,264
HA, COPD +65	1	1,121	5,638
ERV Asthma	14	704	1,055
Symptoms	251,607	503,214	1,761,249

Ozone concentration reductions also impact agriculture production. The following table presents the recovered tons of each species considered in the agriculture evaluations as well as the benefits associated to this productivity improvement.

Table 48 Agriculture Bernefits Derived from Ozone Concetration Reductions

Species	Recovered Tons	Benefits (US$)
Dry Vetch	0.000	0
Green Vetch	0.046	85
Dry Grain Vetch	0.001	1
Onion	-0.012	-23
Early Onion	0.098	177
Corn	-0.029	-62
Cauliflower	0.085	125
Annual F	-0.438	-1,640
Permanent F	0.645	2,417
Lettuce	0.672	2,364
Lemon	-0.202	-377
Maize	-0.495	-747
Melon	0.061	41
Nuts	0.038	191
Potato	0.695	432
Internal Consumption Bean	0.019	33
Export Bean	-0.001	-2
Summer Bean	-0.028	-50
Green Bean	0.085	209
Fresh Tomato	0.552	1,983
Industrial Tomato	0.216	776
White Wheat	0.066	128
Wheat	0.302	590
Table Grapes	0.631	2,172
Wines	0.179	617
Carrots	0.182	60
Total Benefits		9,503