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INSTITUTE FOR TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS

Diversificación de la matriz energética en la región metropolitana de Santiago de Chile con enfoque en Energías Renovables

DIVERSIFICATION OF THE ENERGY MATRIX IN THE METROPOLITAN REGION OF SANTIAGO DE CHILE WITH FOCUS ON RENEWABLE ENERGIES

THESIS TO OBTAIN THE DEGREE OF
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Zusammenfassung:

Diese Arbeit zielt darauf ab, eine Lösung für die Diversifizierung der chilenischen Energie-Matrix mit einem Fokus auf erneuerbare Energien bieten. Die Untersuchung ist in dem Projekt namens "Risk Habitat Megacity" eingebettet, die die Entwicklung der städtischen Siedlungen, im Nachhaltigkeitskontext untersucht. Hierbei wird die Bedeutung der Städte und ihre Relation als Zentren des Energieverbrauchs untersucht, dies im generellen und im chilenischen Kontext. Es wird die historische Analyse der Energiesituation analysiert und die drei Energiekrisen des Landes beschrieben sowei Ansätze der Energiesicherheit vorgestellt. Chile hat vor kurzem seine politischen Rahmenbedingungen zugunsten der Erneuerbaren Energien geändert. Der Elektrizitätssektor ist ein wesentliches Element der Analyse, denn nur ein wettbewerbsorientierter Markt mit positiven Rahmenbedingungen ermöglicht die Integration von erneuerbaren Energien. Es werden verschiedene Maßnahme diskutiert, die einen Weg zu einer nachhaltigen Entwicklung ermöglichen zusammen mit einer verbesserten Situation der Versorgung der Energiesicherheit mit einer geringeren Abhängigkeit von Importen. Hierzu ist es unumgänglich, dass die chilenische Regierung einen umfassenden und langfristigen Plan für die energiepolitischen Rahmenbedingungen schafft, dass die Energiepolitik und Energieeffizienzprogramme gleichermaßen berücksichtigt. Diese Arbeit liefert dazu eine kleinen Beitrag.
Stichworte: Energiematrix, Energiekrise, Elektrizitätssektor, Energieeffizienz, Energiesicherheit

Summary:

This work aims to provide a solution for the diversification of the Chilean energy matrix with a focus on renewable energies. The research is embedded in the project called Risk Habitat Megacity, which investigates the development of urban settlements in the context of their sustainability. The first part explains the importance of cities and their link as energy consumption centers in the Chilean context. A historical analysis of the energy situation describes the three energy crisis the country has suffered from and how to overcome the energy shortages. Chile has recently changed its policy framework in favor of Renewable Energies. The electricity sector is a vital element of the analysis, as only a well-designed and competitive market allows the integration of renewable energies. The fourth chapter discusses measurements and shows a path into a more sustainable development, with enhanced energy security, a lower import dependency, but with the necessity for the Chilean government to develop a comprehensive long-term energy policy framework, that includes energy policy and energy efficiency programs alike. This investigation is an initial attempt.
keywords: energy matrix, energy crisis, electricity sector, energy efficiency, energy security

Resumen:

Este proyecto tiene como objetivo proveer un solución a la matriz energética de Chile con foco en las energías renovables. Esta investigación forma parte del proyecto llamado "Risk Habitat Megacity", que investiga el desarrollo de asentamientos urbanos en el contexto de la sustentabilidad. La primera parte explica la importancia de las ciudades y su conexión como centros de consumo energético en Chile. Un análisis histórico de la situación energética describe las tres crisis energéticas que sufrió el país y cómo afrontar las escasez de energía. Chile ha cambiado recientemente su marco político a favor de las energías renovables. El sector de energía eléctrica es un elemento vital del análisis, ya que sólo un mercado bien diseñado y competitivo permite la integración de las energías renovables. Las mediciones discutidas en el capítulo cuatro muestran un camino hacia un desarrollo sostenible, mejorando la seguridad energética, dependiendo en menor medida de la importación, pero con la necesidad de que el gobierno chileno desarrolle un marco político-energético, que incluya políticas energéticas como los programas para la eficiencia energética. Esta investigación brinda una contribución inicial.

Palabras clave: matriz energética, crisis energética, sector de electricidad, la eficiencia energética, la seguridad energética

Index

List of abbreviations

CORFO – Economic Development Agency (Corporación de Fomento de la Producción)

bcm – billion cubic meters

b/d – barrels a day

CDEC – Economic Load and Dispatch Center (Centro de Despacho Económico de Carga)

CPD - Commercial public and residential sector

DISCO – Distribution Company

DSM – Demand Side Management

ESCOs - Energy Service Markets

EIA – Environmental Impact Assessment

EMSC - Energy Security Market Concentration

GHG – Greenhouse Gas

GDP – Gross Domestic Product

HHI - Herfindahl-Hirschman Index

HVDC - High Voltage Direct Current

LA - Latin America

LAC - Latin American Country

MBtu – Million of British Terminal Units

MEPS - Minimum Energy Performance Standards

MIT – Massachusetts Institute of Technology

MMA – Ministry of the Environment

MR - Metropolitan Region of Santiago de Chile

Mt – Million tons

Mtoe – Million tons of oil equivalent

OECD – Organization for Economic Cooperation and Development

OPEC – Organization of Petroleum Exporting Countries

PEC – Total Primary Energy Consumption

PIEE - Energy Efficiency Preinvestment Program

PPEE - National Energy Efficiency Program

RET – Renewable Energy Technology

SEC - Superintendent of Prices of Electricity and Fuels

SIC – Central Interconnected System (Sistema Interconectado Central)

SING – Greater Northern Interconnected Grid (Sistema Interconnectado del Norte Grande)

TFC – Total Final Energy Consumption

TPES – Total Primary Energy Supply

USD – US American Dollar

0. Introduction

The Republic of Chile is located in the south west of America with Peru, Bolivia and Argentina as neighboring countries. The geographical profile includes 39 grades of latitude with an north-south extension of 4300km which provides diverse climatic and geographical conditions. Located in the north, the driest place on earth, the Atacama desert, with an N-S extension of nearly 1700 km. The central region, where the majority of Chilean population lives, is characterized through a Mediterranean climate with the highest point of the Andes called "Ojos de Salado" reaching 6880 meters. In the southern zone predominates a rainy temperate climate with yearly precipitation of 5000 mm.[1]

Chile is one of the most successful countries in the southern hemisphere in terms of political stability, economic growth and pioneered a market reform process in the electricity sector. With the end of the Pinochets' dictatorship in 1990 the economy regained its pace and since then grew faster than any other country in the region. The economy is largely based on abundant mineral resources mostly located in the north as well as agriculture, forestry products and fishing. By 2008, Chile had signed trade agreements with 58 countries including the United States, China, the EU and Japan as the most important trading partners. Due to its liberal free market policy thinking export share has risen in two decades from 26 to 45 percent in 2006. Sound monetary policies and anti-fiscal management enabled a fast recuperation through stabilizers such as the Economic and Social Stabilization Fund as well as the Copper Stabilization Fund with savings of more than USD 21 billion (12 percent of GDP, because of high copper prices in the last two years) by the end of 2008.[2] The unemployment rate remained near nine percent with a low inflation rate of three percent. Due to the vigorously reducing interest rate from 8.25 percent to 0.5 percent the central bank has set an impulse on the monetary side in the first half of 2009 that permitted an strong incentive for investments to stimulate the economy after the property markets crash in the United States.[3] In total numbers Chile has been developed very successfully reaching the highest GDP per capita in PPP term of USD 14500 in 2008, ahead of Brazil and Argentina which totaled 236 billion US-Dollar in the same year.[4] This has lifted the share of people that came out of poverty from 54.9 percent in 1987 to 86.3 percent in 2006.[5] For its merits on economic sound policy making and political stability Chile has become the first OECD member in South and Central America by January 2010. This membership marks a milestone and can be seen as model for other countries in the region.[6]

[1] UNEP Country Profile Chile.
[2] IEA (2009).
[3] OECD (2010a).
[4] IEA (2009).
[5] CNE (2008), p. 36.
[6] OECD (2010b).

On the other side, a high growth demands more energy and causes more environmental impacts. This work will investigate the energy situation of Chile. The country has suffered from three severe energy crisis in the past two decades and is highly dependent on imports of fossil fuels that contribute a high percentage to the primary energy matrix. The focus will be on the central electrical grid, the SIC,[7] which has an extension of more than 2000 kilometers and provides more than the half of the overall energy for around 90 percent of the population living in Chile.

The work is embedded in the 'Risk Habitat Megacity' project, with Santiago de Chile as model city for investigation, more detailed explained in the **first chapter**. Urbanization and energy consumption are closely related, especially considering the fact, that the majority of the Chilean population lives in urban areas. The phenomena is not only observable in Latin American Countries (LACs), but is a world wide trend, as well as the evolution of the Metropolitan Region of Santiago de Chile (MR). The chapter briefly describes the historical development of Santiago and its relevance today. It shows the immense importance of cities, such as Santiago, in terms of today's economy and what make them important in the context of their possible contribution to a sustainable development.

Chapter two examines the historical and current energy situation with respect to security of energy supply in Chile. It describes the three most recent energy crisis and the reasons for this developments. The different concepts of energy security are employed and applied on the Chilean case.

Chapter three examines the basic characteristics of the Chilean electricity grid. The deregulation and privatization process in the longest running in history and serves in the world as example for a developed and developing countries alike. The first reform steps were undertaken in the late 1970s with the foundation of the National Commission of Electricity and a law of 1982. In a first step the reform process until 2000 is examined. Then the policy framework has changed in favor of NCRE, especially in the recent decade. The Post-privatization process follows with an analysis of the challenges and opportunities to improve the electricity market. The last part introduces approaches to electricity security and closes the electricity section with recommendations and international experience of RE implementation.

The increased or additional energy and electricity demand can by covered in very different way concerning the demand and the supply measures, detailed analyzed in **chapter four**. In this context the a sector analysis of the MR is done to figure out the potential contributions of the MR to lower the energy needs. On the demand side intelligent Demand Side Management (DSM) programs, smart grids and integrated energy efficiency measures as they are implemented, for example, in California or Italy in the electricity sector. At the supply

[7] Central Interconnected System – Sistema Interconectado Central (SIC), the acronym in Spanish.

side, Chiles indigenous natural resources will be analyzed that could cover a part of the future energy demand, the implementation of renewable energies such as hydropower, geothermal energy, solar power, wind energy, biomass as well as ocean energy and the possible option of nuclear energy are discussed. The final section concludes the previous outcomes.

The work aims to develop an energy policy approach, that is so far by June 2011 non-existent. A perspective for the year 2030, where all measures are integrated that will result in a significant improvement for the energy security, especially the implementation of these measurements will contribute to the ultimate governments goals of economic efficiency, social and environmental sustainability and energy security.[8] The second target is largely expressed in the 2008 program to fight climate change, which would co-benefit of the implementation of NCRE in the SIC grid lowering the GHG emission in comparison to fossil resources. The government has to consider, that the development of an integrated comprehensive approach for energy and electricity security is not only important for an uninterrupted functioning of the economy, the supply security for consumers and pathway for sustainable development but as well as the way to keep the energy costs in the long-term perspective at a reasonable level with less influences from the world market, as the energy generation will be more independent in future.

[8] Rudnick (2010).

1. Cities & their relation to energy

1.1. Historical Context

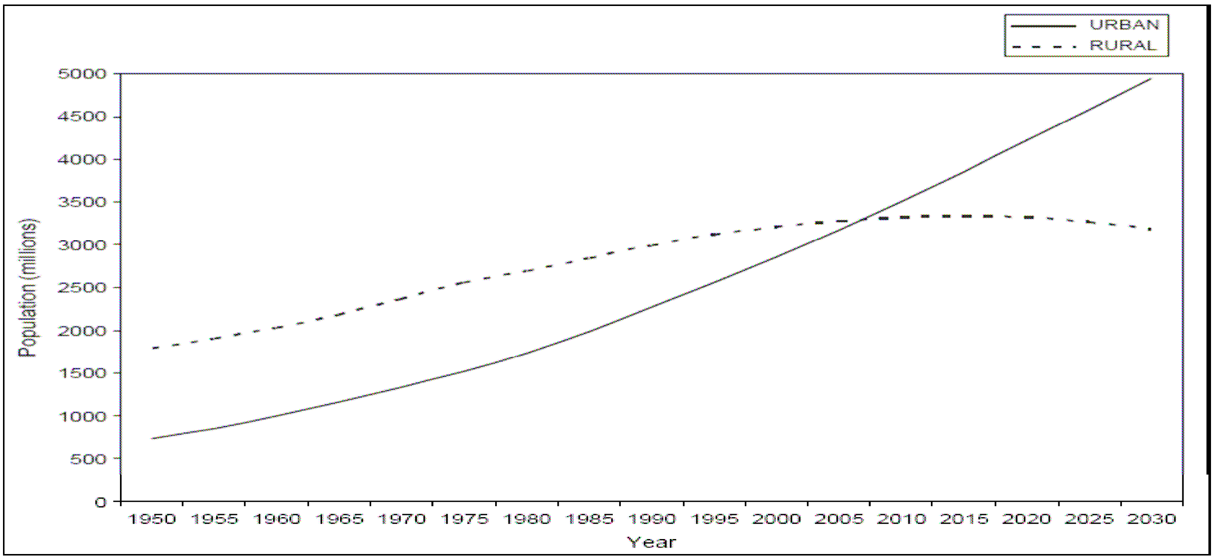
The phenomena of cities is not an occurrence of recent history. The first human settlements already existed in Mesopotamia 3000 to 4000 B.C. Since then, most of the important evolutions of human mankind have occurred in cities.[9]

Hereby, the two processes of urbanization and population growth are closely connected with each other. During the European apogee epoch, which coincides more or less with the Middle Ages, most cities and settlements have been established. The next surge in growth of cities was caused by the European industrialization and the increased need for labor in these settlements, firstly started in England and then spread around in the rest of continental Europe. Therefore, the University of Liverpool was the first to established the first formal course dealing with cities. In 1909 a degree program for town and country planning was establish and at the same time the MIT established a course in urban planning.[10] This process of industrialization, beginning in the 18th century, historically never seen before, caused a high demand for workers and thus sped up the population growth. Today, the share of people working in the industrialized sector is less important, due to the growing service sector, but in countries like Brazil or Chile, the industrial employment is higher creating a large share of the economic growth. Since the industrialization, the pace of every additional billion human beings on earth has happened in ever shorter periods of time. Earlier, this amount of people was absorbed by rural and urban areas alike until the point, when metropolitan areas became known for their opportunities to find better jobs, better health care and several other reason that make people move to cities or to live there, so that more than 60 percent will habit in urban areas.[11] This has pushed the emergence of more and more megacities.[12] While in 2000 worldwide existed only 15 cities of that size, in five decades there are to be projected 54,[13] with increasing problems of congestion, health problems and an increased social spatial separation as some negative consequences related with the evolution of megacities. The other challenge is to meet the energy requirements of future cities, discussed in chapter 1.4, which is one of the vital tasks for (local) governments, as most cities were not contrived for such an massive growth of population in modern cities in LA, Asia and Africa. In 2008 for the first time in history, urban and rural population where equal with an increasing population living in urban areas, see figure 1. The next development step is the evolution of new emerging megaregions with China's Hong Kong-Shenzen-

[9] This also includes the diseases like the pest in the 14th century, which provoke higher standards for hygiene and the important observation of basic necessities of people sharing a quite compact space.
[10] LeGates/Stout (2003), p. 13.
[11] UN-Habitat (2009/2010).
[12] In terms of UN definition, cities with more than ten million inhabitants.
[13] Rogers et al. (2008), p. 323.

Guanzhou, an agglomeration of 120 million or Sao Paulo-Rio de Janeiro with 43 million inhabitants.[14]

Figure 1: Estimated and projected size of the world's urban and rural population (1950–2030)



Source: Cohen (2006), p. 69.

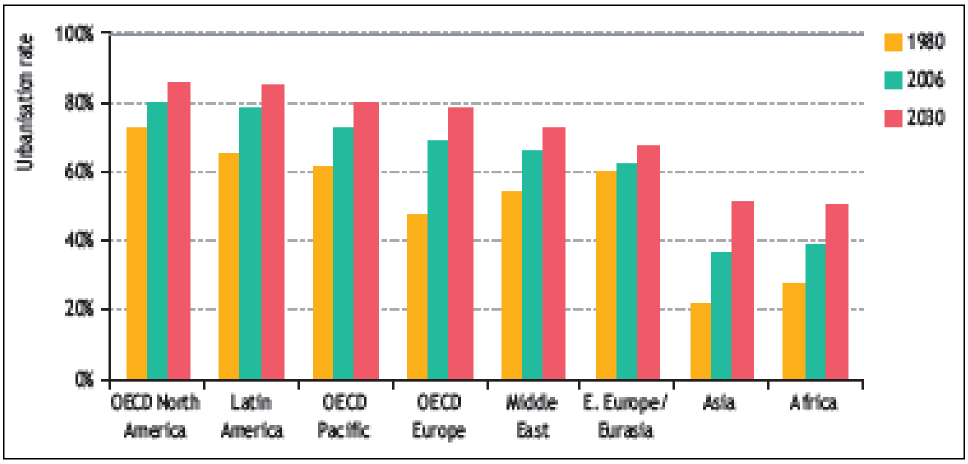
1.2. The development of Santiago in the context of Latin American cities

One of the trends discussed above if the population growth and the urbanization process. Today, cities gain around 70 million people a year or more than a million per week. However, cities are obviously not always beneficiary for their residents. A lot of developing countries lack sanitary sewage disposal and around 50 percent have no adequate supply of drinking or water supply at all.[15]

Latin American cities are, unlike their African or Asian counterparts, already highly urbanized. While in 1950 already 41.9 percent in LA and the Caribbean have lived in urban areas the share will increase to 84.6 percent in 2030,[16] so the total urban population in LA has increased from 59 million in 1950 to 306 million in 1990 or with a growth of 4.2 percent per annum. Average population in LA will grow from 520 million in 2000 to 768 million in 2050, with an expected slight decline after 2050.[17] Today, North America has the highest urbanization rate, but while the principal urbanization in the past has taken place in North America and Europe, the following decades are determined by strongest urban growth in Africa and with the most of the people living urban area in Asia, see trends in figure 2.

[14] UN-Habitat (2010/2011).
[15] Rogers et al. (2008), p. 86; A more comprehensive overview of pros and cons of large cities, see table 2 in appendix.
[16] Cohen (2003).
[17] Gilbert (1996); UN (2004).

Figure 2: Regional trends in urbanization



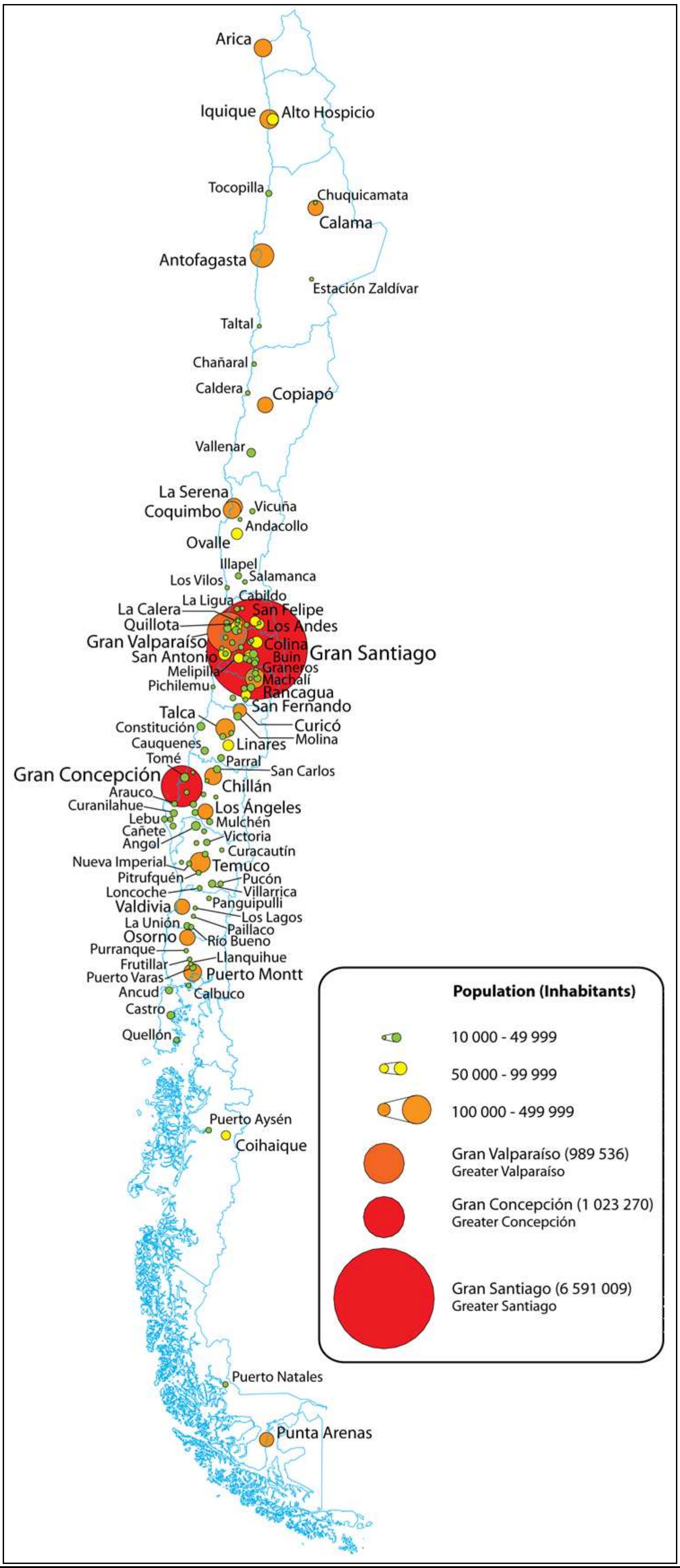
Source: WEO (2008), p. 180.

The development of Santiago de Chile is no exception in this context. In 1865 already more than a fifth population out of 1,8 million Chileans have lived in cities. While urban population grew by 481 percent between 1885 and 1930, the rural grew only by 40 percent in the same period, with the consequence, that by the middle of the 20th century more than the half of the population have lived in urban environments.[18] This trend has continued in the 20th century, where Santiago had 1.41 million inhabitants in 1950 and today the MR remains the largest agglomeration with 6.5 million or 40 percent of the national population.[19] Today, around 85 percent of the whole Chilean population live in urban areas, with the MR as being the cultural center, which generates nearly the half of the Chilean GDP.[20] See the urban center of Chile map 3. It is worth to state, that there is so far no internationally common definition for a city or urban agglomerations. The WEO (2008, p. 181) refers to an urban area, ranging from megacities to small towns, where in the Chilean context urban are the "populated centers which have definite urban characteristics such as certain public and municipal services."[21]

In the 1970s the city experienced a quite aggressive expansion. The barriers of rural and urban were removed so that the expansion towards the periphery, an additional push for the expansion of the city especially in the north east region. Today, the city expands in the suburban, while the core of Santiago has a zero growth or is slightly declining.[22]

[18] Grove (1983), pp. 82, 185.
[19] Out of these 5.8 million live in the city of Santiago and another 700.000 in the MR.
[20] IEA (2009), p. 25; ITAS (2010), p. 1.
[21] UN (1980).
[22] Harms (1997).

Map 3: Principal Urban Agglomerations in Chile



Source: http://upload.wikimedia.org/wikipedia/commons/b/b7/CI-cities.png, (June 15th 2011)

After the period of the dictatorship in 1990, the MR of Santiago[23] grew with 8.5 percent over national average per year until 2000. This development has enabled a success in coping with poverty and especially with share of indigent people. Between 1987 and 1996 the share of people living in absolute poverty has significantly decreased in whole country, but the population living in poverty in Chile was nearly double compared to the MR, see graph 1. This is one of the multiple reasons, why people move, for better opportunities, to cities beside the fact that the Chilean population is growing at a rate of about a percent per year, which accelerates additionally the share of urban population.

Graph 1: Poverty in the MR and the rest of Chile (percentages)

Years	Poverty		Indigence		Non-indigent Poverty	
	MR	Chile	MR	Chile	MR	Chile
1987	38.7	45.1	13.5	17.4	25.2	27.7
1990	33.0	38.6	9.6	12.9	23.4	25.7
1992	26.1	32.6	6.0	8.8	20.1	23.8
1994	19.8	27.5	4.6	7.6	15.2	19.9
1996	14.8	23.2	2.7	5.8	12.1	17.4

Source: Dockemdorf et al. (2000), p. 175.

The Metropolitan Area itself is structured into 39 municipalities, where 37 are located in the Province of Santiago and each one in Cordillera and Maipo, while there exist the MR which has 52 so called *comunas*, which have more responsibilities.[24] In administrative and political terms, Santiago can not be considered as a city.[25] This is quite common for LA cities, where there is no single authority which administers the whole urban area. Due to an administrative reform in 1982, local governments have received a considerable scope of responsibilities and are directly elected for four years. The management and a good governance is vital for a successful transformation of a city into a more sustainable future, under consideration of principles of a good governance and emerging imperatives for the 1990s. There are three tendencies observable, first democratization process has also evolved new ways in managing cities, second, a political shift towards greater decentralization and devolution, and

[23] Located in the central part of the country with the five principal *comunas* Las Condes, Vitacura, La Barnechea, Providencia and La Reina, see map 1 and 3 in appendix.
[24] Borsdorf et al. (2006); See *comunas* of Santiago, see map 1 in appendix.
[25] Dockemdorff et al. (2000), p. 172.

finally, a better transparency in the budgeting of public services. In conclusion, none of the LA cities has fulfilled all the principles of good governance, but the management of Santiago de Chile comes closest in fulfilling the criteria.[26]

In spite of the positive economic development and a Human Development Index (HDI) of 91, which is highest of all LACs, Chile has a very high inequality in income distribution. Its Gini-coefficient[27] is one of the highest in LA with 0.52 in 2006 and has just slightly improved from 1990 levels.[28] One of the consequences of this income difference is the development of gated communities or so called *condominios*, considering the higher security requirements. By 2004, there existed 2,323 of these gated-communities in the 39 comunas of the MR covering 0.92 of the total surface which equals 2,730 hectares.[29] Furthermore, environmental and energy considerations and as consequence, a massive use of space per capita, which created gated-cities built for 50,000 inhabitants or more with own highways, which have let to a growth of the north eastern part of the city of 15,000 ha in the decade of the 90s and have let to an increased automobile use.[30]

1.3. Project Context

The research is embedded in the 'Risk Habitat Megacity' project, which is a comprehensive research program of cities initiated by the German government, probably oriented on the publication of the UN-Habitat 2004 and 2006, with cities as general object of research. In their completeness there are three German projects concerning the topic cities and their possible contribution to a sustainable development:

(a) Future Megacities
(b) Megacities and Megachallenges, Informal Dynamics of Global Change and
(c) Risk Habitat Megacity.[31]

Megacities per narrow definition of the UN-Habitat are cities with and population of more than ten million inhabitants, with currently 19 and projected 26 in 2025.[32]

While (a) is a research project of ten different megacities, mainly located in Asia and Africa with only one research object, (b) is focused on the informational structures of megacities, (c) is the most comprehensive approach with focus on one model city, Santiago de Chile. The

[26] Gilbert (1996), pp. 31-32, 45.
[27] The Gini-Coefficient measures the income distribution of the 10 percent of the population with highest and lowest income. A value of zero means total income equality, and one a complete inequality.
[28] UN-Habitat (2009/2010).
[29] Borsdorf et al. (2006).
[30] Borsdorf at al. (2007); Dockemdorff et al. (2000).
[31] Ehlers (2009), pp. 14-15.
[32] UN-HABITAT (2008/2009), p. 6.

principal objective is to develop strategies for sustainable development in urban agglomerations considering seven investigation categories. The areas 'Governance', 'Risk concept and Management' as well as 'Sustainable Development', that are cross sectional fields influencing all the other fields of research. These are transport systems, air pollution, social issue and energy systems. The latter one is focal point of this Masters thesis. The importance and interrelation between the growing urban spaces and population in relation to their energy needs is part of the next section.

1.4. Urbanization & Energy

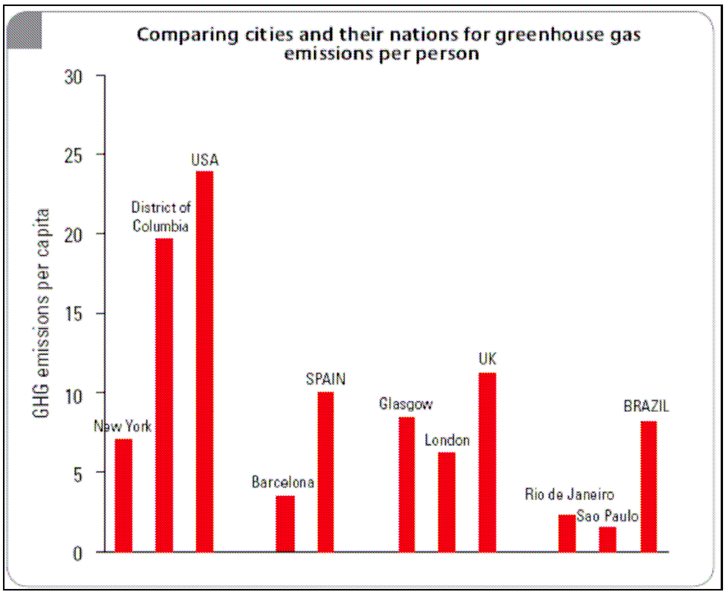
"Cities are civilization,"[33] dynamic and an inspiring source of diversity of cultures and people, which represent technological progress and are mostly the important centers of economic development. For LACs, cities are more than a cultural and inspirational source, they represent the opportunity of finding any new or better employment and often better medical coverage, access to basic infrastructure like water or electricity, which is often not guaranteed in remote areas. As the city of Santiago is growing strongest in the north-western part, where a system of gated communities has evolved. This increased per capita space use is consuming energy, which ranges from industries and financial businesses to the single household and personal customer habits. While around two centuries ago, London was the only city with more than a million of inhabitants, today the world counts with 408 cities, an ever increasing number, if trends continue.[34] Cities currently use two-thirds of the world energy and emit around 70 percent of the world's carbon dioxide emissions. This share continues to increase until 2030, according to the World Energy Outlook 2008.

Considering energy consumption and the relation between energy and the share of population living in cities, that consume a higher amount of energy per capita. Newman and Kenworthy (1991) conducted a study between the relation gasoline consumption and population density. Their conclusion is, that with the increase of population density from 1000 to 3000 inhabitants per square kilometer the gasoline consumption per capita would be reduced by the half. This potentials can be applied to other sectors of a city or an economy, but finally one factor has to be considered at the end, that the standards of living, value systems and the education considering environmental decisions are an important determinant in analyzing a city metabolism. An investigation between the relation electricity consumption and population density in the provinces of Quebec has resulted a five percent lower electricity in the highly populated areas.[35] These energy conserving potentials should

[33] LeGates/Stout (2003), p. 21.
[34] Rachel (2007).
[35] Larivíere/Laffrance (1999).

be conducted for various sectors to exploit the overall potential in energy conservation not only in the case of population density as well as the general plan in city planning and construction or in case of modifications and expansions. Basically all infrastructure like power plants, houses, transport systems are constructed for several decades and more. In 2050, when five billion people will habit in cities, there is a large potential in contemplation these large potentials in the initial phase of the, for example, expansion of a city. Decisions, made by the city government about urban form and structure have impacts lasting more than a century.[36] The case of Santiago has grown considerably in the 90s were basically the city expansion took place in the north eastern parts where the city expanded by 15,000 hectares. There newly built communities with high security were constructed, so called gated-communities that are up to 50,000 people with their own infrastructure like shopping facilities, school and universities inside of this little towns with own highway that connects the home and the work place.[37] These construction on the one hand side, reduces traffic congestion, which is one of the major problems in large cities, but at the other hand promote individual traffic, which is the least efficient form of a transport system. As the Kingsley Davis has stated, that "the urbanization of the human population" will always be linked with more congestion, air pollution, sprawl, exhaustion of natural sources and other consequences of the outrageous urban agglomeration growth.[38] In 2030, urban settlements will be home of 60 percent of the world population with an primary energy consumption of 73 percent, according to UN projections.[39]

Figure 3: Cities and their GHG emissions in relation to the country level



[36] For further information, see WDR (2010).
[37] Borsdorf et al. (2007).
[38] Davis (1965), p. 25.
[39] WEO (2008).

Source: Urban World (2009), p. 15.

But cities are not only large energy consumers, a source a waste and a growing complex form, it is as well the chance to develop intelligent city structures involving the public in order to manage the challenges to come and to pave the way into a 'more' energy friendly future, so the cases of Barcelona and New York considering their greenhouse gas (GHG) emission that are far less than the rest of the country, see figure 3.

Decisions that are made today, will affect future generations and are an initial set up for sticking to the old governance structure or to open the way for new way in managing a city.

An approach to the unlimited growth of cities is the „movement" green urbanism. The whole idea is already from the beginning of the 20th century and was developed by the Scottish biologist Patrick Gaddes. His idea was simply, a systematic approach that is adopted to natural systems. This was the evolutional stage for more and more design ideas in this area. Cities in this sense, were various exist for example in Europe, that "strive to live their ecological limits, fundamentally reduce their ecological footprints, and acknowledge their connections with and impacts on other cities and communities and the larger planet."[40] The sustainability debate has received a boost from the Conference in Rio de Janeiro in 1992 and the resulting Agenda 21 and initiatives such as Local Government for Sustainability Initiative (ICLEI).

The European Commission and the Council of Sustainable Development have developed a line of measurements in order to achieve more urban sustainability.[41] Especially trends of suburban growth, increased sprawl and the growth in automobile use are current trends in LA cities that also includes Santiago.

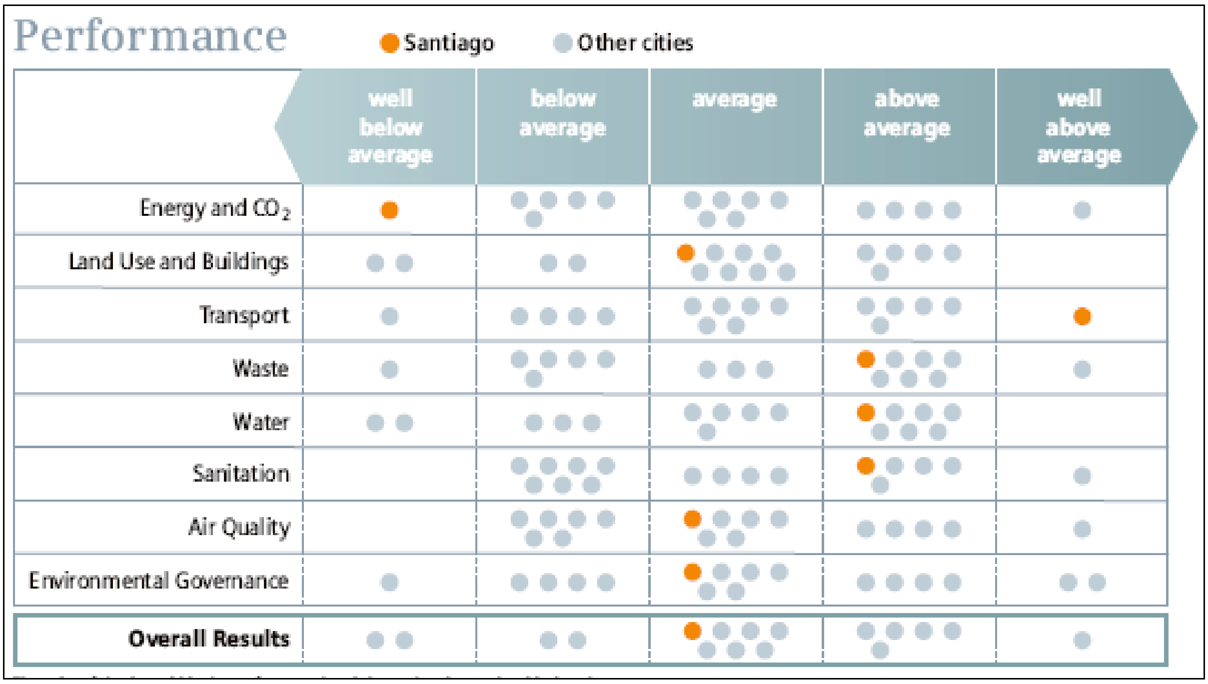
According to the Latin American Green City Index report of the Economist's Intelligence Unit (2009), the overall performance of Santiago is just average, with only one city that reaches the above average raking, Curitiba in Brazil. Santiago has its successes in waste, water and sanitation, while having an average performance in environmental governance, air quality and land use, but especially the ranking in the category energy and CO2 of Santiago is well under average, the worst ranking possible as only city, so the improvement potentials are high. As already mentioned above, the MR is using about 40 percent of the overall energy of the country. It is quite important, that in comparison with the other 17 studied cities in LAC, the energy consumption of Santiago is 1,200 megajoules per USD 1000 of GDP, which is considerably higher than average with 761 or compared to Mexico City with 279 megajoules per USD 1000 of GDP, not using half of average. The CO2 emissions shows a similar picture

[40] Beatley (2003), p. 401.

[41] Some of these are: compact urban form, preservation of open spaces, reduced automobile use, reduced waste and pollution, reuse and recycling of materials improved social equity, see Wheeler (2000).

and is more than twice as high as the average with 463 kilograms per person per year of the cities surveyed.[42]

Table 2: Performance of Santiago in comparison to other cities in LA

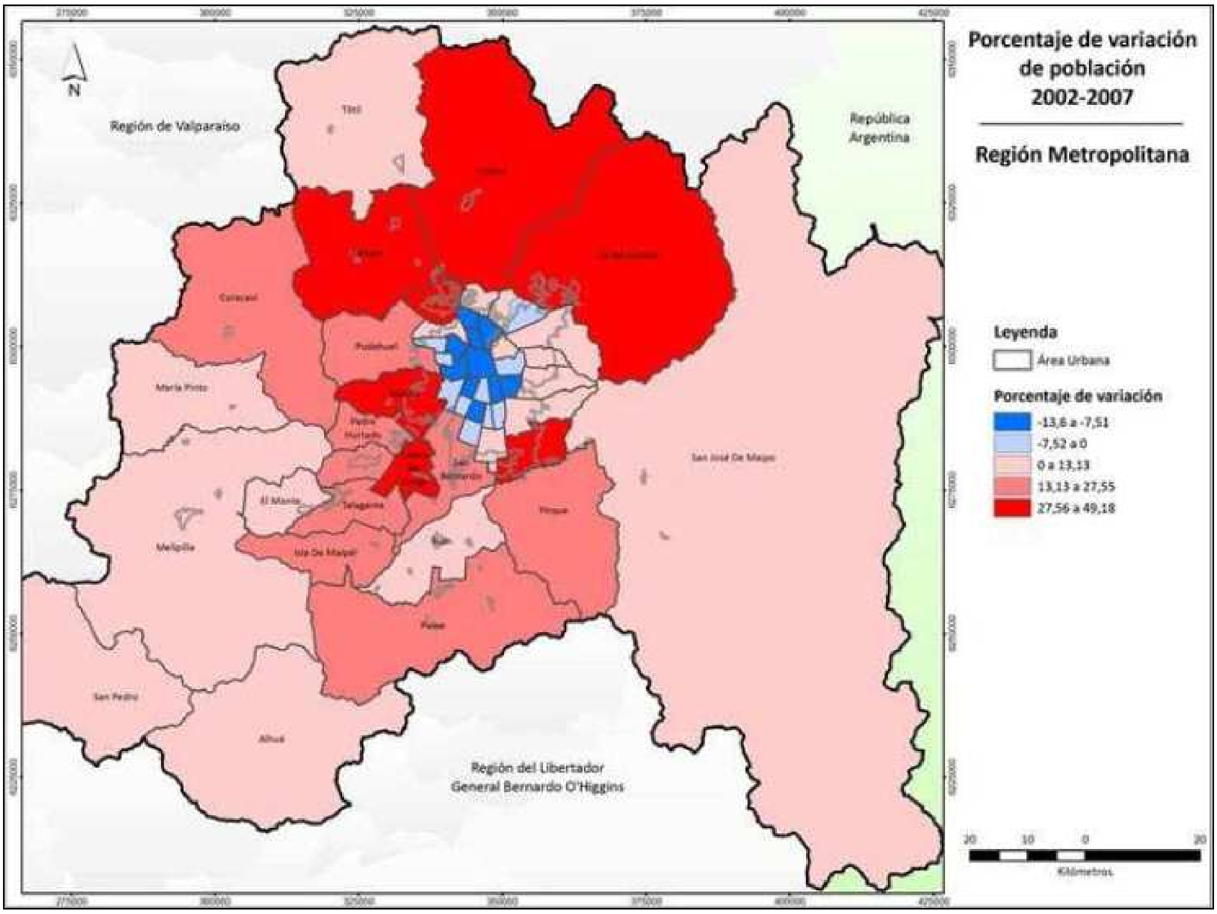


Source: EIU (2009), p. 47.

One reason for the increased energy demand in the transportation sector is the expansion of the city, especially the Greater Santiago, combined with a population growth of 14.2 percent between 1992 and 2002. The motorization rate in Chile between 1992 and 2002 increased from 86 to 147 vehicles per 1,000 inhabitants. A survey of 2001 indicated that 42 percent of people use the bus while 38.1 percent used the car. This is a radical change to the picture in 1991, when these percentages were 59.6 percent and 18.5 percent, respectively, even in a context in which the authority established policies with a clear disincentive for car ownership. Or measured in absolute terms, bus travels have increased by 20 percent while car use has increased in an unexpected amount of 248 percent in the same period.[43] The growth of Greater Santiago is expected with 11,000 hectares between 2002 and 2012, which implies another increase of personal transport towards the suburbs with population losses in the city center, like that around Plaza Italia.[44]

[42] EIU (2009).
[43] Curauma (2005).
[44] See map 6 in appendix for expected expansion of the MR until 2012.

Map 2: Expansion and migration movements of the MR (1992-2007)



Source: Hidalgo et al. (2008), p. 117.

Only a mixture of energy conservation, the promotion of Renewable Energies and an integrated city planning approach will lower the energy demand and at the same time support the governments plan to fight climate change and to lower the ecological footprint of the city. The next chapter will analyze the energy matrix of Chile, that has suffered from three severe energy crisis. It also introduces the different concepts of energy security with a detailed analysis of the existing demand and supply situation in Chile.

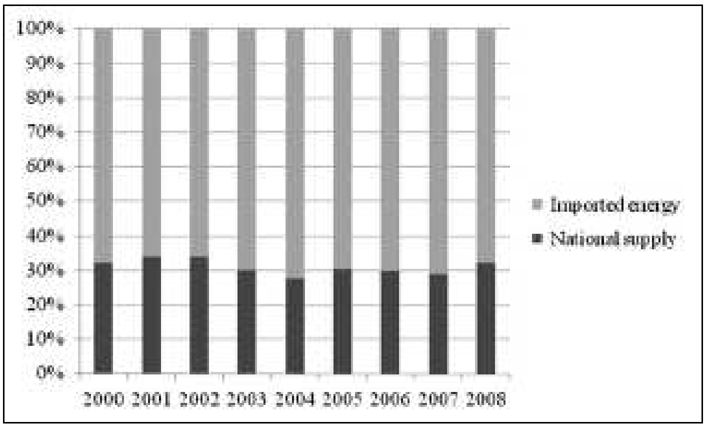
2. Energy Situation

2.1. Introduction and development of energy matrix

This chapter describes the energy situation of Chile of the recent three decades. Chile has performed, in economic terms, quite impressive due to market liberal leaders in advisory positions in the government. A consequence of a growing economy always leads to an increased energy and electricity demand, where Chile is no exception.

The energy sector of Chile has three essential characteristics. In comparison to neighboring countries like Bolivia or Venezuela, Chile's natural indigenous energy resources are limited. As a result, most of fossil fuels have to be imported. Fossil fuels account for 80 percent of the country's the total primary energy supply (TPES). 98.7 percent of crude oil, 95.8 percent of coal and 54.8 percent[45] of natural gas of primary consumption were imported in 2007.[46] This situation has not changed significantly in the past decade, see figure 4. And thirdly, Chile has, for several reason explained later in detail, suffered from insufficient energy security and supply three severe energy crisis that have affected the economy negatively.

Figure 4: Energy import dependency of Chile (2000-2008)



Source: Garcia et al. (2011), p. 2078.

Therefore, diversification is one of the most vital issues related to Chiles energy situation especially in the last two decades. The government has set security, efficiency and sustainability as its strategic target, in meeting the current challenge of energy security.[47] Problems arise from insufficient gas supplies, high oil prices and the vulnerability of droughts that affects the hydroelectric power generation and makes Chile's economy vulnerable.[48]

[45] The 'relative' low level of gas imports is due to export restrictions from Argentina as principal gas supplier.
[46] Méndez (2009).
[47] Tokman (2009).
[48] Martin (2007); In the energy crisis 2007/2008 the spot price for electricity has risen to 350 USD/MWh in the SIC, which has a high percentage of hydroelectricity generation, IEA (2009).

In 2007 the TPES amounted 30.8 Mtoe, see table 3. The energy mix consists predominantly of fossils fuels, lead by oil with 56 percent, followed by natural gas and coal each accounting for eleven percent. The contribution of renewables were dominated by biomass and hydroelectricity making up sixteen and six percent, respectively.[49]

Secondary energy for the production of gasoline originates principally from petroleum. Chile has three refineries, located in the regions Valparaiso, Bio Bio and one in the Magallanes with a combined refining capacity of 34,300 cubic meters per day. For electricity power generation the principal sources are hydroelectricity, and fossil fuels, mainly coal used in thermoelectric plants.[50] The overall installed capacity by December 2010 was 15,558MW. The largest grid, the SIC, had the dominated with 11,845MW or 76.1 percent of installed capacity, followed by the northern SING with 3,575MW, and the two small southern grids Magallanes and Hydroaysen with 89MW and 49MW, respectively. Interestingly, wind power installed capacity in the SIC has doubled from 78MW by the end of 2009 to 160.5MW by the end of 2010.[51] Historically, hydroelectric power has been the dominant source in the SIC to cover power and electricity production, while industrial and residential sector were highly dependent from oil until the mid 90s.[52] This has changed due to changes in governmental policy to lower the dependency of one source beginning to diversify its energy mix.

Table 3: Chiles energy balance 1973-2007

Supply	1973	1990	2000	2004	2005	2006	2007
Total production	5.08	7.43	8.20	8.07	8.86	9.14	8.46
Coal	0.96	1.45	0.24	0.13	0.27	0.26	0.10
Oil	1.79	1.13	0.43	0.38	0.34	0.33	0.55
Gas	0.53	1.41	1.60	1.37	1.61	1.55	1.08
Combustible renewables & waste[1]	1.33	2.68	4.26	4.30	4.37	4.49	4.73
Hydro	0.48	0.77	1.67	1.89	2.28	2.51	1.99
Wind	-	-	-	-	-	-	-
Net imports[2]	3.39	6.99	18.27	21.29	21.04	22.17	24.13
Coal	0.20	1.13	2.92	2.58	2.42	3.00	4.01
Oil	3.19	5.86	11.59	12.82	13.16	14.14	17.64

Source: IEA (2009), p. 27.

In the second half of the 80s, together with a sharp decline in energy prices have been strongly influenced by ideas of privatization, deregulation and market-liberal thinking, that where particularly strong in Chile, already during the Pinochet period, and later also spread

[49] IEA (2009).
[50] EU/Government of Chile (2007), p. 7.
[51] CNE – installed capacity December 2010.
[52] EU/Government of Chile (2008), p. 2.

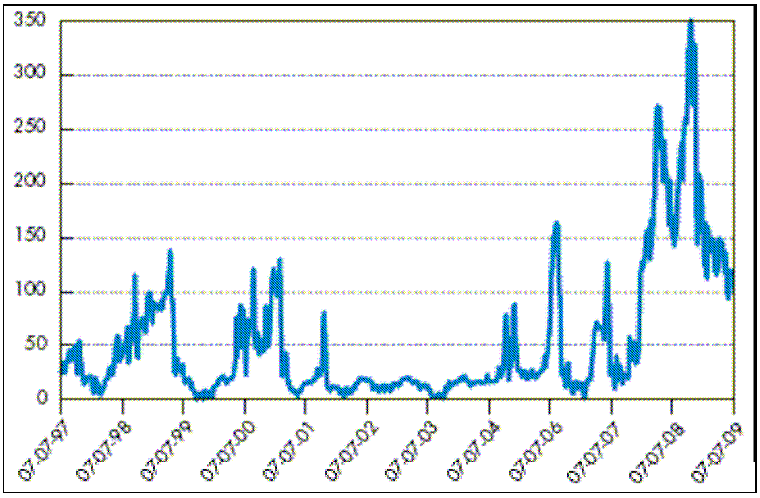
to Argentina and Brazil.[53] In 1973, Chiles energy production was about 5.08 Mtoe with imports of 3.39 Mtoe. This has changes drastically in the year 2007, where production not even doubled but imports have risen by more than 600 percent to 24.13 Mtoe.[54] This has changed slightly in the 1980ies, where around two-third of TPES was produced in Chile covering the residual part of energy supply by imports. In 1990, the share of imports has increased, reaching its peak with an import dependence of about 70 percent by the year 2000 and is since then remained constant at a high level. The increased energy demand is only a part of the explanation for the high import dependency. Beginning in 1982, the domestic crude oil production fell from 32 percent of total oil supply to around three percent due to less off-shore resources. The coal imports rose for reason of decommissioning coal mines with poor quality and low energy content supported by the agreement with Argentina to deliver natural gas.[55]

In the mid 90s Chile started to diversify its energy mix mainly by substituting oil for natural gas with Argentina as main supplier. The liberalization and deregulation of the Argentinean gas and oil industry in the early 90s facilitated the integration of both countries' infrastructure. This was fixed in a contract between the two countries to deliver natural gas, beginning in 1995. However this relation with its neighbors is quite complicated. Due to historical dispute with Bolivia, which has abundant natural gas resources, gas cannot be purchased directly. Argentina imports natural gas from Bolivia to cover its own energy necessities and exports their own gas resources to Chile. In case of energy shortages from Bolivia, Chile is always indirectly affected with the risk of energy shortages from Argentina. The increased dependency on Argentine gas, as sole supplier, on one side, together with one of the most severe droughts in years has lead to the **first energy crisis** in the SIC grid in 1998/1999, due to its high hydroelectricity production. This crisis was triggered by various factors, therefore the price in the SIC has risen significantly. The regulatory authorities have set the wrong price signals and thus worsened the situation. The node price[56] in the SIC decreased almost twenty percent during the energy shortage.[57] This has set an incentive to the consumer to expand their energy use as it is cheaper, but electricity is a very inelastic good, so that the effect might not have been significant, but economically it makes no sense to offer a scarce good for a lower price. Furthermore, this was aggravated by several delays in the entry of a new gas plant (Nehuenco), which would have increased the installed capacity by five percent. This has left the SIC vulnerable with reserves below the minimum operating

[53] Rosa (2009).
[54] See Table 3 for detailed information.
[55] Ortega et al. (2010).
[56] The regulated customer's price has two components: "a node price, at which distributors buy energy from generating companies, and a distribution charge. The node price is equal to the sum of the marginal cost of energy, the marginal cost of peak power and the marginal cost of transmission", Bitran/Serra (1998, 948); in detail explained in electricity market analysis in chapter 3.
[57] Watts/Ariztía (2002).

conditions forcing the authorities to approve three Electricity Rationing Decrees. This was repealed due to improved hydrological conditions in May 1999.[58] Furthermore, an unusual amount of melting ice in the winter has let to larger amounts of released water, so the basins were more than full, some water had to be released, with a loss in generation and additional sediments, that had negative impacts on the turbines.[59] The **second crisis** of 1999 was caused by two large disturbances which has led to partial blackouts in the SING. The grid has principally large consumers such as the mining sector, which consumes 90 percent of the total energy. Inadequate norms for coordination between the large generation units and entry of new capacity, considering that the largest company's peak load is with 1,567MW around 50 percent of the installed capacity of the SING.[60] The **third energy crisis** has evolved out of the high gas import dependency from only one supplier, Argentina. Out of all additional installed capacity between 1996 and 2004, both in the SIC and SING, gas represented 72 percent, that by 2003 half of the electricity production was generated by gas. Due to a economic recovery in Argentina, energy demand has risen. In August 2005 gas exports were cut by 59 percent, in May 2007 by 64 percent,[61] which has caused several blackouts in Chile, forcing the electricity plants to switch to expensive diesel power generators.[62] Additionally, Argentina has fixed the natural gas delivery in long-term contracts in US-Dollar, which means that the gas arrives at a price of USD 2.5 MBtu, compared with USD 0.6 MBtu in Argentina.[63]

Figure 5: System Marginal Cost in the SIC 1997-2009 (USD/MWh)



Source: IEA (2009), p. 144.

[58] Fereidoon/Pfaffenberger (2006).
[59] J. Barton, University of Chile, personal communication.
[60] Fereidoon/Pfaffenberger (2006), p. 100.
[61] See import dependency of natural gas from Argentina reach partially over 90 percent in 2007/8, see figure 23 in appendix.
[62] Enerlac Magazine, No.1, October 2009, p. 14; see outrage cost Chile's industry was confronted with in: Serra et al. (1997) discuss a planned energy shortage which leads to lower cost for the economy.
[63] Crisis Energética, In: Acontecer, Publication of the Instituto Tecnológico de Buenos Aires, May 1st 2004.

Besides the fact, that Argentina has increased its natural gas export tax from 20 to 45 percent, which might cause more difficulties in future to cover natural gas needs at a reasonable price,[64] and due to low rainfall and a prolonged dry period in the first half of 2008, prices for electricity generation have increased explosively in the short term, see figure 5.

Out of this experience, Chile tried to diversify in the way to substitute natural gas for Liquid Natural Gas (LNG) with the advantage, that the existing gas infrastructure can be used without a lot of additional infrastructure investments. Before LNG was imported, Chile was almost completely dependent on Argentinean natural gas. This has raised the gas related electricity production from former one percent in 1997 to nearly 33 percent in 2004. In the same year, Chile signed a preliminary contract with Indonesia for the delivery of LNG starting in 2007.[65] Since then two LNG terminals have been built, one in the SIC and one in the SING. The Quintero terminal was built 155 kilometers north of the MR with a capacity of ten million cubic meters a day, which equals about 2,300MW of generation.[66] A second, the Mejillones terminal, went on-stream in April 2010,[67] fulfilling the energy needs of the mining industry in the north.[68] Since then, in the SING 27 percent of the energy needed could be covered by LNG, liberating the SING from Argentinean gas imports, allowing 5.5 million cubic meters of gas imports a day or a 1,100MW of generation equivalent.[69]

The latest price developments especially for electricity generation in the SIC are worrying. In February 2011 the energy prices were the highest in three years. In some sub-systems prices have risen to more than 200USD/MWh, the second highest after the energy peak price in 2008. This is partly explicable due to higher oil prices, but as well hydroelectricity generation was down to 42 percent of total output in February. Marginal costs of the electricity system increased 75 percent compared to prices a year ago.[70]

2.2. Concepts of Energy Security

The construct of energy security is highly complex and interrelated, expressed in a recent UN paper, that states: "Emerging global energy security risks stem from a complex diversity of political, social, economic, financial, legal, geographic and technical factors, including

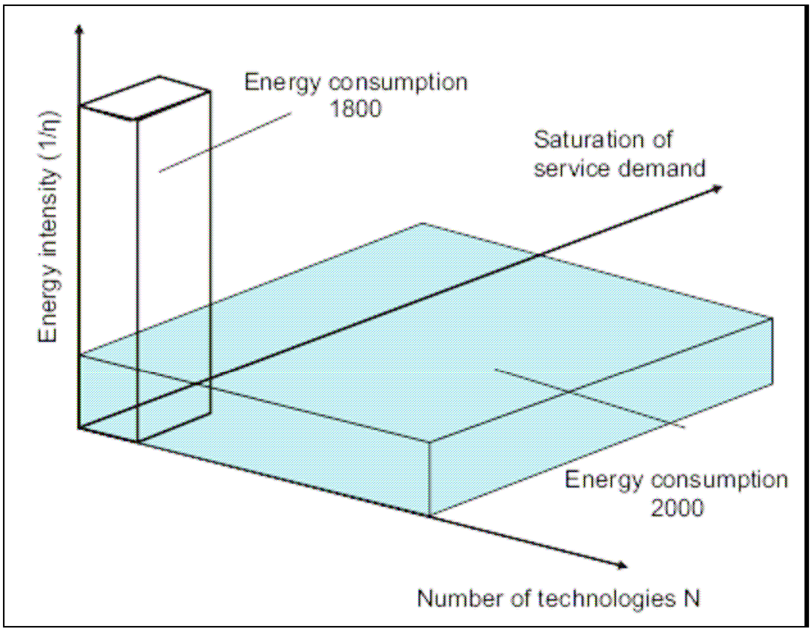
[64] The Encyclopaedia of the Earth, "Energy Profile of Chile," available at: http://www.eoearth.org/article/Energy_profile_of_Chile, (accessed March 27th, 2010.)
[65] See 'Govt. reportedly signs MOU with Indonesia for LNG supplies - *Chile*', Business News America, Julian Dowling, November 25th 2004.
[66] LNGWN (2010).
[67] www.globallnginfo.org (update April 2010).
[68] In the short term, LNG is an interesting solution to diversify the energy matrix, but as the international market tightens the prices will probably go up in the near future as more and more countries use LNG. Furthermore transportation costs remain relatively high, because of process inherent energy needed and terminal infrastructure; For a detailed discussion on LNG, see Jensen (2004).
[69] Jensens (2011).
[70] Seitz (2011); Diaro Financiero (2011).

ongoing civil strife, ethnic conflicts and growing international tensions; these also include international terrorism as an important factor menacing global energy security."[71]

As shown in the previous chapter, in Chile so far no exist an integrated energy planning, where the CNE (2008) guidelines are an initial step but no complete integrated approach to secure the energy supply with a prospective long-term strategy.

The general definition what is energy secure does not exist, just as concept that is adapted for various aspects in different contexts. There are many actors involved and the topic is vital for all well-functioning economies, with a high complexity. All services and goods consumed require energy in the production process or are demanding energy while using or both, which can be divided in direct services like lighting, heating, etc. and indirect services like cloth, furniture food and other. Furthermore, the economic growth of Chile in the last three decades has enabled a larger share of the population, through a larger purchasing power, access to consumer goods like refrigerators, air conditioning or the change to electrical stoves that enhances the quality of life but on the other hand create new demand for electricity.[72] So observable, that in Chile energy demand has increased less than electricity demand which grew about seven percent in the recent years. All this relations are vital in understanding the relations between energy services, energy, quality of life and growth of an economy over time.

Figure 6: The three dimensions determining the energy consumption



Source: Haas et al. (2008), p. 4018.

[71] UNECE (2007), p. 6; In the definition of the IEA, a secure energy supply is fulfilled when it is adequate, affordable and reliable, see IEA/OECD (2007).

[72] Haas et al. (2008), p. 4015.

The efficiencies the are used today are only a few percent of their potential. This means a huge potential that can be deployed in future. As long as the increase in service demand is faster than the efficiency improvements, there results an increase in energy consumption, as shown in figure 6. This can be reached by for example means of higher energy prices, regulatory mechanisms or change in consumer behavior.[73]

Apart from the concept of improving energy efficiency which will be examined in detail in chapter 4, a quite old concept of Amory B. Lovins has to be mentioned, the "Negawatt" concept. This is a theoretical unit of energy that is not used, which was presented by the Chief Scientist of the Rocky Mountain Institute at a congress in 1989 explained by the following example: "Think of such a compact bulb, with 14 watts replacing 75, as a 61 negawatt power plant. By substituting 14 watts for 75 watts, you are sending 61 unused watts -- or negawatts -- back to Hydro, who can sell the electricity saved to someone else without having to make it all over again. It is much cheaper to save the electricity than to make it -- and not only in thermal stations. It is cheaper for society to use these bulbs than to operate a Hydro plant, even if building the dam were to cost nothing. Each bulb has a net cost of minus several cents per kilowatt- hour, and no dam can compete with that!"[74]

From a simplistic point of view, the improvement of the Chilean energy situation can be achieved through several measures and programs considering the demand and/or supply side. A recent paper of the UNECE (2007) has identified seven developments that have negatively affected the energy situation in the recent decades, which are:

(a) The narrowing margin between oil supply and demand, which has driven up prices.
(b) The volatility of oil prices arising from international tensions, terrorism and potential for supply disruptions.
(c) The concentration of known reserves and resources in a limited number of the world's sub-regions.
(d) The restricted access to oil and gas companies for developing hydrocarbon reserves in some countries.
(e) The rising cost of developing incremental sources of energy supplies.
(f) The lengthening supply routes and
(g) The lack of adequate investment along the energy supply chain.

If these developments are applied for the Chilean case, similar results can be obtained from the literature. Reviewing (a) it is obvious, that in Chile exist a large difference between the domestic available supply of energy and the quantities of fossil fuels, which have to be

[73] Ebd. p. 4019.
[74] Lovins (1989); www.ccnr.org/lovins.html, (accessed February 18th 2011).

imported. The energy balance between 1973 and 2007 explains this relationship quite well. While in 1973 energy imports made up 66.7 percent of the total production in 2007 imports grew at 285 percent or nearly three time the total production, see table 3. Increased world energy prices, energy scarcity and a large share of energy imports and prices, that are one of the highest in Latin America, which as well due to the fact, that Chile has no major subsidies for fuels.[75] The recent development with energy generation costs passing the 200USD/MWh or the crisis of 2007/8 with peak electricity prices of 350USD/MWh in the SIC explains the trend in energy prices, which is far above the 30-120USD/MWh were prices fluctuated between 1997 and early 2007.[76] This trend (b) has to be understood in a global context of increasing energy prices as result of international tension caused by conflicts, terrorism and temporarily shortages in energy supply.[77] Another reason for price increases are the fast pace economies, especially the BRIC countries, which share in global GDP and energy consumption is expected to grow above world average until 2050, see figure 7 in appendix.[78] Another important aspect (c) and (d) is the resource concentration of the world's fossil fuel resources in a few countries that dominate the market. A way to measure the concentration is the Energy Security Market Concentration (EMSC). It is based on the Herfindhal-Hirschman Index (HHI), which provides information about market concentration or concentration of risk that exist in a certain market.[79] The value varies from zero, which is a highly competitive market to 10,000 which features a high market concentration. The international oil market has a high resource concentration, where five most potential exporters account for 86 percent in the market. By 2030, this share will increase to 88 percent, the OECD accounting for 67 percent up from 56 percent level in 2004. The EMSC will increase in the same period of time 30 percent to 4,800 in 2030. In the coal market similar trends are expected. The five largest coal exporters Australia, China, Colombia, Indonesia, and South Africa remain still in 2030 the most important exporters, while their global market share will present 88 percent up from 83 percent in 2004. The EMSC will rise from 1,900 to 2,300 in the same period.[80] The development in the international gas market is quite different due to several reasons. First, the LNG trade has been and will be integrated to the international gas market, where the pace is yet difficult to calculate.[81] Second, gas contracts are often made in bilateral agreements, therefore a concentration estimate is difficult to make. The share of the five largest producers Russia, Algeria, Qatar, Oman and

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[75] IEA (2009).
[76] As result of the short-term price increases, the government had to intervene with temporary tax reductions, injections in the fuel price stabilization fund of USD 1.26 billion, the installation of more back—up capacity which might drive prices further up, and other, see Tokman (2009).
[77] A review on international conflicts and their implication concerning energy security, see Luft/Korin (2009).
[78] Goldman Sachs (2007).
[79] www.finanz-lexikon.de (accessed January 18th 2011).
[80] Lefevre (2010).
[81] IEA (2006).

Norway is expected to drop to 60 percent in 2010 from 90 percent in 2004. As outcome, the EMSC for gas is anticipated to fall from 2,200 in 2004 to around 900 in 2030.[82] The explanation of (e) is principally due to the fact, that cheap resources are exploited first. The easy accessible oil fields in the Middle East have lower cost of exploitation than oil or gas from Russian Permafrost or deep water drilling which might have other related risks and environmental impacts. This leads to increased costs for exploitation and production in the mid and long-term which will reflect in price increases for fossil fuels in future. A similar trend (f) is anticipated for the transportation of energy sources. The distances to transport energy from the physical location of the energy source to the end consumer will increase, as close or indigenous are utilized first, so that a price increase is probable. As a result of spatial distances between energy production and consumption, international trade is expected to rise by 142 percent by 2050, based on 2008 levels.[83] Chile imports coal principally from Colombia, Indonesia, Australia and Canada. Major oil exporters are Brazil, Ecuador, Angola and Colombia.[84] The discussion whether these are reliable exporter will not be further discussed. Finally the argument (g) lack of adequate investment in the energy supply chain is a common problem in many developing countries and LACs.[85] The investment in the energy production sector as share of the GDP is extremely low for Chile with 0.01 percent.[86] Investments of 2.6 percent of the GDP in the energy sector are necessary for a sufficient energy supply until 2020. This would mean investments of USD 3.64 billion in the low case and USD 4.4 billion in the high case scenario to close the gap in order to avoid energy shortages.[87]

Even if there is no common definition of what is energy security, an evolution for an approach for the establishment of a long-term energy security supply (SOS) has been developed by Kruyt et al. (2009).[88] The basic assumption of this concept is that an uninterrupted energy supply is vital for a functioning economy. It embraces the four dimensions of availability, accessibility, affordability and acceptability.[89] Availability is related to the geological existence or disposability of indigenous resources in Chile, while accessibility contemplates geopolitical elements like resource concentration and conflicts. For Chile, it is important to get more independence from Argentinean gas imports, what has been done in an initial stage by substituting it for LNG from Indonesia and other exporters using basically the same infrastructure. Another aspect is the high dependency from imported fossil fuel like coal and

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[82] Lefevre (2010).
[83] Kruyt et al. (2009), p. 2166.
[84] IEA (2009).
[85] Kessides (2004).
[86] Popov (2009).
[87] APERC (2003).
[88] The concept framework has been developed by the Asia Pacific Energy Research Center (2007).
[89] An overview of the distinct SOS indicators and their relationship to the dimensions addressed, see table 4 in appendix.

oil. In 2006, of the total primary energy consumption, 98 percent of oil, 75 percent of natural gas and 96 percent of coal were imported.[90]

The element of affordability is the same aspect of another facet, the economical one. As resource concentration is expected to increase as shown above and a high dependency of fossil fuel imports, prices are expected to rise in Chile, but not only rise in a predictable future as well with more fluctuation in the short term.[91]

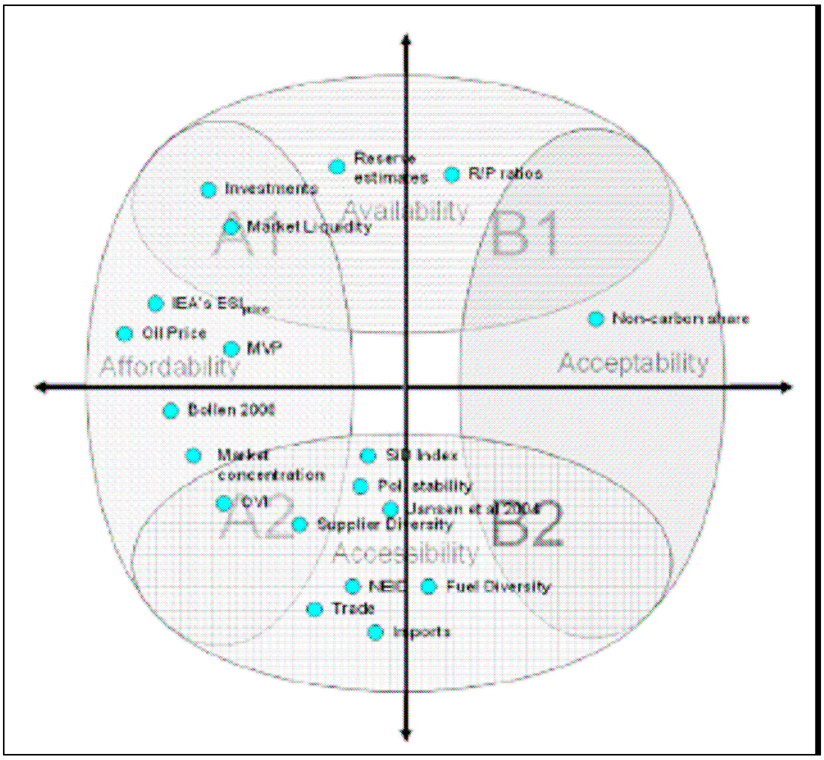
As there are no direct energy (price) subsidies, and only short-term interventions are applied to keep the price in a certain range, an price increase for fossil fuels at the world market will have an negative impact on the domestic price level in Chile. As prices for energy are already one of the highest, compared to other LACs, a further increase might cause problems for people with low income to pay their energy bills which will force the government to intervene in the market to avoid social conflicts or energy poverty, especially considering, that the country has a very high Gini-coefficient, so that a large part of the population would be affected of price increases. The last dimension, acceptability includes various environmental and social aspects, so the acceptance of new technologies like nuclear power or RE technologies (RET) that are not yet well know in the population, like the installation of a wind or solar park. Considering the environmental aspect, RET have benefits in the clean production of energy which coincides with the governments 2008's program to fight climate change. It inherits as well challenges of the implementation of RE in the electrical grid, which requires an intelligent management approach and additional infrastructure to harmonize the intermittent technologies in order to harmonize the demand and the supply side. The four dimensions with their different relations regarding energy security can be illustrated graphically, on a scale that varies between regional and global levels, see figure 8.[92]

[90] EU/Government of Chile (2007); Possible solutions are discussed in chapter 4.

[91] CNE (2008).

[92] An alternative approach in improving the energy security (ES) situation has been developed by Hughes (2009). He introduces the concept of ES in the 4R concept. These dimensions are review (understanding the problem), reduce (using less energy), replace (shifting to more secure energy sources) and restrict (limiting new demand to energy source.

Figure 8: The energy security spectrum



Source: Kruyt et al. (2009), p. 2171.

The possibilities of diversification of the Chilean energy matrix are discussed in detail in chapter 4, divided into measures of demand and supply side. Here, a wide spectrum of measures is analyzed to represent, that there are a lot of opportunities including RE, programs of Demand Side Management (DSM) and energy efficiency programs and the possibilities for the contribution of the MR to lower the energy needs in the SIC.

Before, the electricity market will be analyzed in the following, as it plays an important role in explaining the increasing energy demand of the SIC grid in the recent decades. Chile has one of the longest running electricity reforms in history and therefore an interesting case study as well in order to integrate RET. The deregulation and privatization that has started in the early 1980s with focus on the regulatory framework that has changed in favor of renewable energies analyzed in the following part. Furthermore, the concepts of electricity security and the regulatory framework are examined plus an outlook, what has to be done to make the electricity market properly functioning and competitive in Chile.

3. The electricity sector

In the 1930s the electricity provision was privately organized. After the Great Depression in 1944, the public corporation Endesa (Empresa Nacional de Electricidad) was created, responsible for generation, distribution and transmission. Due to a high governmental influence in the provision of public services in the 1950s and 1960s tariffs for electricity were kept very low. Therefore, private companies had no or hardly an incentive to invest.[93]

Chile is a pioneer country that has reformed its former government-owned electricity sector. The process started in 1982, when Chile's first important electricity law passed the legislation. As of the LAC Argentina was next in 1992, followed by Peru, Bolivia and Colombia in the following two years.[94] In the 1970s, the situation was quite different from today's, when in 1974 the two largest energy generators, Endesa and Chilectra, were in 'desolate' conditions resulting in a negative net income of 4.3 percent and 3.2 percent, respectively.[95] This problems of chronic underinvestment, underpricing and low operating and financial performance have occurred in various transition economies around the world.[96]

Since then the energy policy in Chile has been based on two crucial concepts: competition and privatization.[97] The government enabled a deconcentration of generating and distribution companies, especially by establishing the institutional framework conditions.[98] This structural change of legal framework was supported of economists in the government, coming from the University of Chicago, where these free market ideas are referred as best case solution to optimize social welfare.

The whole electricity reform process has been considered as a very successful example that has served as a model for privatization in the industrialized and developed world alike.[99]

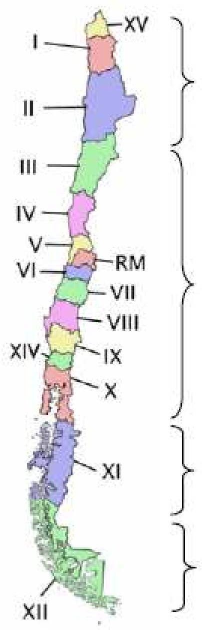
3.1. The electricity grid in Chile

Chile's electricity system consists of four separate autonomous functioning networks,[100] the northern SING (Sistema Interconectado de Norte Grande), the central SIC[101] (Sistema Interconectado Central) and two in the South located networks Magellanes and Aysen. The four major energy players are ENDESA, AES Gener, Colbun and GDF Suez Energy Andino. The characteristics of the networks are very different. The two major networks SING and SIC

[93] Basañes et al. (1999).
[94] Rudnick (1998), p. 189.
[95] Fischer et al. (2002), p. 23.
[96] Kessides (2004).
[97] An important step in the evolution of the policy framework was already set up during the Pinochet regime in the late 1970s.
[98] Bernstein (1988).
[99] Pollitt (2004).
[100] There have been plans to interconnect the two larger grid as well as plans to connect to the Argentinean SADI grid but by January 2011 there was no interconnection realized in the SIC, ESC (2011).
[101] The detailed SIC grid and its connections, see figure 18 in appendix.

together have an installed capacity of about 99 percent, see figure 9. In 2010 installed capacity of the SING grid was 3,575MW. Out of these around 90 percent were provided to mining and larger industrial companies in the north, where nearly all energy was thermally generated. In comparison to the SIC grid, most of energy produced was sold to private customers in the MR including larger cities like Valparaíso and Concepcion, which alone represented nearly 50 percent of the countries' population in 1999.[102] By 2010, installed capacity was 11,845MW, with more than the half generated by hydropower. The installation in the two southern networks amounted together about 138MW. The share of renewables was 3.4 percent slightly below world average of 4 percent in 2010.[103] According to projections of the CNE (2008), the country's installed capacity will double until the year 2020 to around 24,000MW or an projected annual growth of nearly six percent. Due to a severe drought situation which has affected the hydroelectricity generation negatively, an increased demand for electricity as well as high world market prices for fossil fuels prices have led to higher energy prices in the SIC grid, that are significantly higher than a year ago and well above the long-term trend. In March 2011 the marginal electricity generation cost has increased from 155,77USD/MWh in January to 225,55USD/MWh.[104]

Figure 9: The four Chilean electricity systems



1. The Interconnected System of the Norte Grande (SING – Sistema Interconectado del Norte Grande)
   Regions: Arica/Parinacota (XV), Tarapacá (I) and Antofagasta (II)

   Installed capacity: 23.2%

2. The Central Interconnected System (SIC – Sistema Interconectado Central)
   Regions: Atacama (III), Coquimbo (IV), Valparaíso (V), Región Metropolitana (RM – Santiago), Libertador General Bernardo O'Higgins (VI), Maule (VII), Bio Bío (VIII), Araucanía (IX), Los Ríos (XIV) and Los Lagos (X).

   Installed capacity: 75.9%

3. The System of Aysén (XI region)

   Installed capacity: 0.3%

4. The System of Magallanes (XII region)

   Installed capacity: 0.6%

Source: ESC (2011), p. 3.

[102] Zegras (2005).
[103] ESC (2011).
[104] www.cdec-sic.cl, own calculation; Marginal price in January 2010 in SIC was at 118,31 USD/MWh, while the marginal cost remains high with 227,96USD/MWh in May 2011.

3.2. The reform process until 2000

The change of policy orientation has ended after a nearly 40 years old trend of increasing governmental intervention with reached its peak with the government of Allende in 1970-1973, where 100 percent of public services were under governmental control.[105] The reorganization of the electricity sector has to understood in the context with changes during the 17 years of Pinochet, who already pushed towards a liberal market. Policy was considerably influenced by free liberal market ideas of the Chicago Boys, which is represented in a large part of the current economic policy in Chile. Before the large reform in the 1980 the SIC was divided into two vertically integrated companies, the central region was provided by Chilectra, while the rest was supplied by Endesa. The electricity reforms under the military regime were quite 'extreme', so the abolishment of cross subsidies which allowed the chronically poor financed sector to residential price increases of 700 percent between 1974 and 1982 as well as the establishment of regulatory bodies in the sector.[106] The privatization process in Chile can basically be distinguished in three phases. There is a first stage in the period between 1974 and 1980, where 259 companies that have been expropriated under the Allende's government were restored to their original owners. Second, the decade of the 80s characterized through privatization of telecom and electricity companies so that by 1989 only a quarter of these enterprises remained governmental owned. In the last period 1990-2001 the privatization process slowed down. The government sold three large water and sewage companies and consummated the electricity sector privatization.[107]

The fundamentals of the reform process in the electricity sector was set with the law of 1982, a new legislation and the establishment of new regulatory bodies in the late 1970s. By decree in 1978, as first institution, the National Energy Commission (CNE) was founded, as a regulatory authority responsible for planning and coordinating policies and the establishment of standards to ensure compliance on energy-related matters. Their principal responsibilities are: the proposition of sector norms and regulations; coordinating the planning policies and norms for a well functioning market and the calculating and enforcing of regulated prices in generation and distribution.[108] In 1981 the unbundling separated Endesa in five independent distribution companies and three generating systems.[109] Shortly after, the Electricity Act of 1982 paved the way for vertical and horizontal 'breaking-up' (unbundling), commercialization and the partly privatization of the former state owned electricity system which involves different institutional actors. Furthermore, the law decree No. 1 defined rules for the supply of electricity in the specific concession zone; set minimum quality service level standards;

[105] Fereidoon/Pfaffenberger (2006).
[106] Murillo/Le Foulon (2006).
[107] Fischer et al. (2002), p. 2.
[108] IEA (2009), p. 32.
[109] Basañes et al. (1999).

maintaining and operation of safe facilities and the interconnection with concessionaires.[110] The law of 1982 created the rules for the distinction between two types of customers: a regulated and free one. The regulated is forced to pay the tariff that is set by the authority (CDEC) based upon a cost calculation for an 'ideal' distribution company. The free user can directly negotiate their tariff with distributing company. The consumer are divided in three sub-categories: Large-scale, above 2MW consumption, medium sized consumers between 2MW and 0.5MW and small consumer that require less than 500kW per month. The threshold for free customers was reduced twice, first in 1982 to 2MW and in 2004 to 0.5MW with the law 19,940. If the consumption is less than the threshold the customer is free to change to become a free customer. These represent two-third of the SIC and a tenth of the SING customers. Free clients, on the other hand, have a high energy consumption and therefore are able to negotiate their prices and conditions with suppliers directly.[111]

In 1985, a second institution the Superintendent of Prices of Electricity and Fuels (SEC) was set up in order to check, if the operation of electricity, gas and fuel services work properly in terms of safety, quality and price, based on the law 18,410. Furthermore it has responsibilities for data collection, enforcement of laws and regulation as well as all kinds of customer affairs. The Economic Load and Dispatch Center (CDEC) coordinates the optimization of the generation system, especially the overall security of the system, the economic operations and installations and to ensure access to the transmission system. The Antitrust Commission, which is devoted to all non-market conform conduct and in avoiding noncompetitive behavior. The Ministry of Economy sets the tariffs as proposed by the CNE and responsible for an efficient development in the three electricity services.[112] An improved world economy and decreasing inflation together with a reform in 1985, which allowed Pension Funds to invest in private companies have stimulated the investment in the domestic power sector since then.[113]

The next large reform step in the electricity sector was taken in 1999, after the second energy crisis which has led to energy shortages. Under the law 18,410, the SEC was given more monitoring and sanctioning power,[114] which has been identified as one of the major reasons for the crisis. The reform redefined the compensations mechanism for customers in cases of energy rationing and the obligation to supply energy even in the absence of a contract which has provided to electricity producers an incentive to invest in more capacity and reliability of the system.[115] Furthermore, it imposed a three-year restriction on SEC executive members from disclosing any relevant internal information. It established rules,

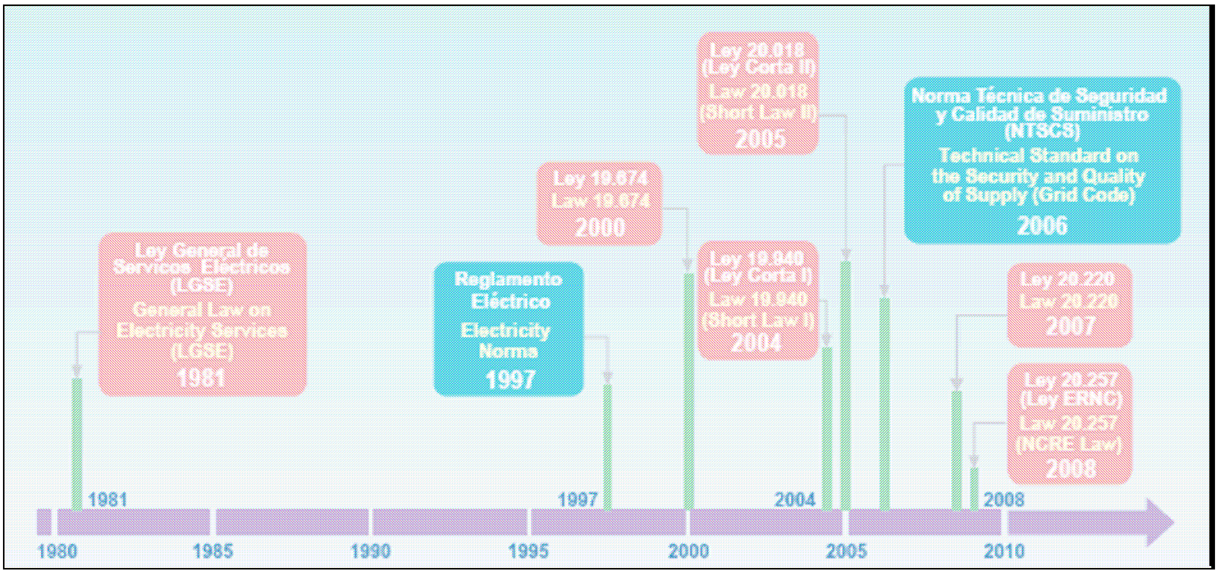
[110] For additional information, see Rudnick/Raineri (1997).
[111] GTZ (2009), pp. 36-39.
[112] Basañes et al. (1999).
[113] Pollitt (2004).
[114] The original fines were increased 240 times in case of non-compliance.
[115] Frei (1999).

that even in the case of rationing all, even large consumers, have to be supplied with electricity and finally, it was made harder for companies to make use of the force majeure rule, that applied before and liberated the generation companies in case of extreme weather events or similar.[116] Additionally it has set incentives for the provision of electricity in rural areas. While in the year 1982 only 62 percent of rural house-holds were supplied with electricity this share has increased to 98.5 percent in 2008.[117]

The amendment of 2000, the law 19,674, regulates the service charges related to the power supply that are not subject of the current price fixation. This for example may include the suspension and reconnection of supply to delinquent clients, the renting, maintenance or removal of power meters or hook-ups or the provision of duplicate invoices or bills.[118]

A chronology of the most important an recent developments and changes in the regulatory framework is shown in figure 10.

Figure 10: Chronology of the regulatory process



Source: GTZ/Government of Chile (2009), p. 77.

3.3. Post-Privatization period and the electricity market structure

The principal gain of the reform and privatization process is an improvement in economical performance of the enterprise. In many countries subsidies have provoked major welfare losses in terms of overall economic welfare.[119] In a competitive situation there is the profit-driven motive, that gives companies a strong incentive for an efficient use of resources which

[116] Murillo/LeFoulon (2006).
[117] IEA (2009).
[118] ILO (2000).
[119] Chile so far has no price capping or major subsidies for fuels. (IEA 2009, p. 42)

results in lower costs of production and finally stimulates competition (that does not exist in a monopoly situation with only one supplier) where at the end the consumer benefits from better services and lower prices.[120]

By 1989, the privatization process of the electricity sector was completed after financial and corporate restructuring. The sector performance was relatively good but was reformed as a larger rationalization process of the economy. In the northern SING grid competition between companies has been improved formidable. For the SING resulted gains in efficiency, price drops and a better service quality.[121] As result, two groups have benefited from the reform process; the consumers and the electricity companies. In the former monopoly market a sole state-owned company has delivered all services. These are in the electrical sector three principal activities: generation, transmission and distribution. A prerequisite for effective competition on the generation sector is sufficient high number of companies that compete with each other or no market dominance where new market entry is more difficult. In Chile the pooling agreement is set up in the way, that there are two separated systems that are coordinated by the CDEC-SIC and CDEC-SING ensuring supply security and optimization of generation. The coordinating committee is 'strongly' represented by the large producers, so that asymmetric market information might let to a disadvantage for small competitors. Transmission companies have to provide open access to all generators. They provide the interface between the producers and the major customers or distribution companies. It is considered a natural monopoly and therefore regulated by the government.[122] Transmission charges consists of three components: a tariff revenue; a basic toll and an additional toll. The benchmark calculation in Chile for distribution companies is done by a hypothetical 'model utility'. The 36 distribution companies have nonexclusive public service concessions over a determined geographic area, which are mandated to serve the electricity demand at a regulated predetermined value. The regulated price has two components, which is the node price at which distribution companies buy energy and power from generators and a distribution value added. The node price is determined by the components of the forecasted short-run generating marginal costs for 36 month to come, based on the investment program of each generator in the same period plus transmission costs are added, while the regulated price is not able to derive more than ten percent from the forecasted value.[123] Since 2010, the node price[124] is determined by distribution company tenders, established by the law 20,018 and its associated regulations. In addition, the price rises by the VAD (Added Value of Distribution), which is calculated every four years, based on a mean distribution model. The VAD is a multiple-part tariff with the following elements: a fixes fee for managing, billing

[120] Bacon/Besant-Jones (2001), p. 332.
[121] Lalor/García (1996), p. 1.
[122] Lalor/Garcia (1996).
[123] Bitran/Serra (1994).
[124] The node price is calculated twice a year in April and October.

and serving the customer, average energy and power losses, a fixed fee for operation, maintenance and reinvestment. The calculation is made on a basis that an efficient company makes a ten percent profit.[125] Finally, the regulated customer pays with its final tariffs all the components mentioned above. All the deregulation process has created the opportunity for new market entrants, that under former conditions, would have had no chance to compete in a monopolistic market structure. While in 1991, Chile had eleven generation companies, 21 distribution companies and two integrated companies, in 2006 the market environment has changed with 31 generation, five transmission and 36 distribution companies.[126] The two largest operators could visibly improve their performance. Chilectra, that has been split into three firms, has doubled its annual sales in electricity between 1987 and 2001 while at the same time customer base grew from 973.000 to nearly 1.3 million. The sales per worker in GWh rose by over 700 percent and energy losses have decreased from former 19.8 percent to 5.2 percent in the year 2000.[127] A similar performance resulted for the second largest enterprise Endesa. The consumer, on the other side, benefited from lower energy prices. In the SING grid prices dropped from 0.05 to 0.022 USD/KWh in between 1996 and 2002, while in SIC prices decreased from 0.038 to 0.022 USD/KWh, which means a price decline in Peso terms of 73 percent and 33 percent, respectively.[128] In most of LACs illegal use of electricity has implied a serious burden to the utility. Therefore the government has provided financial assistance after the reform process, especially by the installment of meters in shantytowns where energy thefts have decreased quite considerably.[129] All these measurements have lowered the technical losses (due to resistance) and non-technical like thefts. The major electricity provider in the MR, Chilectra could lower its overall losses from 19.8 percent in 1987 to 5.6 percent in 2003.[130] All the operational gains due to the privatization process and the low prices have more than doubled the installed capacity between 1982 and 2002 and the transmission lines went up from 4,310 to 8,555 kilometers in the same period.[131]

In spite of a considerable success of the privatization and deregulation process, the electricity market has potentials for improvements. It remains the fact, that Chile has in spite of considerable growth a quite small installed capacity, where it is more difficult to establish a real competition as in large countries like Brazil. In particular, the missing connection between SIC and SING prevents the formation of a larger electricity market with cost advantages and possibilities of compensation, in case of an energy shortage. The short-term electricity spot or clearing price is calculated by fixed regulated mechanism and the result of

125 Fereidoon/Pfaffenberger (2006).
126 Bennett (2009).
127 Fischer et al. (2002), p. 35.
128 CHILESUS (2003).
129 Rudnick (1999).
130 Fischer et al. (2002); Chilectra Annual Report 2003.
131 Kessides (2004).

acting of the market operator (CDEC) which may differ from zone to zone.[132] This separation of the three businesses allow room for competition with an incentive to increase efficiency and performance-based regulation provide space for new market entrants as well as an incentive regulation in the distribution sector. This implies a setting of prices for distribution companies, with a predetermined rate of return and a lower risk level in a competitive market.[133] Chile has and had a high level of market concentration. Between 2000 and 2006, the three largest companies Endesa, Colbún and AES Gener including their subsidies owned around 90 percent of the public service power in the SIC, a virtually unchanged situation.[134] The concentration in the MR is similarly high, with Chilectra delivering 45 percent of the whole market and Enersis the largest distribution company accounting for more than 40 percent in the SIC. Market concentration can be measured and expressed by the Herfindahl-Hirschman Index (HHI). Through an analysis of the HHI index can be concluded that the countries considered in this study show a degree of concentration of ownership of the electricity industry between moderate and highly concentrated. Compared to other LACs, Chile has the most concentrated market. A study by CEPAL[135] classifies Chile first in the "highly concentrated" category with a value of 3.541, followed by Brazil with a value of 2.004.[136] Compared to Argentina, the HHI of Chile is three times higher, which results in more competition and around 30 percent lower prices for the end consumer in Argentina.[137] This is due to the fact, that the regulatory mechanism have not worked appropriately to control market power. This is due to three principal reasons. First, different from other countries the measures to reduce market power, restriction on cross ownership in the three segment have been applied, but they were not defined in Chile. Second, the lack of resources in human capital principally of the regulatory bodies. There has to be put more effort in strengthening the technical capacities and the regulatory anti-trust commission. Third, more financial support is needed to hire better qualified staff and change their model of remuneration. Currently, in accordance with the year of work people are better paid instead of introducing an incentive-compatible system based on their performance. Furthermore, the staff should be banned for some years to work in the corresponding industry[138] in order to

[132] GTZ/Government of Chile (2009).
[133] Fischer/Serra (2000); For further discussion, see Pollitt (2004) and Bacon/Besant-Jones (2001).
[134] EU/Government of Chile (2009), p. 70; Kessides (2004).
[135] Herfindahl-Hirschman Index (HHI) which divides markets into three segments (non concentrated market, HHI below 1.000; relatively concentrated HHI between 1.000 & 1.800; highly concentrated, HHI above 1.800).
[136] Maldonado/Palma (2004).
[137] In a World Bank study of Bacon/Besant-Jones (2001) Chile has the largest market concentration with 0.43 in the SIC, still more concentrated than the SING, where Argentina is best of LAC with HHI of 0.06, where zero stands for perfect competition, see table 5 in appendix. Chile has adopted the wholesale market competition model, which "allows distribution companies to purchase electricity directly from generators they choose, transmit this electricity under open access arrangements over the transmission system to their service area, and deliver it over their local grids to their customers, which brings competition into the wholesale supply market but not the retail power market." (Bacon/Besant-Jones 2001, pp. 337-338.)
[138] Bitran/Serra (1998).

avoid information asymmetries or benefits in favour of the electricity industry. There are three basic problems in the distribution pricing. First, the VAD obtained in a study creates incentives for an artificial cost structure, which does not represent, like intended, an efficient model company. Second, the discount rate of ten percent in fixed and in real terms, so that it may not reflect the opportunity cost of investment, which might let to disadvantages for investments in RET with mostly higher initial investments. In other industry sectors, the capital asset pricing model is uses and should be applied as well for the electricity sector. And thirdly, until 2004 electricity distribution pricing lacked the mechanism for free market access[139] by the charge of access fees that have been defined more precisely with the law 19,940 in 2004.[140]

As long as electricity prices remain high, it might be more attractive to opt out the market and instead generate power independently from the grid. Furthermore, the node price should better reflect or be close to the real price, which would lower the importance of the compensation mechanism. Therefore, node prices should be calculated monthly to reflect the real price changes more precisely. As a result of inflexible price resulting economic losses in the range between five and ten percent, especially in the crisis year 1998 as the price signal mechanisms failed completely, which is problematic in a system closely running at its limits.[141] Therefore, another recommendation in order to make the system less vulnerable, is to increase the reserve capacity around 30 percent. A dynamic pricing in the retail market could set more flexibility and shift the peak load to the mid load which would lower the overall costs of the system, benefiting the customer and producer alike.[142]

3.4. Framework for Renewable Energy Integration

Chile has changed its regulatory framework quite recently in favor of NCRE. Most important laws passed the legislation in 2000, 2004, 2005 and 2008. First the law 19,675,[143] which regulates the exploration of new geothermal sources. In particular the Concessions and tenders for the exploration or exploitation of geothermal energy sources; the relationships between the traders, the State, the owners of the land surface, the holders of mining and parts contracts oil operations or companies authorized by law for the exploration and exploitation of hydrocarbons, etc. The exploration concession entitles the owner to perform a series of operations aimed at identifying the potential of geothermal energy, including drilling

[139] Fereidoon/Pfaffenberger (2006).
[140] For a further review, how to make an electricity system sustainable, see Patterson (2007).
[141] Montero/Rudnick (2001).
[142] Watts/Ariztía (2002); Another opportunity to lower the energy costs, which are the highest in the region is the energy sharing by interconnection to neighboring countries like Peru, Colombia, Bolivia and Ecuador, which could at least lower the cost in the northern SING, starting in 2014, see ESC (2011).
[143] Ley sobre Concesiones de Exploración y Explotación Energía Geotérmica–Law on Geothermal Concessions.

wells and measuring the gradient and deep exploratory wells. Consequently, the exploration concession grants the right to perform the studies, measurements and other investigations to determine the existence of sources of geothermal resources, physical and chemical characteristics, their geographical spread and their skills and conditions for its use.[144] The exploration of geothermal energy has a longer history than any other form of NCRE. This process was initiated due to large risk in exploration of drilling, that could sum up to several million dollar each, for every failure in drilling which are sunk costs for the company.[145] Second, the so-called Short Law I (No. 19,940) which came into force in 2004, benefiting mostly small producers of NCRE.[146] These producer were given the legislative framework to connect to the national grid and to sell their energy at the node or market price regardless of generation source, size or ownership. Plants smaller 9MW were included in the energy price stabilization mechanism and additionally they were exempted from paying the trunk toll charge. These payment increase for producers larger 9MW until the full toll has to be paid for producers passing the 20MW of installed capacity.[147]

A year later in 2005 another law ,the so called Short Law II has been approved. This has created the opportunity for long-term supply contracts until fifteen years between generators and distribution companies, which lowers the risks and facilitates cost calculation during the contract period, allowing price above the node price. This enables companies to consider low cost generation as well as more costly NCRE in their energy portfolio. So far generators can deliver five percent of their energy production but are not forced to do so.[148] In 2006, the law decree No. 4 was enacted as complement to the Short Law I and II, regulating the production, transport, distribution, concessions and electricity tariffs.[149] On September 14th 2007, the Law 20,220 was published in the Official Gazette establishing the rules applicable in the event of bankruptcy of a generator or early resolution of power supply contracts. In the event of a favorable ruling in the arbitration proceedings filed together with Emel, this legislation means that Gas Atacama would have to continue to supply on current conditions for the next eighteen months.[150] Consequently the law 20,257 of 2008 for the promotion of NCRE introduced an obligation for electricity generation companies with a production capacity above 200MW, to produce at least five percent of their energy out of NCREs, beginning with the year 2014. This share will increase steadily by 0.5 percent points a year

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[144] Guia del Servicio del Estado, available at: http://www.chileclic.gob.cl/1542/w3-article-194847.html (accessed April 25th 2011).
[145] Guzowski/Recalde (2010), p. 4.
[146] Small producer have to be connected by the closest local power producer, when technical requirements are fulfilled. CDEC-SIC controls the production, which is remunerated with the marginal cost of local generator, personal communication, R. Barbagelata. CDEC-SIC, more details, see Decree 244.
[147] Bennett (2009a); IEA (2009), p. 166; A calculation of an 15MW plant, which exemplifies the changes after the introduction of Short Law I, see Leonardo (2008).
[148] Könemund (2006), p. 20.
[149] GTZ/Government of Chile (2009).
[150] http://www.finanzen.net/nachricht/aktien/Endesa-Reports-Third-Quarter-Results-2007-252156, (accessed April 24th 2011).

from 2015 onwards reaching the ten percent margin in 2024. The obligation lasts for 25 years until 2034, preventing a massive installation in fossil fuel capacity after 2024. Only NCRE projects that have been installed after January 2007 will be considered in the energy mix. Companies that do not meet their requirements will be penalized with increasing fines if non-compliance repeats within the first three years of occurrence.[151] The penalty is proportional to the amount missing to fulfill the compliance. In June 2008 that fine was at 0.4 monthly tax units (UTM) per MW, which equals 29USD/MWh. The fine rises to 0.6 UTM when the company fails again to comply their obligation.[152] Under the law 20,257 their has been defined a portfolio standard, which allows a company to sell its excess allowances to another company in order to fulfill their obligations. This option has similarities to the European Emission Trading of GHG allowances to fulfil the mitigation targets of the Kyoto protocol. Prices and conditions free to be negotiated between the two trading partners.[153]

Apart from the more favorable regulatory framework there are other drivers and support schemes for the implementation of NCRE. Chile supports the NCRE with a large expenditure of R&D of 0.68 percent of the GDP and ranks at the second place in Latin America, after Brazil, reaching a budget of USD 646 million in 2004. The Chilean Economic Development Agency (CORFO) plays an important role in attracting foreign investment capital for the NCRE market. Since 2005 it provides subsidies for pre-investment stages of NCRE projects, providing maximum USD 60,000 or 50 percent of the study cost. By 2008, some 130 NCRE projects which include biomass, wind energy, biofuels, geothermal energy and others received support from CORFO. In 2009 the Chilean Center for Renewable Energy was founded to support the renewable energy developments, like technological advances and the application of best international practices. CORFO as well support foreign products and service providers through their High Technology Invest Program, delivering grants for pre-investments and incentives for start-ups. The program supports a broad range of assistance to start with wind power logistics, maintenance, manufacturing, to the provision of laboratories, etc.[154] Due to stable political conditions, Chile is as well seen partner of the Kyoto Protocols Clean Development Mechanism (CDM) and had as of the end of the year 2008, 56 CDM projects in pipeline. Chile has the best framework conditions according to the CDM Investment Climate Index (CDM-ICI) as host country for CDM projects where only four countries, that have been verified with very good. It could improve the score slightly from 93.9 in 2008 to 94.6 in 2011.[155] According to Carbon Point (2009), this makes the country the

[151] IEA (2009), p. 167.
[152] These amounts are low compared with those in other countries. The equivalent penalty price in the United Kingdom's similar Renewables Obligation Certificate scheme is 35.76GBP/MWh in 2008/09, equivalent to 55USD/MWh using the July 2009 exchange rate.
[153] GTZ/Government of Chile (2009).
[154] IEA (2009), pp. 30, 168-169.
[155] DEG/TÜV; www.kyoto-coaching-cologne.net, (accessed May 4th 2011).

third most favorite for CDM projects in Latin America accounting for ten percent of all CDM projects after Mexico with 18 percent and Brazil with 44 percent until 2012.

3.5. Technology Approach – Smart Grids

This approach aims to improve the system by an intelligent management. The application requires, that certain precondition are fulfilled. The mean lifetime of a normal high voltage equipment is about 30-50 years. This is the opportunity to upgrade (or in case of new instalment) the common system with the "smart grid technology."[156] A smart grid is able to balance supply and demand which is, especially in future with an increasing share of RE intermittent technologies a challenge. It refers to a system, that "would enable this integration of renewables and shift from reliance on fossil fuels, while maintaining a balance between supply and demand."[157] Three key components are necessary to make the system work: first, a storage technology; second, a demand side management (DSM)[158] and third, enhanced IT systems. The storage facility can be resolved in different ways. As many RE are intermittent, excess from a wind farm can be used later when more electricity is needed in combination with an interconnection between countries in order to achieve a buffering effect. Storing can be realized at household level, in a community or in a large hydro reservoir or if available in future grid connected e-cars.[159] The second requirement, an intelligent DSM is needed in order to ensure and enhance the reliability of the network. A price responsive demand is import for the funcioning of the system. In a case of energy shortage in Norway consumers have reacted to a 30 percent price increase with a seven percent lower demand avoiding interventions or a blackout.[160] If programs are implemented, the consumers reacts by using large utilities like boilers or washing machines when prices are low, shown in figure 11. The example of the UK illustrates the advantage of a lower capacity requirements when load shifting is applied.

In Santiago, peak electricity prices are about 25 percent higher than the night or low demand tariffs,[161] creating an incentive to shift a part of electricity demand into base or mid load.[162]

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[156] Battaglini et al. (2009).

[157] Crossley/Beviz (2009), p. 55; Alternatively, the European Technology Platform SmartGrids defines smart grids as "electricity networks that can intelligently integrate the behaviour and actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies," available at: http://www.smartgrids.eu/?q=node/163, (accessed May 6th 2011).

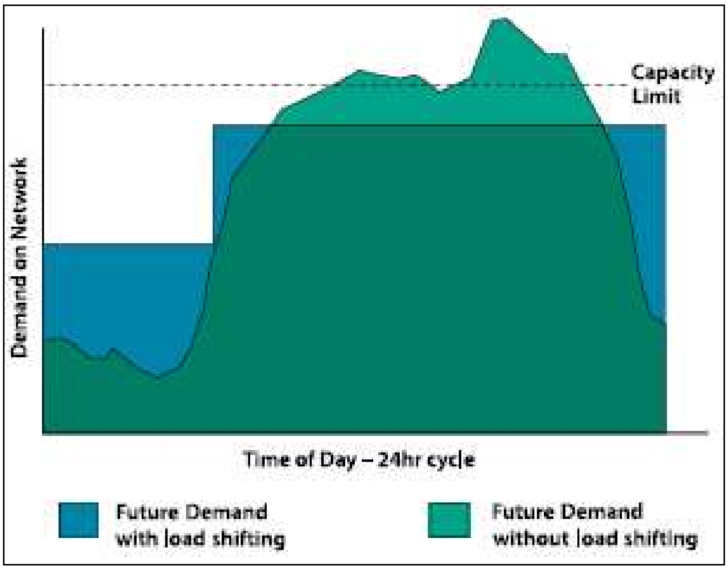
[158] As DSM measures can be grouped five items, peak reduction, valley filling, load displacement, conservations strategies and growth strategies, see Alamos/Rudnick (2008).

[159] Thinking of future visions, when e-cars function as a buffer for the fluctuating loads on the grid. If there are 200,000 e-cars with 40 kW capacities apiece would provide 8 gigawatts of power to the grid, if needed. That is more than all of Germany currently needs as controlling power for buffering load peaks, see World Energy Survey (2010). On April 20th 2011 the first electronic public electronic docking station for e-cars was inaugurated in Santiago.

[160] Jamasb/Pollitt (2008), Another pre-requisite is a well-designed and competitive wholesale and retail market, that is able to reflect the conditions in very short-term.

[161] Reference to BT1 tariff on Electricity bill in MR.

Figure 11: Current UK 24 hour demand curve with load shifting



Source: Crossley/Beviz (2009), p. 56.

To balance all the incomming information on supply, demand, storage, and as a third precondition, an enhanced grid communication system is required. This device can provide 'real time' information to smart meters in homes integrating all elements with the interface of the electrical grid. This allows the just in time respond to external factors such as change in weather patterns like a dry period, which affects the electricity generation,[163] especially the hydroelectric sensitive SIC grid.

Ongoing developments make this technology more and more viable. The Netherlands Energy Research Center has designed the Powermatcher, a system matching the energy supply and demand more efficiently.[164] There exist some pilot projects of interconnected High Voltage Direct Current (HVDC) lines, like Kythnos in Greece, Mannheim in Germany and the smart-grid project in Boulder, Colorado. This learning process will reduce future technological uncertainties.[165] Today, already two percent of all electricity is transmitted by HVDC lines, with more than 90 existing projects worldwide by 2008.[166] This new line would enhance the transport of the Hidroaysén electricity to transport power to the consumption centers, mainly the MR, with less transmission losses.

[162] So far DSM tools and price-quality menus have almost been absent in the Chilean ESI by 2006; Fereidoon/Pfaffenberger (2006); Today, the consumer has the choise between varios tariffs, depending on their energy habits, divided into summer and winter tariffs and three price schemes during the day, personal communication Chilectra.

[163] Crossley/Beviz (2009).

[164] Materialstoday (2009).

[165] Battaglini et al. (2009).

[166] Higgins (2008); Theoretically a power transmission of solar energy from Morocco to London, with a distance of 2,700km would have had less than eight percent losses; for technical specifications, see McCall (2009).

Efficiently applied, the consumer benefits from lower electricity prices, by demand shifting and incentives to lower electricity needs, while at the other side electricity companies are able to lower their capacity limits and facilitates the implementation of RET.

3.6. Approaches to Electricity Security and Recommendations

As already discussed above, the Chilean electricity market shows a high market concentration, represented by the highest HHI of all LACs. This is a challenge to deal with in order to stimulate competition, based on new rules for regulation and an extended financial support by the government. As there are no significant economies of scale in the generation sector, as small producers generate their electricity to similar prices as large utilities, a competition and deconcentration are a vital element to keep the price low.[167] The implementation of energy efficiency measures in the distribution sector is one element to stimulate competition. There are three basic approaches to improve the energy efficiency in the distribution sector. First, as applied in Brazil, forcing the companies to reinvest one percent of their revenues in energy efficiency measure. Second, the Revenue Decoupling, applied in California, a renumeration scheme for DISCOS, with the aim to lower the energy consumption per capita by ten percent in 2013. The third application, White Certificates, first applied in Australia, have maintained the efficiency levels targeted at low costs due to a freely regulated certificate price while minimizing the costs for implementing the EE programs.[168]

Particularly the node price has to be calculated monthly which provides more flexibility with respect to the time to adapt to new entry capacities. The United Nations Economic Commission for Europe (2009, p. 29) defines the basics of security of electricity supply depends on several factors. It states first the importance of sufficient generation capacity, a sufficient transmission network, and an improved interconnection between different countries like the existing system in Europe, which enhances the energy security of a system considerably.[169] The generation capacity in Chile is increasing but not sufficient to allow flexibility in emergency cases. The transmission regulation in Chile, such as toll arrangement and expansion procedures do not facilitate the introduction of large RE capacity into the grid. Modifications in 2004 were made in order to include the participation of small (independent) power producers in the electricity market. The transmission lines are an obstacle in implementing new capacity, where a wind park can be set up in 18 months the construction of a transmission line takes 42 months, which constrains the generation growth. The

[167] Rudnick (1998b).
[168] Alvarez et al. (2010).
[169] The only interconnection so far exist between the northern grid SING and the Argentinean grid in Salta.

regulation has to chance from a their old approach of pure baseline power to a more integrated approach making space for the grid necessities of RE. This allows more security for project financing in the RE sector and allows the grid to adapt to new requirements of more intermittent sources.[170] There should be considered that there are economies of scale in the transmission sector, the higher the nominal voltage and the transmission capacity the lower the cost per unit of power transmitted.[171]

There is, in spite of several plans to connect the SIC and SING, no interconnection so far, as well as the plan for 2014 to interconnect Chile with neighboring countries like Bolivia, Peru and Colombia are plans for the future.[172] This again shows that an integrated and long-term complementary energy policy is vital to ensure the opportunities for optimal use of RET in the Chilean electricity generation.

A study from Lund/Mathiesen (2009) has been conducted with an energy system 100 percent provided by renewable energies. The result is a flexible energy system with the ability to balance the electricity supply and demand. With a combination of biomass, wind, solar and wave power an 50 percent renewable share until 2030 is realistic provided as a domestic energy source, making the electricity sector of Denmark independent from fossil fuel imports.

Energy security in another perspective can be contemplated as a portfolio analysis, with external risk to exposed fossil price risks. The study exemplifies in a three case study how an electricity-generating mixture can benefit from additional shares of wind, geothermal and other renewables. The new more efficient portfolio reduces the generating costs with a higher RE share which results in an enhanced energy security situation, against the expectation, that RET would increase the overall generation costs. Chile is highly dependent on fossil fuel imports, has a high potential if not one of the greatest in the world for the usage of renewable energies and might therefore consider a portfolio analysis as well with respects of the extreme high electricity generation costs, that nearly tripled from 2009 levels.[173]

An approach for options energy regulator to enhance electricity security in an competitive market-oriented environment has been studied by Batlle et al. (2010). The concept considers four dimension for scope of action in time.

- Security, as short term issue expressed as the “ability of the electrical system to support unexpected disturbances such as electrical short circuits or unexpected loss of components of the system” (NAERC, 1997)

[170] Araneda et al. (2010).
[171] Rudnick (1998b).
[172] ESC (2010); The CNE executive secretary Juan Manuel Contreras has assured that in six years the interconnection between the two systems will be realized, see EO (2010).
[173] Awerbuch (2006).

- Firmness, as short-to medium term issue as the ability of the already installed facilities to supply electricity efficiently, which depends of the current generation portfolio and mid-term decision making of the generators.
- Adequacy, a long-term issue defined as the existence of enough available generation capability, both installed and/or expected to be installed, to meet efficiently demand in the long term and
- A strategic expansion policy, concerning the very long-term availability of energy resources and infrastructures, entailing the fuel provision and the technology mix.

In summary it can be said that in the electricity sector in Chile is still a lot of potential, not only in terms of energy security but also in terms of regulation and technical equipment, and a comprehensive energy plan for the medium and long-term period, which has not been considered by the Chilean government. This plan would leave less uncertainty for investors in the RE sector and establish an integrated plan for future implementation necessities for RE. From the regulatory point or view, the CNE would have to do their contribution in the following areas:

- A regulatory regime that decouples the revenue of electricity distribution, removing disincentives from companies promoting EE to the finally consumers.
- Conduct feasibility studies about an obligation in the distribution sector, as discussed
- use an integrated energy planning approach to need customer demand and supply in an more efficient way (and to avoid failures like during the second energy crisis)
- retrofit programs to learn from their international predecessors and avoid the common failures in retrofit programs, etc.[174]

Considering the economic growth of Chile between 2008-2020, there has been projected an additional electricity requirement of 14,500MW. A 20 percent increase could be covered by increased energy efficiency. This would reduce the additional capacity needed by 1,600MW or 11 percent of the 2020 electricity demand.[175] A potential, which is lower in the SIC than in the SING, due to its nearly 100 percent thermal generation is the gap in the Chilean law, that LNG imports, which are realized by subsidies of larger energy conglomerates have not to be published. This opens the possibility to expel prices higher than they really were, making misuse of an oligopoly.

[174] For further information also including other sector's energy efficiency potential, see APEC (2009).
[175] CNE (2008), p. 77.

4. Diversification Options

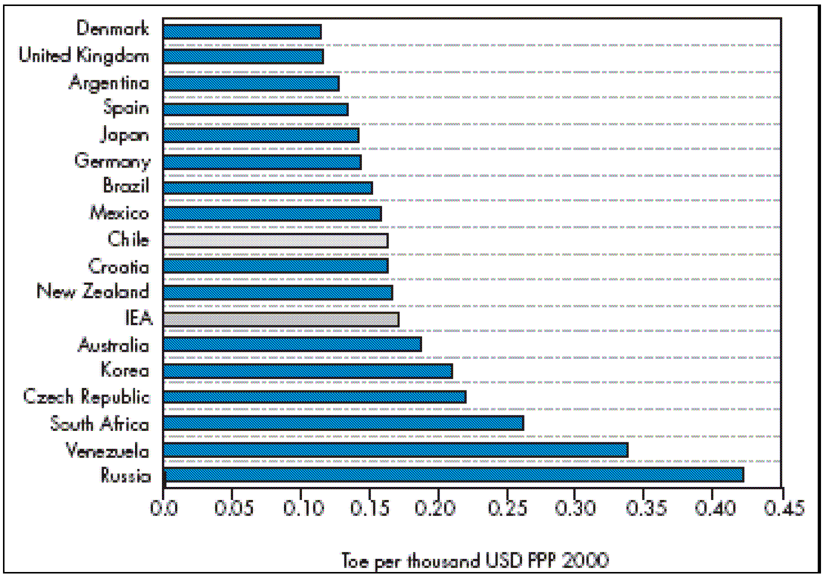
This chapter will evaluate the different measures, that can be applied in order to improve the energy supply and energy demand. As with the investigation of both sides, energy security can be improved considerably. Applications in the context of electricity security were already discussed in the former chapter three. Demand side options will focus on energy efficiency measures that can by applied in the largest consumption sectors, principally the industry, transport as well as the commercial and residential sector. On the supply side, examined measures are RET, indigenous energy sources and the nuclear option. In the context of the MR, the implementation of specific measures will be examined.

4.1. Demand Side Options

4.1.1. Energy Efficiency

In spite of recent efforts in improving the Chile's energy intensity, the energy consumption is strongly related to the GDP growth.[176] As energy growth in Chile is expected to rise in future, energy efficiency measures are an suitable instrument in order to partially lower the growth of energy demand, that has reached nearly three percent in the past decades, while electricity demand has grown by nearly six percent.

Figure 12: Total Primary Energy Supply per GDP (PPP) in 2007



Source: IEA (2009), p. 89.

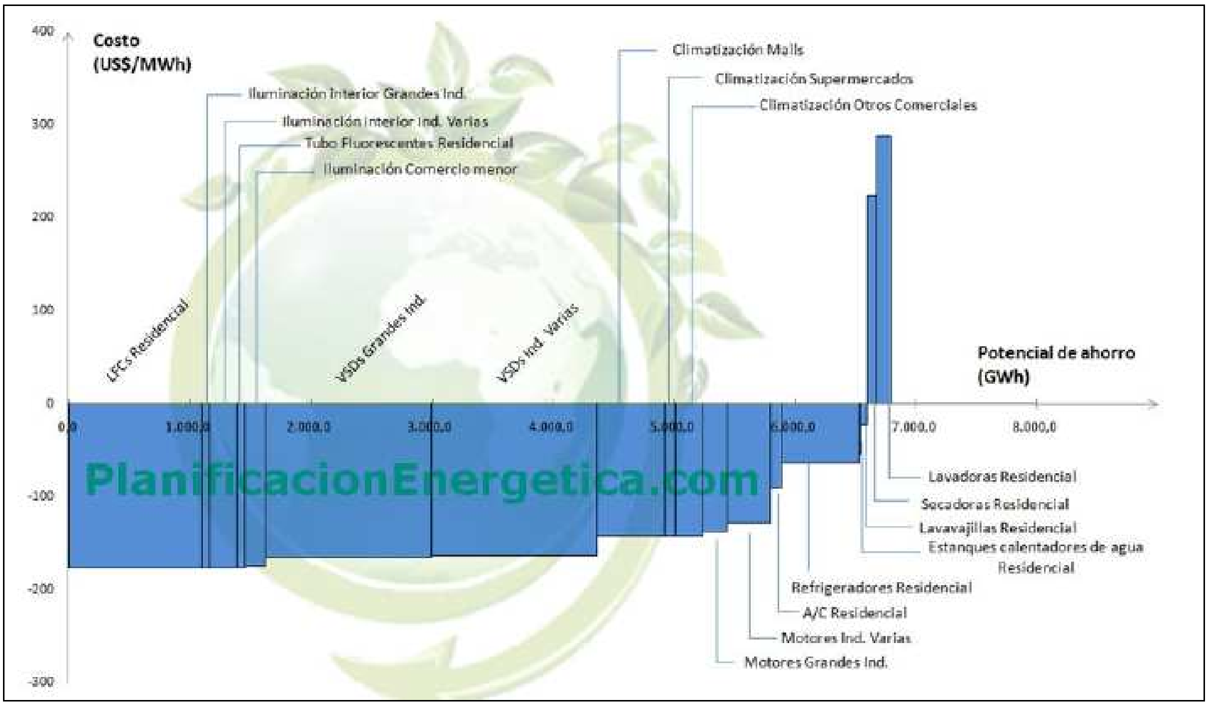
[176] Araneda et al. (2010).

A way to measure the current energy intensity[177] with energy to GDP as most common ratio, where Chile's relation is relatively low, but higher than in Mexico and Brazil and some other OECD member countries like Germany.

There exist six sectors, that consume nearly 100 percent of energy and electricity. Out of these three sectors consume more than 70 percent of the overall energy, the transformation sector, the transport and the conglomerate of commercial public and residential sector (CPD). The highest electricity use has the mining sector, followed by the CPD and the industry sector, which make together more than 90 percent of the electricity requirements.[178]

EE potentials are available in all sectors. In the specific case of Chile, Watts/Moreno (2009) have identified measures to be implemented in the different sectors. Hereby, measures have been identified with negative costs, meaning, that the investment in EE measure will be paid off shortly after the initial investment, where the residential sector has the highest potential in cost effective applications, see graph 2.

Graph 2: Energy Efficiency in the SIC grid



Source: Watts/Moreno (2009), p. 1.

The overall market investment potential for EE is estimated with USD 187 million, lead by the industrial and residential sector, with investments of USD 85 million and USD 51 million, respectively. Hereby, the investment opportunities for Energy Service Markets (ESCOs) are

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[177] Energy intensity is the amount of energy used per unit of activity. It is commonly calculated as the ratio of energy use to GDP in real terms. Energy intensity is often taken as a proxy for energy efficiency, which is not entirely accurate, but will suffice the following explications, see IEA (2007) for further information.

[178] GEF (2010), p. 9.

estimated with USD 100 million.[179] An example is the project "Ciudad Parque Bicentenario" which is also administrative part of the Ministry of Health, a project for designing efficient hospitals. This has initially stimulated the first large energy service contract between two hospitals and energy service companies. Another example is the Public Private Partnership program in which the company Philips and GTZ, together with the Chile's national energy efficiency program have agreed on the ongoing implementation of efficient lighting.[180]

Basically until 2005, in Chile EE has not attracted much attention. In December 2005, the government started the National Energy Efficiency Program (PPEE),[181] an instrument to lower the energy necessities and promote the sustainable development pathway.[182] By early 2008 the program was officially transferred to the CNE and budget grew from USD one million to USD 34 million in the four years to 2009.[183] The CNE (2008) paper expresses the four most important points:

- Establish the institutional framework for energy efficiency;
- Build a suitable knowledge base for decision-making;
- Promote energy efficiency across all sectors;
- Regulate markets, in particular the electrical market, providing incentives for energy efficiency.[184]

In 2009, Chile participated in a peer review on EE conducted by the Asia-Pacific Economic Corporation (APEC) to evaluate EE measure in the mid and long term. In 2010, the Ministry of Energy was created, a basic framework, which gauges this measure as important mean of a long-term energy strategy. And finally, in April 2010, the Chilean Agency for EE was founded in charge of promoting programs in the different sectors and guarantee their enforcement.[185] The ISO 50001, as standard on energy management is expected to be implemented in July 2011.[186]

The following part will discuss the sector specific approaches for EE in the three sectors: industry, transport and CPD, their potentials, measures, that have already been implemented and recommendations for each sector.

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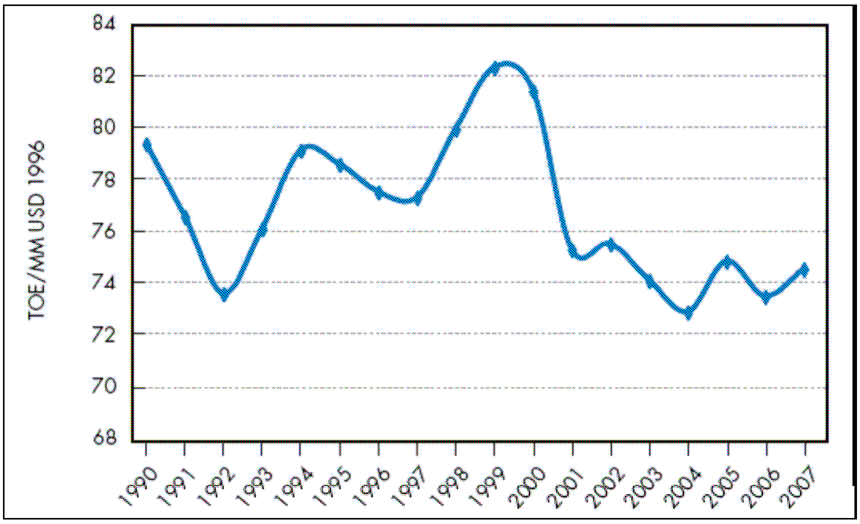
[179] FC (2007).
[180] GTZ (2009a).
[181] Here the approach is a very broad one which covers studies in the mining as well as in the fruit processing and wine sector, covers labeling programs, pilot programs for the introduction of standards in the freight transport sector until studies about residential consumer behavior, see Romero (2009).
[182] The German Technical Assistance Agency (GTZ) has contributed a program between 2006 and 2010 in order to improve the EE in Chile over all sectors.
[183] IEA (2009), p. 94.
[184] CNE (2008), p. 73.
[185] GEF (2010).
[186] Chilean Energy Efficiency Agency, press release December 13th 2010, available at: http://www.acee.cl/577/article-62101.html (accessed June 21st 2011).

4.2. Transport Sector

The transport sector is one of the fastest growing end-use sectors that represents 35 percent of the overall consumption. Final energy consumption grew slightly above average with 5.2 percent a year between 1990 and 2007, while the principal source was almost exclusively petroleum (99 percent). Here, the road sub-sector made up 69.6 percent of overall consumption, followed by martime and air sector with 21.1 and nine percent, respectively. In terms of energy intensity in transportation has declined about ten percent between 1999 and 2003 and has remained at this level since then.[187]

Figure 11: Evolution of energy intensity in the transport sector



Source: IEA (2009), p. 92.

The transport sector can be divided in three segments: freight transport, light vehicles (private cars and collective taxis) and non-motorized transport. In the first segment, government has focused on fleet renewal, eco-driving training, with expected reduction of five to ten percent, and the provision of technical assistance and maintenance. In the passenger sector a tax incentive for hybrid cars and a fuel economy labelling is intended.[188]

By 2010, in Chile there exist no national standard for automotive fuel economy, neither a technology mandates or targets. In order to improve air quality, the city has introduced a maximum sulphur content, while in September 2011 the norm will be lowered from 50 to 15 ppm, where 70 percent of vehicles are equipped with catalytic converters.[189] As a better income is a determining factor of transport choice, which results in increasing the trips made and higher opportunity costs of time and finally reflects in a higher energy intensity of

[187] APEC (2009), pp. 1-2.
[188] IEA (2009), p. 98.
[189] UNEP (2010).

personal individualized transport. For the whole transport sector in the next two decades to come will account for more then the half of TFC, compared to 33 percent in 2007.[190]

On the other hand, Santiago has one of the best functioning and best-developed public transport networks with a 90 kilometer metro with five lines and integrated bus rapid transit system. Authorities have reduced the total number of buses from 7,000 to 4,500 with gradual replacement of older vehicles. All efforts in improving the public transport system started in 2005 with the General Urban Transport Plan (Transantiago) with total investments of USD 2,360 million.[191]

4.3. Commercial, public and residential sector

The sector largest energy consumer represents 25 percent of TFC. According to the CNE, shows that the largest energy source in the residential sector for heating, water heating and cooking, while electricity show a strong increase in term s of final demand. Data availability for building sector showed some weaknesses as well as the availability for the separate *comunas* of the MR.[192]

The most effort since the implementation of the 2005 programs to introduce and promote EE has been made in the residential and commercial sector. There have been considerable successes, in spite there are still sufficient potentials left for improvements. As the most important results can be summarized:

- A reduction in electrical demand through widespread adoption of compact fluorescent lamps (CFLs) for residential lighting.
- Energy labelling for refrigerators, incandescent light bulbs and CFLs.
- Development of minimum mandatory standards for roofs since 2000 and minimum mandatory standards for envelope insulation in new homes since 2007, with planned revision of the standards by 2015.
- Design tools for energy efficient new buildings, including energy consumption simulation.
- Insulation retrofit programmes for existing homes.
- An energy certification programme for residential buildings.[193]

[190] O´Ryan et al. (2009).
[191] EIU (2009); Curauma (2003).
[192] A contribution to the energy demands and small scale sub-sector like food sectors and others, see Barton et al. (2007); O´Ryan et al. (2009).
[193] IEA (2009), p. 97.

The improvements of the residential building sector presents an 20 percent improvement to the previous standard, but further improvement have to be considered. Energy audits have been implemented in two pilot project facilities in order to develop guidelines for the government-owned buildings. So far, there is a deficit in energy data for commercial building, a gap that should be closed in further corporation or initiatives of the PPEE.[194]

4.4. Industry Sector

The industry sector represent 23 percent of the national PEC, and an additional 13 percent is utilized by the mining industry. Here, the PPEE has its main focus on energy audits of facilities. Out of these energy audits, conducted by energy experts, recommendations and implementation measures are extracted. Project can be co-founded with a financial support of CORFO and the Energy Efficiency Preinvestment Program (Programa de Preinversión en Eficiencia Energética, PIEE) limited to companies with annual sales up to USD 30 million to hire consultants or to do energy audits to quantify the energy saving potentials. The financial aid of CORFO is limited to 70 percent of the total cost or six million Chilean pesos which equals around USD 10,700. Between January 2007 and January 2009 there have been 192 projects carried through while 67 very completed.[195]

A project which is based in industrial appliances aims to replace low efficiency motors (10 hp and below) supported by the PPEE and four large mining companies participating. As international experience has shown, that the key to success is a continuous improvement process accompanied by an experience energy manager.[196] Especially, the best available technologies or new developments and their implementation are crucial for a steady improvement process. In the mining industry, especially in the energy intensive exploration process, new technologies like remote sensing can minimize exploratory drilling and digging. According to a study of Siemens VAI, arguments that with the most electrical drive in the mining sector would amount 130 TWh of energy saving, with an investment of around Euro nine billion.[197]

EE today is one of the principal objectives in the Chilean energy policy. Therefore, the governmental has continued its efforts with the Action Plan on Energy Efficiency 2010–2020 will continue the path in implementing measures and sector approaches. It is a plan, that specifies the lines of action, target, instruments of evaluations as well as modalities of

[194] APEC (2009).
[195] IEA (2009), pp. 97-98.
[196] APEC (2009).
[197] McIvor (2010).

financing. This could be an initial step in order to develop a long-term strategy of EE measure with concrete achievements for every sector to be defined later in the program.[198]

4.5. Regulatory measures

These measures[199] will be examined, without a sub-categorizing, embracing mandatory labelling, minimum energy performance standards (MEPS), minimum thermal standards and voluntary measures. Chile has introduced a labelling standard similar to the European, with seven efficiency categories, from most efficient appliance labelled with A until G, the least efficient. The *labelling* covers refrigerators, light bulbs, air conditioners, microwaves as well as single and three-phase induction motors. The introduction of MEPS in based on the law of the Ministry of Energy and was first introduced for light bulbs. This standard is later applied to other appliances in accordance with the law. Thermal standards are applied in residential buildings to improve their energy efficiency regulated under the Ministry of Housing and Urbanism. The utilization of voluntary measures is firstly foreseen for the mining industry organized through round tables. These aim to promote EE research in the sector and to disseminate the outcomes fostering the steady improvement within the members.[200] These measures will be implemented as well in other sectors like chemical, food processing and retail industry.[201]

Finally, in consideration of utilizing EE measures the overall gains, that are achieved have influence on the national level. The benefits are clearly surpassing the problems that might occur. First, it enables a country, especially with resource scarcity, to lower the future installed generation capacity, that are estimated with 11 percent of the installed capacity in 2020.[202] Second, it is a source of energy that is independent of imports or depending on a third party, so can be qualified as secure measure to improve energy security situation. Problems, that might occur, that these programs as far as consumptions pattern have to change or people have to get used to think about their energy consumption, it might take time until the benefits surpass the cost of implementation of campaigns, etc.[203] On the other hand, a study made for the Caribbean estimates saving of USD 125 million for a population of about five million people, which would be in the case of Chile three times the amount.[204]

[198] www.ppee.cl.
[199] The is an overview, but not the complete spectrum of regulatory measures that have been implemented.
[200] Every year the best performing company gains a award as best performer in each sector.
[201] APEC (2010).
[202] CNE (2008).
[203] The first approaches in environmental educational programs of energy use and energy efficiency have been applied, see for more information www.ppee.cl.
[204] Barrett (2011).

4.6. Supply Side Options

4.6.1. Renewable Energies

Renewable energy sources are well known for their low or non-environmental impact. This stands in opposite to fossil fuels like crude oil, gas or coal that are not renewable, which means that there is a point in future, where the maximum production is reached, for oil the so called peak-oil, and production is projected to decrease. The group of G8 estimates the world energy demand for the next 25 years to increase by 60 percent requiring an additional estimated investment of USD 16 trillion.[205] The problem of fossil fuels is not only the point in future when they will be completely exploited, as well there is a certain concentration of fossil resources in oil, controlled by the OPEC cartel or several concentration of gas in the Middle East and Russia, which has important implications for the energy security situation, see chapter 2. When energy sources are scarce and demand is increasing in a situation where the supply can not be expanded, prices will increase.[206]

Renewable source are derived from natural sources such as water, sunlight, wind rain, tides, geothermal sources or biomass derivates like crops or organic waste. They are constant or they enervate or exhaust in geological terms, like the sun will provide radiation for another five billions years. The IEA (2007) distinguishes between three different generation technologies of RE due to their technological process and market feasibility and maturity. The first generation technology reaching back more than a century ago, emerging by the end of the 19th century that are hydropower, biomass combustion and geothermal power and heat. The evolution and research of the second generation has started in the 1980s entering more and more in the international markets. These forms of energy are modern forms of biomass, solar cooling and heating, wind power and solar photovoltaics. The latest, the third generation technology is still in a development stage, including solar power, ocean energy, enhanced geothermal systems as well as integrated bioenergy systems.

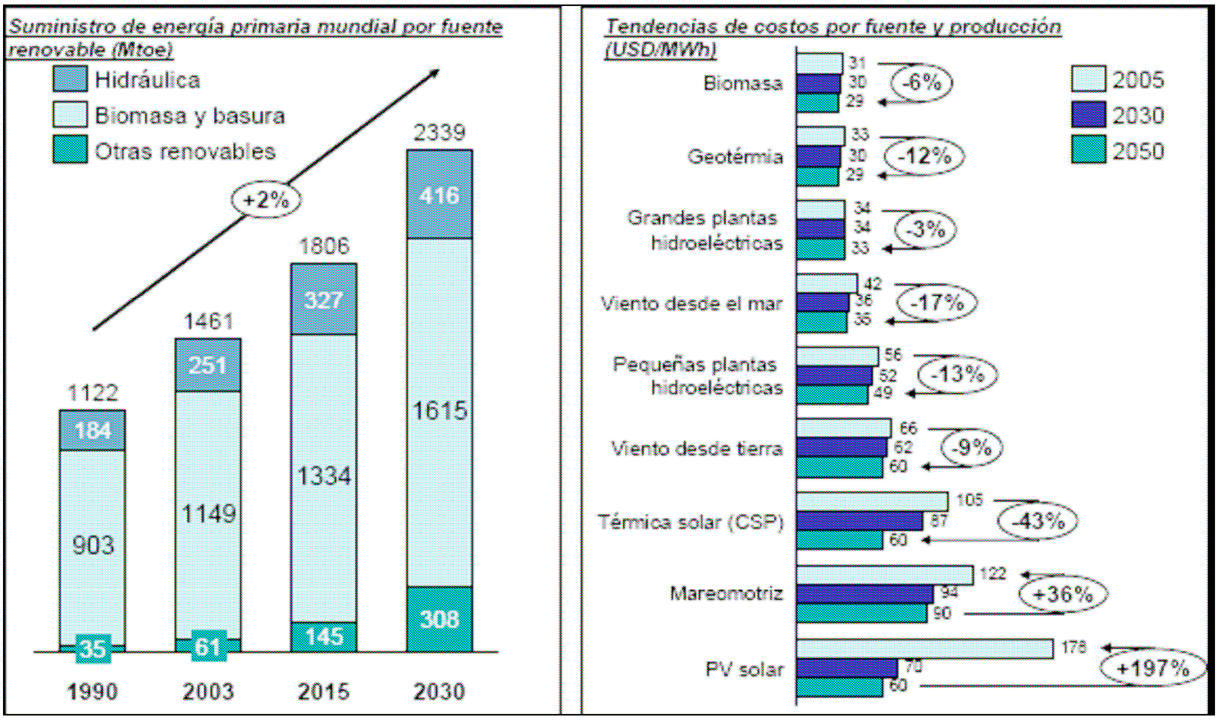
Depending on their maturity, the RETs still have a considerable potential of cost reductions in future. This applies especially for second generation technologies, recently entering the markets and third generation where potential is still not yet fully visible, but commercial use is expected in the coming decade. The decreasing generation costs due to mass production or economies of scale, economies of learning and more efficient transmission lines, that enable the transport of energy over larger distances with considerable lower energy losses, will

[205]Group of Eight Nations. Gleneagles declaration on climate change, clean energy and sustainable development, http://www.fco.gov.uk/Files/kfile/PostG8_Gleneagles_CCChapeau.pdf (accessed May 10th 2009).

[206] There exist besides the conventional production enhanced oil recovery technologies. It is possible to extract oil from oil shales or oil extraction from deep water sources, but it is often more expensive and environmental impacts are hardly calculable, as happened at the 2010th BP catastrophe.

promote RE as option for energy and electricity production.[207] All RET have, where first generation technologies have already experienced a considerable cost reduction potentials. The potential is expected highest for PV, CSR and ocean energy, but still more than ten percent for off-shore and on-shore wind as well for geothermal energy until 2050.[208]

Figure 12: Growth of RET until 2030 and expected cost development until 2050



Source: Dalberg/CNE (2008), p. 22.

In spite of a high dependency of fossil fuels due to the existing infrastructure investment that have been realized in the past decades it is only a question of time when renewable sources will produce larger amounts of energy and electricity in the future energy matrix. The projections of the OECD/IEA (2007) forecast a growth of nearly nine percent for RE until 2030, where oil demand is projected to decline by more than two percent per annum in the same time, see annex table 3.[209]

The potentials that are in RE are noticeable. Apart from the theoretical potential, which is not useable, the current world electricity demand could be covered several times, the technical potential for each energy type, except for geothermal and ocean energy, the current world electrical demand could be covered entirely.

[207] With a new HVDC line, electricity transport from London to Morocco, a distance of 2700 kilometers, would result in losses less than eight percent, see Higgins (2008).
[208] For technological development stages of different RET, see figure 22 appendix.
[209] Chile is not part of this projection, as it has become a member of the OECD in January 2010.

Table 8: Worldwide theoretical and technical potential of renewable energies

	Theoret. Potential [EJ]	entspr. % der derzeitigen Stromerzeugung	Technisch nutzbares Potential [EJ]	entspr. % der derzeitigen Stromerzeugung
Sonne	2 484 070	4 600 000 %	600	1 111 %
Wasser	158	293 %	100	185 %
Wind	11 002	20 373 %	100	185 %
Biomasse	2 999	5 553 %	115	213 %
Erdwärme	1 001	1 853 %	10	19 %
Meer	256	473 %	34	63 %
davon Wellen	79	147 %	11	20 %

Source: Knapp (2005), p. 4.

4.6.2. Renewable Energies in the Chilean context

The diverse geographic and natural conditions allow Chile a great variety of applications of renewable energies. The country is 4300 kilometers long and around 175 kilometers wide and spans the hottest desert, the Atacama, with high solar radiations in the north until very humid regions extreme south, which is very apt for hydroelectricity. The coastline of more than 4000 kilometers makes wind and ocean energy attractive. A tenth of the worldwide volcanoes are located in Chile, which makes geothermal energy an usable form of renewable energy. Biomass use in the southern regions is an important source, as Chile has abundant woodlands. The Inter-American Development bank has provided a loan of USD ten million last year for a sustainable woodland management. Chile ranks with 2.1 million hectares second in Latin America, after Brazil and tenth in the world.[210] In conclusion the geographical preconditions are highly preferable for the implementation of renewable energies. With Non-Conventional Renewable Energies (NCRE) the Chilean law refers to "those energy sources, or combinations of energy sources and technology, which are not generally used in the country. It includes wind power, geothermal energy, solar energy (thermal and photovoltaic), biomass (solid, liquid and biogas), marine (currents, tides, waves and thermal gradients) and hydraulic energy (restricted to small hydro plants, defined by Chilean law as smaller than 20 MW of installed capacity). NCRE is, in broad terms, what is usually known internationally as "new renewable energy."[211]

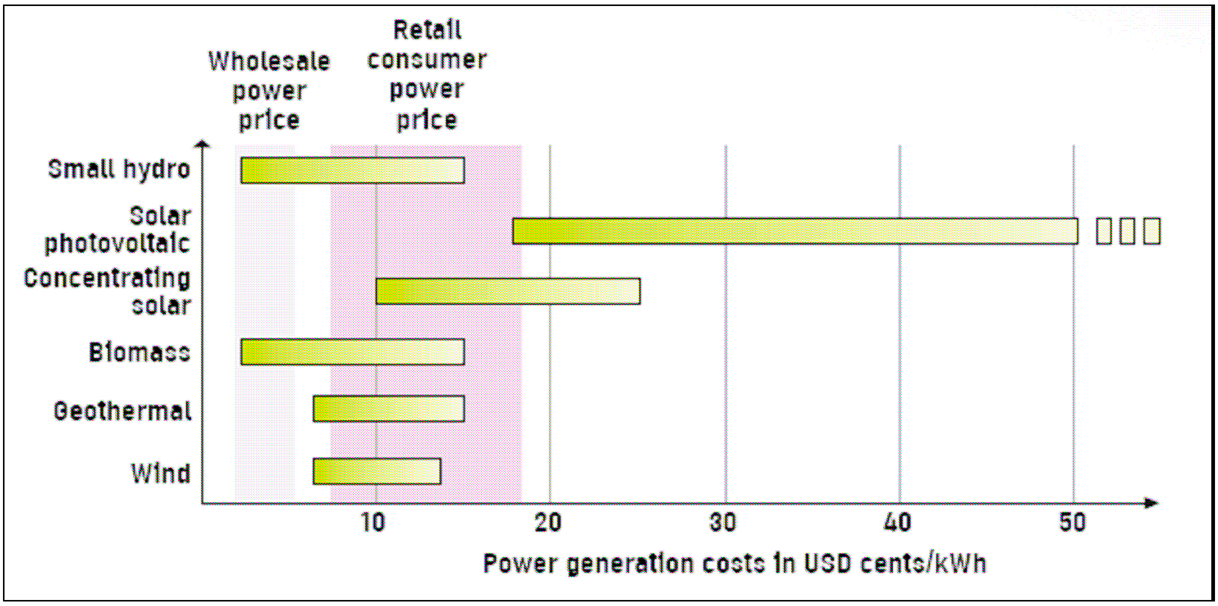
In 2007 NCRE (that excludes large hydropower) make up out of the energy supply only 2.7 percent or 347MW of produced energy.[212] The share of installed capacity in the SIC grid is

[210] Urban World (2010).
[211] CNE (2008), p. 94.
[212] Bennett (2009a).

with 3.3 percent of the overall capacity, much higher than in the northern SING, where only 0.4 percent of the energy is provided by renewables.[213]

At the first glance, there remains challenges in implementing renewable energies in Chile. A study of Chilesus (2003) mentions basically three principal challenges in implementing renewable energies. First, the higher initial costs that differ depending which technology is used. Hydropower, biomass and wind energy are the most competitive forms, having similar generation costs compared to fossil fuels, see figure 13. Here solar power is, in spite of technological advances the most expensive way for electricity production, when applied as rooftop solar PV.[214] In case of CSP generation costs are considerably lower at 0.14 – 0.18USD/kWh.[215] Secondly, there is a technological uncertainty about the newest third generation RET diffuse the market, so with more experience and large scale production, so for ocean energy, the least mature technology. A third problem is the 'free' grid access. This has changed with the change in regulatory framework condition, see chapter 3. But there is an obligation missing, like in Germany, where the purchase of electricity from renewable energies has priority which would change the situation in Chile considerably.

Figure 12: Cost-competitiveness of selected renewable power technologies



Source: IEA (2007), p. 6.

In the following part the potentials of each renewable energy form will be examined including hydropower, solar energy, wind energy, ocean energy, geothermal energy and biomass.

[213] CNE (2008).

[214] Under the condition, that there is a grid excess available. For autonomous systems in remote areas without grid access the situation might be in favor of the PV installation.

[215] REN (2010); Here the pure generation costs are considered, excluding the environmental externalities that are caused by fossil fuels like air pollution, water contamination that implicate health costs, etc.

There will be a discussion about generation costs as well as the possibilities of transportation of energy to the large demand centers like the MR and the benefits and disadvantages of each energy form will be explained in detail.

RET are no exception from the environmental approval. Projects that might cause an environmental impact, which includes high voltage transmissions lines and substations and energy generation plants larger than 3MW that have to be approved by an EIA.[216]

All renewable energy installation require an Environmental Impact Assessment (EIA) that has its specific requirement, if fulfilled there are generally no further obstacles from the Ministry of the Environment for in the process of implementation.[217] The previous authority responsible, the National Environmental Commission (CONAMA) was set up in 1994 by law 19,300 to ensure citizens the right to live in a pollution-free environment.[218] The establishment of the Ministry of the Environment (MMA) in October 2010 has brought some changes. The newly created Environmental Evaluation Service is now responsible for EIAs, in order to relieve the MMA from this more and more work intensive task.[219] The EIA has partly replaced for a Strategic Environmental Assessment (SEA), for reasons of international harmonization and in enabling and facilitating the decision making of the MMA.[220]

4.5.3. Hydropower

At global scale hydropower has the largest share of all renewable energies in the electricity production. As of 2005, hydropower accounted for 87 percent of the world's total RE generation. The share will decrease to 66 percent in the 2030 projections but will remain the dominant renewable energy source.[221]

Since a long time hydropower plays an important role in the electricity production of Chile. Installations larger than 20MW do not count under the NCRE definition of the CNE. Chile had by 2007, 21 hydroelectric plants with a total capacity of 4,130MW installed, spread all over the country with the exception of the regions Antofagasta and the Magallanes region.[222] Hydropower still accounts for a considerable part of the energy mix, but there are still important potentials. According to the new policy guidelines of the CNE (2008), the potentials could amount to as much as 20,000MW. Those projects, which have already entered the Environmental Impact Assessment System (SEIA) in recent years, together with concrete

[216] Law 19,300; Art. 10b,c and 11.
[217] Personal communication April 19th 2011 with Trudy Könemund, head of the energy department of GIZ Chile.
[218] GTZ/Government of Chile (2009).
[219] Law 19,300 and 20,417; Servicio de Evaluación Ambiental in Spanish.
[220] The SEA is normally undertaken before the EIA, reducing the amount of work, which has amounted to more than 70 percent of the overall work time of the former CONAMA; UDC (2011); On May 24th 2011 the SEA was incorporated in the law 20,417 as new instrument in environmental management, see www.mma.gob.cl.; For further information on SEA, see European Union Directive 2001/42/EC and www.sea-info.net.
[221] Resch et al. (2008), pp. 4053-4055.
[222] GTZ/Government de Chile (2007); IEA (2009).

initiatives that are being studied by generating companies, amounting an additional capacity of 10,500MW. A new project, the so-called Hidroaysen[223] is highly controversial. It is the largest project under EIA. It would contribute 2,759MW of new installed capacity and therefore, add nearly a fifth to the existing capacity in early 2011, improving the import dependency from fossils with an investment of USD 3,200 million. The Endessa/Colbun projectholders submitted on August 14th 2008 the EIA for the proposed hydroelectric project. It is a 10,000 pages long and USD 12 million expensive document, which took three years to be completed.[224] It has severe impacts on the displacement of local people, the destruction of natural habitats and the disruption of waterways, so that the initial plan to finish construction in 2012 is not possible as the government sets a clear position.[225]

By 2020, more than 30 percent of additional capacity, both in SIC and SING, will be installations of new hydroelectric plants, amounting around 4,400MW.[226]

For **small hydropower plants**, which count as a renwable energy source, projections are much smaller. There are around 300 such potential sited for the exploitation with an additional capacity of 900MW. As similar estimation has been made by the Chilenan CORFO with a potential of 850MW.[227]

Hydropower has the advantage of being a technology that is well know, intensively used in Chile and accepted in the population. There is no need for external experts. Furthermore, it is when a properly EIA is done, an environmental friendly technology to produce energy. The water supply is seasonal, which means that there is a storage needed to overcome the seasonal minimum water flows that limit the generation capacity, which is especially a problem in the SIC. In times of high water availability a hydro plant is able to run base load. Therefore, water is mostly stored in a dam and released when needed to produce electricity.[228] Another solution to compensate for the low-water periods, would be opposed to extending the use of wind cycles. When electricity generation from hydro plant is low, wind generating is high, which together creates a higher availability and reliability of the electricity production. A study from northeast Brazil shows the complementary cycle. Studies conducted for Chile are curently not available.

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[223] A more detailed discussion of the project with current status, see chapter 4.9.

[224] Inter Press Service, "Environment Chile: Patagonia Dams On Hold," http://ipsnews.net/news.asp?idnews=44791 (accessed March 25th 2011).

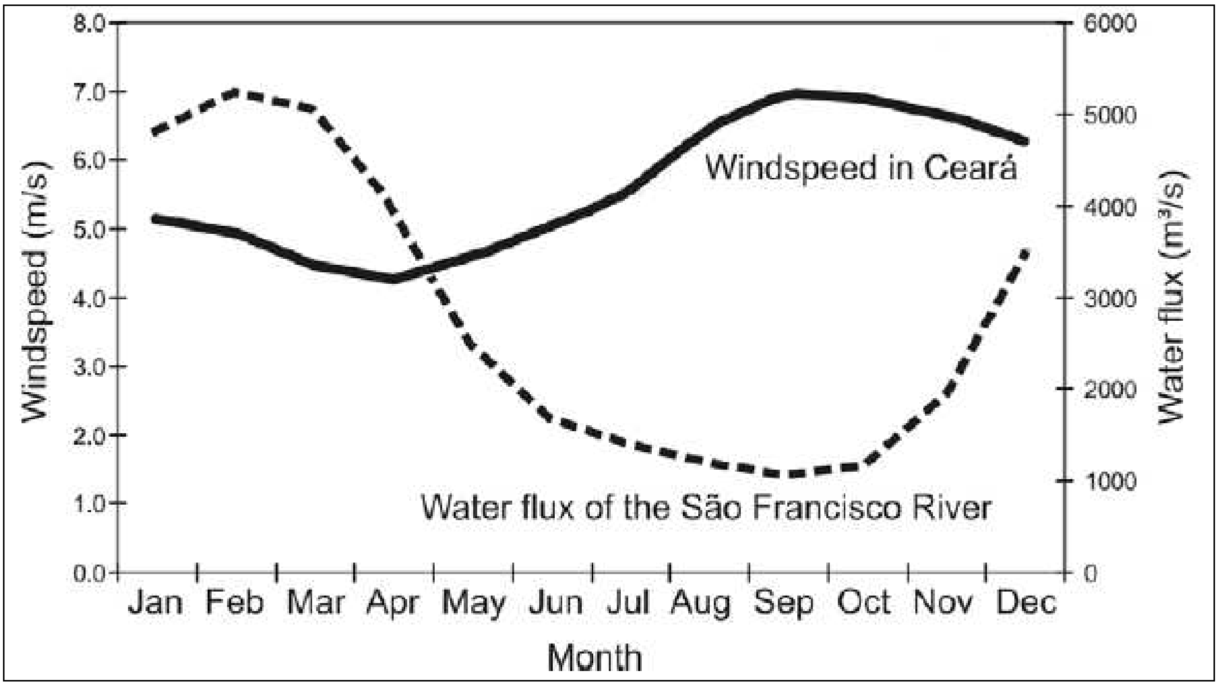
[225] A detailed analysis of the project, see Hidroaysen (2008); http://www.hidroaysen.cl/site/ingles/fundamento6.html (accessed March 22nd 2011); http://www.internationalrivers.org/en/node/6054 (accessed March 22nd 2011).

[226] CNE (2008), p. 94.

[227] Hidroaysen (2008); Bennett (2009a).

[228] Pansini/Smalling (2006).

Figure 14: Seasonal flux of river and average wind speed in Northeastern state of Brazil



Source: Krauter/Kissel (2005), p. 223.

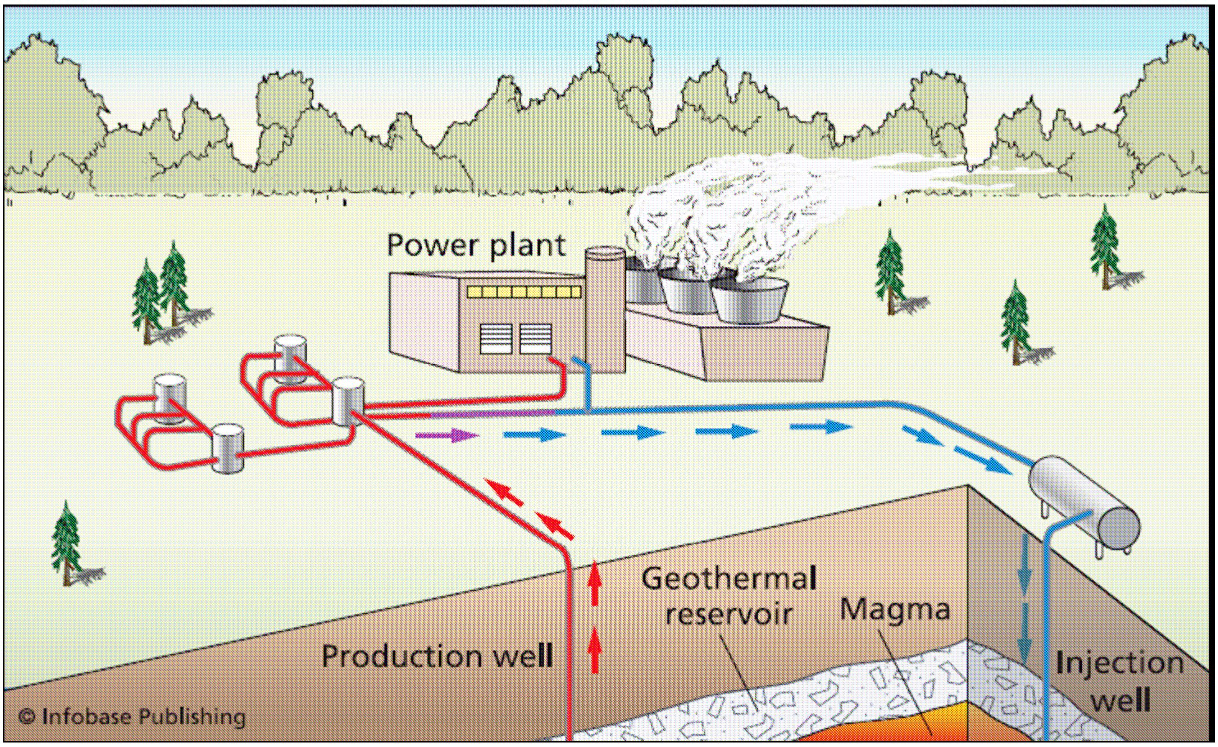
4.6.4. Geothermal Energy

Geothermal energy (GE) derives from the two words thermal, which means heat and of geo, the earth. The earth's core temperature is estimated at around 5,000 to 7,000 degrees. The energy that can be extracted from the earth are the relatively thin outer part of the crust.[229] GE generation is site specific and can be used in only a few places in the world. Chile is one of these places, located in the so-called 'Pacific Ring of Fire' with ten percent of the worlds active volcanoes that make the exploitation of this energy form possible.[230]

Drilling into the crust allows to extract the hot water and the stream, depending on the geographical condition in the specific site.[231] The escaping heat is carried by a pipe transporting it to a plant where steam is allowed to 'flash' or is separated from the water. The steam then runs a turbine generating electricity. Reinjecting the geothermal fluid after it has been used to run a turbine helps to preserve the volume of the geothermal source. A natural decline is not avoidable, but the time of utilization of the reservoir can be extended with a proper management of the well.[232]

[229] Lanterman/Lee (2007).
[230] IEA (2009), p. 53.
[231] For the classification of geothermal resources and their characteristics, see Lanterman/Lee (2007).
[232] Kutz (2007), p. 107.

Figure 15: Geothermal power plant



Source: Kerr Caspar (2007), p. 53.

The first geothermal power plant was built in Italy in 1903. Today there are 43 plants installed, with the largest electricity generation capacity in USA, Philippines and Mexico having a total production of 46 million kWh in 2005. The growth between 1995 and 2010 was annually 18 percent.[233] Despite the existence of several geothermal sources in Latin America, there exist no efficient legislation for the promotion and development of this energy form. A framework passed in Chile and Peru the National Congresses but the incentives for private investors are not sufficient at the moment, which is a precondition for initial developments. Estimates for Chile in terms of electricity production are an decreased share import dependency of today's 60 to 15 percent using the complete potential of GE.[234] The basis for the use of GE was created in 2000 with the law 19,657. This defines GE as a good, that belongs to the State, that may grant concessions for the exploration and exploitation of this resource. The Ministry of Mining is responsible for the application, control and the enforcement of the law. As in the beginning of 2004, twelve concession where granted by the State.[235] By 2010, GE in Chile has only been used for recreational purposes, like swimming pool heating,[236] and by March 2011 there exist no grid-connected plant producing

[233] RED (2008).
[234] Chandrasekharam/Bundschuh (2008), p. 59.
[235] GTZ/ECLAC (2004); More detailed information about the law 19,657 in CNE (2004).
[236] Lund et al. (2010), p. 8.

electricity,[237] but another seventeen exploration licenses have been awarded with an expected investment of USD 106 million.[238]

Due to the fact, that GE can only be used in a few parts of the world, this form of energy has had a positive development. It is a competitive energy source with electricity generation costs of 0.055 to 0.10USD/MWh, having a slightly decreasing trend.[239] GE is clean as there is no chemical or combustion process in the generation of electricity, carbon dioxide emissions are minimal. Furthermore, which is outstanding for a RE source, GE operats with a high number of full-load hours and low maintenance costs and a modern plant has 95 to 99 percent availibility, more than ten percent points higher than a coal power plant. The life span for a plant is 20 to 30 years, which can be exceeded with propper resource management strategies. Apart from power production, GE is also used for agricultural applications, space and district heating and used in geothermal heat pumps, which alone accounted for approximately 70 percent of the worldwide capacity in 2010.[240]

In 2008 the CNE had determined 115 potential sites for exploration half of them are far north or extreme south.[241] Two years later there where more than 200 geothermal areas in the central-southern part of Chile, where Chile has the best precondition, according the heat flow map, see map 5 in appendix. A study of 2004 estimates the potential in the range of 1,235-3,350MW,[242] while recent developments show that Chile has a potential of over 16,000MW for at least 50 years from geothermal fluids with temperature exceeding 150°C.[243]

The implementation of GE in Chile is in spite of the many benefits not that far realized for three reasons. The government has to force more studies and supported by CORFO, the exploration of new sites with the target of electricity generation. Second, the high initial investment costs and the expensive drilling expenditures, which can make up to several million dollar each, depending on the depth and material in the specific region.[244] And thirdly, sites with high potential are located in the south, which requires the transport of electricity over a relative large distance, creating additional costs and transmission lines in the SIC already very close to their capacity limit.

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237 Interview in March 2011 with Prof. Luis Vargas, University Pontificia Catolica de Chile.

238 http://thinkgeoenergy.com/archives/3590 (accessed February 19th 2011).

239 RED (2008).

240 Lanterman/Lee (2007), p. 425; Lund et al. (2010).

241 Bennett (2009a).

242 Speiser, R.M. "Energy Security and Chile Policy Options for Sustainable Growth" U.S. Assessment of Energy Economics, Report USAEE WR08-006, January 2008.

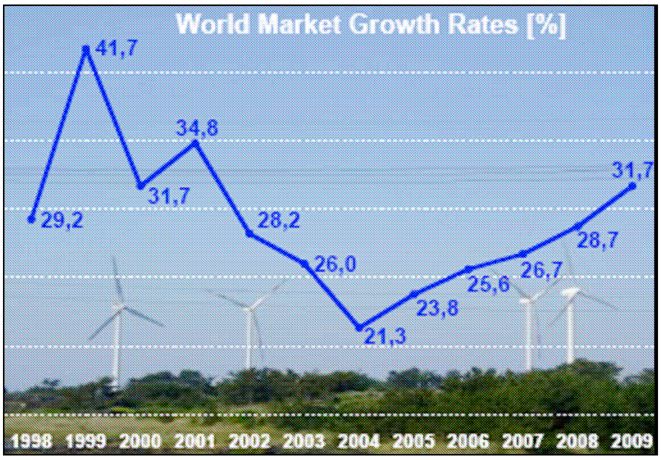
243 Lahsen et al. (2010), p. 1; For electric power generation geothermal should have temperatures above 110°C, depending on the appropriate technology and the nature of the resources, see Kutz (2007).

244 A failure in whole drilling procedure means for a company sunk or non-recoverable costs; The generation company Enersis has mentioned the expensive drilling cost (risk) and geothermal source close to the cordillera as principal obstacle for a use of GE in Chile, personal interview Alejandro Andrés Valdez Leal, ENDESA, June 20th 2011, see map 2 in appendix for source location. The first plant that is approved by law decree of the CDEC-SIC will be built in 2016, CDEC-SIC, Dirección de Peajes, Julio 19 2011.

4.6.5. Wind Power

The heat of the sun drives the wind that can be captured with wind mills, the traditional form of wind turbines that have been used more than 100 years ago. Wind energy in the world is one of the fastest growing technologies in the world. The growth rates where steadily above 20 percent since 1998, see graph 3, with Denmark being number one with 20 percent of electricity generation out of wind energy. In 2009 the fastest growing region in the world was Latin America, with Brazil and Mexico leading the market.[245] This fast pace enabled through changes in technologies concerning the average size and generation capacity of a wind turbine. In the mid 1980s, the typical size was less than 100kW, while today a turbine has a capacity reaching up to 3,500kW.[246]

Graph 3: World wind market growth rates



Source: WWEA (2010), p 7.

Energy derived from wind is one of the more advanced technology source with a high implementation potential in Chile. Due to its coastline of more than 4,000 kilometers, where wind velocities are higher than inland and energy generation costs that are comparable to fossil fuels, see figure 13.

The cost of wind turbine, and the costs of electricity generation depends very much on the location as well as on other factors, like the average wind speed, the height of a turbine, statistical wind speed distribution, turbulence intensities and the cost of the wind turbine components.[247]

The principal future cost developments of a wind park will depend on the design improvement and due to economies of scale with optimised logistics, see table 9, as well as from the intelligent management of the demand side and storage technologies. A recent

[245] WWEA (2009).
[246] Herbert et al. (2007).
[247] Ebd.

development, which uses the direct drive technology, has reduced the amount of magnet cores, which lowers the weight by 50 percent and as consequence the transport and overall costs.[248] Wind power will influence the power flow pattern as well as the dynamic behavior of the whole grid.[249]

Table 9: Estimate of the future cost reduction of wind-generated electricity

Source	*Relative share (%)*
Design improvements – weight ratios	35
Improved conversion efficiency[4] – aerodynamic and electric efficiency	5
Economy of scale – steady serial production and optimization of logistics	50
Other contributions – foundations, grid connection, O&M [5]	10
Total	100

Note: Percentages refer to a total reduction of 15 per cent from 2000 to 2004. O&M: operation and maintenance.

Source: Mallon (2006), p. 52.

The amount of wind projects between 2006 and March 2009 that have been at the stage of a EIA or were already approved amounted 2,021MW.[250] The realization of all projects is not very probable, but the installed capacity in the SIC grid has increased from zero in 2007 to 78MW by the end of 2009, ranking number 39 in the world, lead by the USA with 35,159MW of installed capacity.[251] The installed 78MW in the SIC will increase to 151MW where all plants are already commissioned out of a total installed capacity of 172MW by the end of 2010.[252] The current wind potentials are estimated between 1,500MW and 5000MW.[253] A recent study for eight different wind locations in the north has been conducted by Watts/Jara (2011) with the analysis that six show a very promising capacity factors between 44.8 and 19.4 percent.[254] Furthermore, as already exist in Brazil, the land where the wind farm is built on can be rented in remote areas for generating income to land owners, which allows additionally a land use as farm land or for other purposes.[255] Furthermore, if technology

[248] SZ (2011).
[249] For more information about the interaction of wind park and the electrical grid and the well balanced markets to integrate wind power, see Erlich et al. (2008); Vandezande (2010); Ackermann (2005).
[250] Watts/Jara (2011).
[251] WWEA (2009), p. 15.
[252] Global Wind Energy Council, http://www.gwec.net/index.php?id=171 (accessed May 1st 2011).
[253] Helmke (2009); Könemund (2006).
[254] As reference, the British Wind Energy Association recommends load factors above 30 percent as suitable place to install a wind park, see Jefferson (2008).
[255] Macaquer/Rudnick (2009); Filgueiras/Silva (2003);

transfer is done properly in a fast growing market like the wind industry might be established in Chile with probable job creation in the construction and fabrication sector and the establishment of a future market, analyzed in Pueyo et al. (2011).

4.6.6. Biomass & Biofuels

Biomass is organic material. It derives from energy of the sun that is stored in the growth of plants through a process called photosynthesis. The potential of this source is limited in that way, that earth has limited surface capacity that as well serves for agriculture purposes and other. But today energy from biomass can be obtained from cellulose, firewood, municipal solid waste, agricultural waste, such as husks and wheat straw and other materials. It can be used as solid fuel, converted into gaseous forms and used for electricity generation, heat production or for chemicals or so-called biofuels.[256]

Globally, the use of biomass as part of the potential is highest in Asia (107 percent) and lowest in the former USSR (five percent). In LACs the share is twelve percent, much less than the world average with 38 percent. The world's largest biomass electricity producers are the U.S., followed by Germany and Brazil. Chile has increased its production, even on a very low level, from 0.70 to 1.82TWh between 1995 and 2005.[257]

The potential for using biomass in Chile is large. Due to reforestation and restricted cutting of native woods, the country has the second largest woodland in South America, after Brazil, and ranks 10th in the world with nearly 2.1 million hectares.[258] The forestry industry accounts for 3.5 percent of the GDP, which ranks Chile as number three in woods chips exports and number sixth in exports of pulp.[259] The advantage of biomass it that this resources is even when limited local available, especially in the southern regions. A very promising energy alternative are the residues that result from the forestry and wood-processing industry. This makes it necessary to conduct studies about the local biomass availability in concordance with a sustainable development. The Aysén region has the highest extension of native trees with a plain of five million hectares.[260] A study conducted by the CNE/GTZ (2008) estimates the potential for electricity production from forest residues between 310 and 470MW, depending on the share of residues used, in the case 50 or 75 percent, respectively. The

[256] Kerr Caspar (2007); While first-generation are in direct competition for land, using for agricultural purposes like food production, the second-generation like is not any more competing for the land, because plants like jatropha grow in arid areas where no agriculture could be done. Third generation are advanced in a way that „converting waste into gases that are subsequently processed into methanol. Such a process leads to a CO2-reduction that is four times that of second-generation bioethanol processes and furthermore, it may be put to use as fuel for modern electric cars equipped with fuel cells", see FIB (2007) 4th Vol 21th issue, September 2007.

[257] Demirbas et al. (2009).

[258] Urban World (2010).

[259] OECD (2004).

[260] Depotech (2008); Further and detailed discussion on biomass, see GTZ/Government of Chile (2008).

cost for the raw material is around 15-20USD/ton, which equals a final energy production cost of 63USD/MWh for a 20MW plant or 80USD/MWh for a 10MW plant.

The calculated theoretical biogas potential from waste available in Chile is 534.901 thousand m²/year, which equals an methane volume of 327,182 cubic meters.[261] Another study estimates the biomass potential for the production of biomethanol 869PJ, where 73 percent derives from forest residues and 11 percent from energy crops.[262] In the MR there are large potential that can be exploited. Nowadays, Chile has only one large plant, that started operating in 2008, to produce biogas from sewage located in the MR. This biogas suffices four percent of Santiago's gas consumption.[263] But the usage today, is much wider and by 2009 there existed several studies and projects to make use of this energy. Biogas plants of different sizes that are operating or almost in operation, see table 6 in appendix.

Chile has so far no plant, that produces biofuels in operative stage. One project has passed an EIA with an estimated production of four cubic meter gas per day. A clear trend, especially considering the intense use land in Chile and the MR,[264] is the development of second generation biofuels. A project initiated by BIOCOMSA Inc. intends to develop the base for second generation diesel in eight subproject examining the whole production chain with total funding of USD 3.36 million.[265] Chile potential is large, considering that a part of the 282 municipal landfills can be used for biogas production. The 52 largest landfills have an capacity of approximate 4.7 million tons per year which theoretically equals 160-204 million cubic meters of biogas per year.[266] The country has invested more than USD 30 million in R&D for algae biofuel technology. Due to the large coast, the biofuel production from micro and macro algae is beneficial without competition with farmland.[267] A further status report about liquid biofuels in Chile can be found in Garcia et al. (2011). For second generation biofuels exploration, a corporation with Brazil should help with expertise, especially in plants like jatropha and castor oil plants as well as algae due to the large availability along the more than 4000 kilometer coastline.[268]

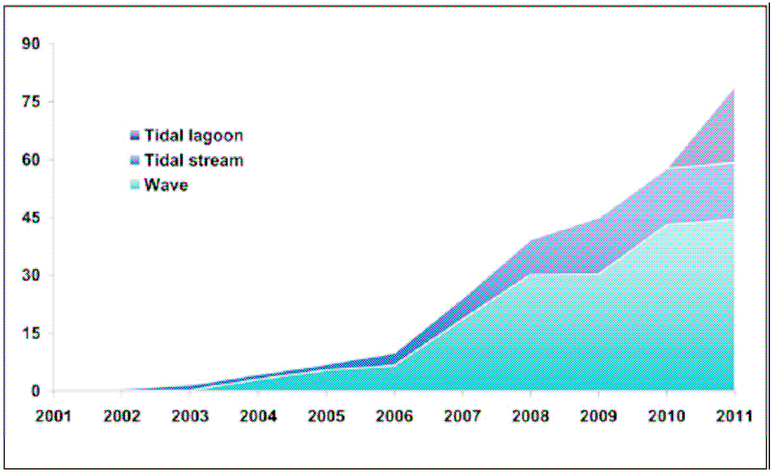
The government should employ a strategy, which includes all related Ministries like the Ministry of Energy, CONAF and CONAMA to create a national wood energy strategy, which represent all kinds of used and possibilities to improve the supply derived from biomass. A final studies from CORFO biomass overall potential is estimated with 800MW.[269]

[261] BTG (2009), p. 18.
[262] Seiffert et al. (2009).
[263] IEA (2009), p. 163.
[264] Where competition for land use is higher, see Tokman (2009).
[265] Garcia et al. (2011).
[266] Mang (2004).
[267] Lesser (2011).
[268] CNE (2008), p. 87.
[269] Gebremedhin et al. (2009).

4.6.7. Ocean Energy

With a coastline more than 4,000km long, Chile meets the basic condition for the use of marine energy. According to the British engineering consultant Baird & Associates, Chile has the highest wave energy potential in the world.[270] As long as there is radiation of the sun there will be movement of the sea, so this source is inexhaustible. The global tidal and wave potential can be roughly estimated with 1 to 1.5 times the current world energy needs, but the most are far from human settlements and technologically inaccessible so that that the technical potential is estimated between 10 and 25 percent of the world energy consumption.[271] The current cumulative capacity is relatively low even compared to the relative expensive solar power but increasing steadily. The largest grid connected tidal power plant 'La Rance' is located in France with an installed capacity of 240MW, which went online in 1966.[272]

Figure 16: World cumulative capacity forecast for tidal and wave energy (2001-2011)



Source: Dal Ferro (2006), p. 46.

Currently there exist three principal technologies to exploit marine energy, tidal energy, wave energy and osmosis.

Tidal-energy generation uses the gravitational pull of the sun and the rotational force of the earth. The difference of the tidal day being 1.035 as long as the solar day, which generates tides, in most regions in the world twice a day (two highs and two lows).[273] Usually the water runs up a ramp and makes use of the height difference. This potential energy is released and used to run, for example a Kaplan turbine, which generates electricity.[274] Recent

[270] OEC (2008); The IEA (2009) states similar in their energy outlook for Chile.
[271] Dal Ferro (2006).
[272] www.reuk.co.uk/La-Rance-**Tidal**-Power-**Plant**.htm (accessed March 22nd 2011).
[273] Charlier (2003), p. 188.
[274] Energy2.0week (2008).

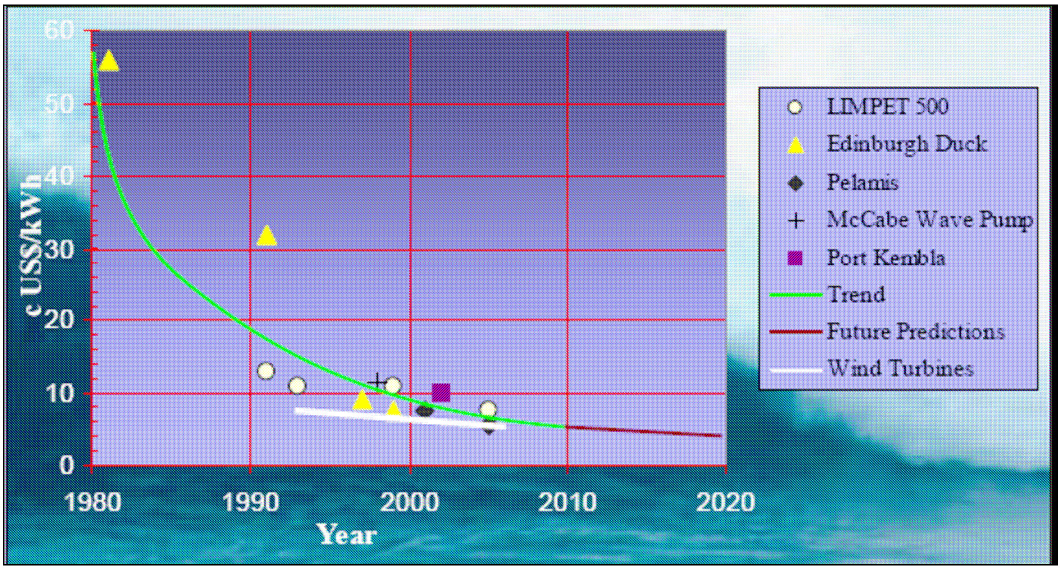
developments in low-head turbines have made around another hundreds of sites ‘suitable’. One of the main advantage is that the annual variation of tidal power generation is less than five percent. The transmission is less expensive than that of coal and the production is free of pollution. As with varios forms of RE, energy generation and energy consumption are isochronical, so that a buffer is needed. As the tides are predictable a combination of tidal current and a storage system ensure a substantial element for a steady supply of energy.[275] Another proposed solution are multiple basins or compressed air systems.[276] In a study for Chile, conducted by Hassan (2009), there have been identified three “top zones” for 30MW plants. Two of them are close to the SIC grid located in Chacoa and Corcovado Gulf, that are realistic to be implemented with support by CORFO to conduct more investment studies.[277]

Wave Energy uses the movement of the waves to produce electricity. A floating device follows the movement of the waves, which either, directly is converted into electricity or is used in a hydraulic system before conversion.[278] The height and form depends on the wind velocity, the wind duration and the distance, where the waves derives from. Apart from electricity generation, locally, to lighten buoys, this energy form can used for desalination as well as for fish and algae farms.[279] Chile has a large potential especially in the region V and further south. Due to the geographical form of the coastline and the average wave power of 47.2 KW/m results an approximate mechanical energy potential of 300GW.[280] The share out of this potential that can be captured is much smaller due to economical feasibility and technical accessibility reasons. Wave energy is, in comparison to solar and wind energy, which have only 20-30 percent availability, much more reliable with around 90 percent.[281] The evolution of the generation cost shows a large progress of wave device technologies. Cost have decreased from about 80 percent from more than 0.05USD/kWh in 1981 to 0.065USD/kWh for the most advances devices Pelamis and LIMPET500.

In 2003, the first wave dragon went online in Denmark, even when technological development is strongest in Great Britain, while Portugal has set a feed-in tariff of 0.235€/kWh, limited to the first 20MW of installed capacity. The Pelamis system is 150 meters long with a diameter of 3.5 meter and weights about 700 tons. Each of these modules produces 750kW. With the installation of 200 dragons around 200,000 households could be delivered with electricity.[282]

[275] Bryden/Macfarlane (2000).
[276] Charlier (2003), pp. 189, 203.
[277] An excellent review of technical specification and precondition for a tidal plant, see Clark (2007).
[278] Energy2.0week (2008).
[279] Graw (2006).
[280] ChileWaves (2006).
[281] The Economist (2001).
[282] Westwood (2004); Graw (2006); SZ (2011).

Graph 4: Evolution of electricity generation costs for wave energy conversion devices



Source: Boyle (2004), p. 43.

The costly transport and the installation of the 700 ton object and the missing long-term experience are some off the disadvantages of this technology. To establish this technology, CORFO has to conduct more site and feasibility studies to push this energy with a large potential, under consideration having the worldwide largest potential for an abundant resource of energy with relative low generation costs wave power could become a cheap domestic energy resource.

Osmotic power, as the third major technology, is a less mature technology. Global power potential is estimated 2000TWh per year. This energy can be used, where freshwater from the river mixes and saline water of the sea, which releases a large amount of energy. The separation of both types of water by a semi-permeable membrane, freshwater will migrate through the membrane and dilute the saltwater due to the chemical potential difference. A process called osmosis.[283] The salinity difference is able to create osmotic pressures of 27 bar.[284] A lifetime of this plant is expected between seven and ten years with relative low generation costs. The biggest challenge so far is the development of a membrane that is capable to of a power production capacity of 4W/m². In 2009 the worlds first osmotic power plant with 4kW went online in Norway. By 2015, the plant is expected to generate 25MW.[285] The large advantage of an osmotic plant is, that it runs 24/7 so that a reliable constant

[283] "Osmosis is the transport of water from an area with low concentration of dissolved substances (e.g. salt) through a membrane to an area with a higher concentration. The membrane is semi-permeable. It allows some substances to pass through, but stops other substances," Statkraft (2009).
[284] Aaberg (2003).
[285] BBC (2009).

energy supply is guaranteed. As the first plant has been built quite recently, a further development has to show how well the technology works.[286]

4.6.8. Solar Energy

Solar energy is abundant available. This due to good weather conditions in the north and central parts of the country and there geographical location. The countries solar radiation is one of the highest in the world, with exceptional levels in the north of the country, the part of the Atacama desert with 5.6 kWh/m²/day. A large scale photovoltaic solar plant installed in this region with an initial investment of USD 90 million could generate 70MW of electricity that could cover the energy needs of 40,000 households or contribute to the energy necessities of the mining industry.[287] The largest challenge is, that there are only global satellite information available. As long as a proper solar atlas is not available to the planning authorities, there will be no solar project in the commercial scale implemented. There is no valid database available. The GTZ has started a project in 2009 and installed 20 wind measuring masts and the first three solar radiation measuring stations, a project targeting an accelerated implementation of renewable energies in Chile.[288] The first radiation measurements are available at the homepage of the Ministry of Mining. The information of the direct solar radiation has to be provided, in order to make use of the concentrated solar power (CSP), which has the lowest energy generation costs with considerable potential for lower future costs in range of over 50 percent due to learning curve effects, etc. The potential for lowering costs in photovoltaic panels is even larger with over 70 percent, see figure 17.
Therefore, solar energy is apart from decentralized off-grid solutions not much applied, this because of insufficient radiation data and the comparable higher costs of generation. At the moment, plants are only used for demonstration purposes and for water heating and recreational purposes.[289]

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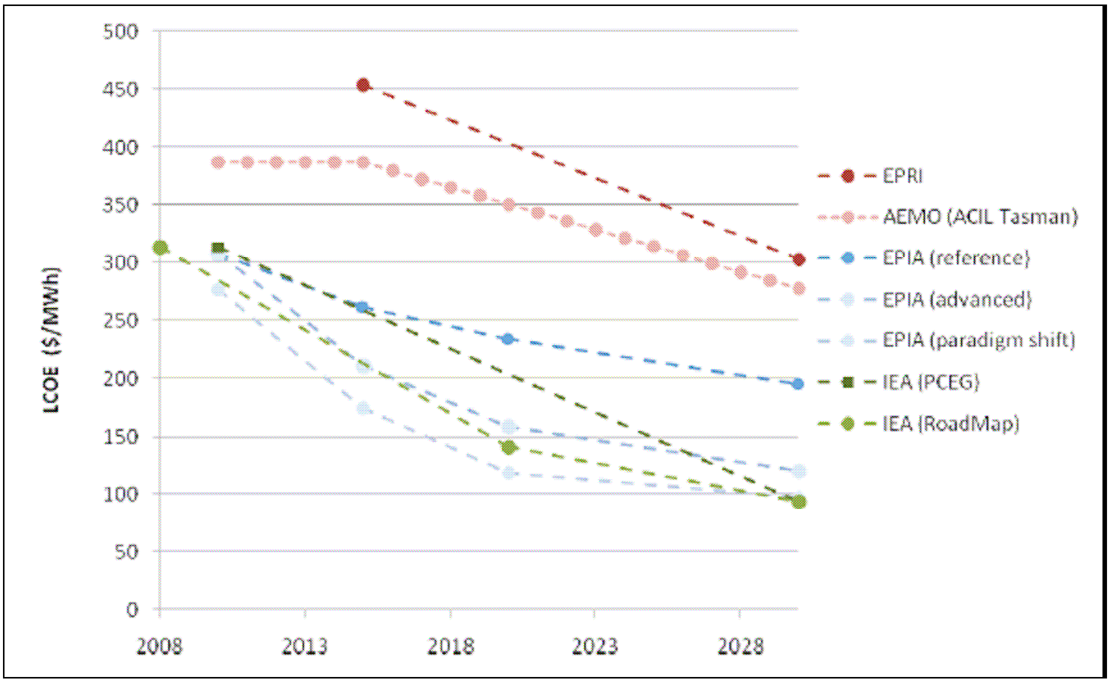
[286] Another form of energy production is the Ocean Thermal Energy Conversion. These systems convert solar radiation into electricity. The thermal gradient between surface water and deep water is used to drive a power-producing cycle. Here, 20 °C are needed to make a systems efficiently so equatorial regions are most suitable, see Westwood (2004).
[287] See 'Chile's Solar Energy Potential Could Make It "A Global Leader", James Fowler, January 7th 2010.
[288] OpenEnergyInfo, Chile-GTZ Public Properties for Grid-connected Renewable Energy Projects, available on: http://en.openei.org/wiki/Chile-GTZ_Public_Properties_for_Grid-connected_Renewable_Energy_Projects. (accessed March 23rd 2011).
[289] Ortega et al. (2010).

Figure 17: Solar photovoltaic cost projections (Irradition 2445 kWh/m²/year)



Source: Hearps/McConnell (2011), p. 3.

However, a number of barriers make the implementation difficult, which often includes the lack of public awareness, high initial costs, large quality differences and often missing skilled labor to set up and maintain the equipment.[290] Another application is the solar space heating and cooling mostly used in office buildings. A new support scheme, introduced in August 2009, allows tax credits for construction companies implementing solar thermal systems.[291] The solar radiation is highest in the northern Chile, but the monthly daily mean radiation in Santiago, a preliminary study shows values above 4kWh/m² in the SIC grid.[292]

4.6.9. Indigenous Resources

The first part will analyze the resources of fossil fuels left that can be exploited in Chile. Oil imports account for 98 percent of its overall primary oil consumption. By 2006, the country had 150 million barrels (equivalent 20 Mt) of proven oil reserves, which allowed a production of approximately 15,000 barrels/day (b/d),[293] while consumption was 238,000 b/d (or 11.7Mt). The domestic production comes from wells located in terra firma and from offshore source in

[290] IEA (2009), p. 162.
[291] Chile: Tax Rebate for Construction Companies, Global Solar Thermal Energy Council, December 22nd 2009. available: http://www.solarthermalworld.org/taxonomy/term/881?module=browse (accessed April 18th 2010).
[292] Ortega et al. (2010), p. 2523.
[293] In 1990 production was at 33,000 barrels per day of own production, for more details see DOE (2002).

the Magallanes regions.[294] Considering the imports, which have increased steadily in the last two decades, the production has went down even on a very low level, see figure 19 in appendix. Chile has three crude oil refineries, which are operated by the governmental owned National Petroleum company or its subsidies with a total refining capacity of 204,849b/d of crude oil in 2000.[295] The National Oil Company (ENAP) has explored more than fourteen new oil wells between 2006 and 2008. Therefore, special operation contracts were signed in order to stimulate private investors in new exploration sites.[296]

The country has to import 75 percent of its natural gas, where the indigenous resource are mainly based in the Magellanes region in the very south. Estimated resources are at 45 billion cubic meters (bcm). Due to a report of the Oil and Gas Journal, gas resources are estimated with 99.11bcm by January 2006, compared to the 7.8bcm of annual consumption. Through special operation contracts new gas resources have been identified, principally based in the Magallanes region with an estimated volume of USD 250 million contributing 750.000 cubic meters a day. In spite of intentions to explore more domestic resources, success has been limited.[297] In 2006, the production has covered nearly 30 percent of the overall consumption. Due to the construction of the two LNG terminals in Quintero (SIC) and Mejillones (SING) the government has reached a lower dependency from its former solely gas supplier Argentina, improving slightly the energy mix.

The third fossil fuel coal is covered to 96 percent by imports. Domestic production exists in the Bio-Bio region, Araucania Region and the Magallanes Region. In 1999, coal reserves were calculated with 1.3 billion tons.[298] The IEA (2009) estimates the low-sulphur, sub-bituminous coal resources, predominantly located in Riecso Island and in the Magallanes Region between 200Mt and 500Mt. The import share of coal, beginning in the 1990s, has risen from about 50 to 80 percent because of decommissioning of several coal mines for reasons of low quality and energy content and the substitution of the relative cheap gas from Argentina in the mid 1990s. As consequence domestic production has declined over the last two decades,[299] see figure 21 in appendix. Through a very recent development and support of CORFO, three new mines have been identified and are under EIA, with an expected lower import dependency of 64 percent by 2012 when passing the EIA.[300] Brazil and Chile will account for the largest amount of coal imports in LA until 2035.[301]

The second part investigates other sources of energy that could contribute to the energy supply. Hydropower above 20MW counts by Chilean law as conventional energy resource. In

[294] EU/Government of Chile (2009); IEA Statistic - Oil Information 2008.
[295] DOE (2002).
[296] CNE (2008), p. 84.
[297] EOE (2008); IEA (2009) confirms the resource estimates between 42 and 98 billion cubic meters.
[298] DOE (2002).
[299] Ortega (2010), p. 2515.
[300] CNE (2008), p. 85.
[301] IEO (2010).

2008, about 4,950MW of hydropower were installed. The potential is estimated with 20,000MW, so hydropower generation could expanded four times the current installed capacity. In the SIC, hydropower has always been the largest power source, accounting for more than the half of the electricity generation.[302] When basins are emptying or water flux is low due to seasons of low precipitation, hydroelectricity production might be negatively affected and cause energy shortages when reserve capacity is too low. Currently 10,500MW of large and small hydro projects are under EIA, the debate about the HidroAysen project with 2,759MW and the Río Cuervo hydro project of 1,000MW. The EIA of the Río Cuervo project has been rejected in on February 2nd 2007.[303] Critics regarding the HidroAysén have been expressed in different ways. The location of the project is in a seismic active area which would add up an additional risk, which might cause a flood harming the National Park of San Rafael.[304] Furthermore, there has to be built a transmission line of 2,000 kilometers in order to transport the energy to the end-user, which is principally the MR.[305] After the first EIA, that had more than 2,000 points of complaints, the final review with 10,000 pages, which still had about 1,000 points unclear by October 2009.[306] In December 2010, the project was again postponed for reasons, that EIA for the transmission line has not begun, where final decision is not expected before April 2011. The positive decision for the investors was made on May 10th 2011, when EIA was approved for the project, in spite of massive protest in the population, while the EIA for the transmission line remains unclear.[307] By June 15th 2011, there has been no EIA turned in to the responsible authorities for the transmission lines.[308]

Another indigenous energy source is the energy production from waste. The MR alone has 6.5 million inhabitants and the production of municipal waste per capita has increased from 0.8kg(cap/day) in 1995 to about 1.2kg(cap/day) in 2008, with a total generation of about three million tons a year. Most of the garbage is deposited in three large landfills. Energy can be produced of the landfill gas emissions by collecting the gas or burning it to produce electricity or heat. The recycling rate of about 14 percent is only achieved due to the separation of paper, cardboard and metals from the informal sector.[309] This makes the use of organic waste for biogas production, which is still the largest share in household waste, very difficult. Another possibility is power generation through incineration. In this process waste is directly burned to produce electricity. Problematic in this context is the high organic share of municipal waste and the problems arising from flue gases and ashes, especially for the

302 IEA (2009); CNE (2008), p. 93.
303 Servicio de Evaluación Ambiental, www.seia.gob.cl.
304 Hughes (2010).
305 Helmke (2007), p. 14.
306 Maxwell (2010).
307 Reuters (2011).
308 Personal interview, Sylvia Hormazábel, June 24th 2011, Servicio de Evaluación Ambiental, Santiago de Chile.
309 Bräutigam (2010).

hazardous substances, where regulation have to be set up.[310] Respectively, regulatory framework has to be established in order to guarantee an adequate disposal of ashes, etc. Another co-benefit can not be utilized as there exist no central district heating system in Santiago to make use of the heat generated in the incineration plant.[311] CORFO estimates the potential of landfill including the agricultural waste of 600MW.[312]

4.6.10. Nuclear Power

As costs of fossil fuels went up in the recent years, the Chilean government has intensified the investigation about the use of nuclear energy for generating electricity. The responsible authority is the National Commission of Nuclear Energy, created in 1964, coordinated by the Ministry of Mining. It is a public service, that functions within the legal framework of law 16,319 and was established to "attend problems related to the production, purchase, transfer, transportation and peaceful use of atomic energy and of the fertile, fissionable and radioactive materials."[313] Under the former president Bachelet, there was an open positive debate on this issue and the Chilean Senate has begun to visit plants in France and Russia. There has been formed a Energy's Nuclear Power Advisory Group in 2008, which "acts as an advisory body for the incorporation of nuclear power into the Chilean energy matrix."[314]

If the nuclear option is considered, the first kWh of nuclear energy is not to be expected before 2020 to 2025 at the earliest. A nuclear plant of 1,000MW or more, which is common size, would cause a major disturbance or high inflexibility in case of plant breakdown. This in a system of less than 4,000MW installed capacity, like the SING or 11,000MW in the SIC could cause major problems. In case insufficient water provision for cooling in a region with constantly high temperatures in the north or low precipitation, as currently in the central region, the plant is running on low generation capacity and would affect severely the stability of the grid.[315] Furthermore, other problems occur such as a larger backup capacity would be required and there is so far no definite solution for the nuclear waste "disposal" the cost for decommissioning plants and the capacity building to establish a regulatory framework.[316] Additionally, the National Commission of Nuclear Energy exist since 1964 with their annual

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[310] As comparison, in Germany incineration of ordinary domestic garbage is only allowed with organic waste share lower five percent, reference Currenta plant visit in November 2010.

[311] Gebremedhin et al. (2009).

[312] http://www.investchile.com/opportunities/renewable_energy/renewable_energy/renewable_energy_in_chile, (accessed on May 5th 2011).

[313] http://www.cchen.cl/.

[314] CNE (2008), p. 68.

[315] In France, that has high nuclear electricity generation, would suffer quite often from energy scarcity, but covered by the interconnected grid of Europe in order to avoid blackouts. In Chile there has not even reached an interconnection between the two large systems of SIC and SING, neither a connection to neighboring countries.

[316] IEA (2009), p. 68.

budget, having not produced a sole kWh of electricity after more than 45 years since its existence.[317]

According to the former energy Minister Tokman, said, that in Chile the legal and regulatory gaps are to large for an use of nuclear technology, in accordance with the IEA, that earliest in 15 years the country can overcome the hurdles in framework.[318]

As with the nuclear catastrophe in Japan this year, President Piñera announced in a TV interview the great potential of renewable energies and declared that Chile will do not construct neither plan to construct a nuclear plant in his term in office.[319] Concluding, nuclear energy in a seismic active region, with insufficient knowledge of the technology, insufficient regulatory framework and the incalculable follow-up costs, like that caused in the Japan catastrophe, this energy form is not considered adequate to diversify the Chilean energy matrix.

[317] The first sarkophag of the Tschernobyl reactor has to be renewed after 25 years of use. The new one is expected to function for another 50 to 100 years with an estimated 1,6 billion USD before new investments have to be done for the next 1000 years or more; http://www.n-tv.de/politik/Ex-Direktor-von-Tschernobyl-warnt-article3057661.html, accessed April 1st 2011). The FAZ (2011) reports investments of USD 940 million for an estimated durance of 100 years. Out of these the international community has 'donated' USD 740 million.

[318] Reuters (2010).

[319] http://www.mefeedia.com/watch/37217167 (accessed March 26th 2011); own translation.

5. Recommendations and Outlook

Chile has reached, what serves for many countries in Central and South America, a striking example of sound policy making with high economic growth in a stable political environment. For its merits, it became a OECD member in January 2010. This work has shown, that in spite of very limited indigenous resources, the country has performed well in terms of economical development and poverty reduction. In this context cities have played a vital role in the development and progress of the country.

Chile is a highly urbanized country, with 40 percent living in the Metropolitan region and 90 percent of the population living in urban areas. Therefore, the contribution of cities and their sustainable development pattern, not only the examined example of the Metropolitan region of Santiago de Chile, are significant factors in order to achieve and improve the current insecure energy situation. Cities, as shown in chapter 1, have a high correlation between the number its inhabitants and energy consumption, Urban settlements have a higher per capita consumption as rural areas, that is enable through a higher income and purchasing power people are able to buy more consumer goods, therefore, electricity consumption was in the SIC steadily higher than the energy growth. The EIU (2009) validates this observation, with having an overall average benchmark, but in energy consumption per capita and carbon dioxide intensity, the city has the worst ranking of all examined 17 cities in Latin America. Here, initial educational programs have tried to set first incentives to make people aware of their consumption habits. In order to conduct sector specific studies the principal problem to overcome are missing data sets, as necessary prerequisite. This, especially the data sets are missing or only incompletely available, so in the energy use in the residential and commercial buildings and transport energy sector. Here the potentials for energy efficiency measure were identified largest. Especially, the government should continue its efforts in promoting efficient public transport systems and on the other hand, limit the growth with disincentives of individualized passenger transport, which is the least efficient form of transport.[320] Here the five principle *comunas* of the MR are Las Condes, Vitacura, La Barnechea, Providencia and La Reina have an above average energy consumption and space use per capita. The government should initiate programs customized for this higher income class, in order to establish first green initiatives, as people are more aware of their impacts to the environment with sufficient resources to contribute as social elite with a new paradigm.[321]

The energy sector in Chile has had a strong growth trend in the recent decades. This is highly related with new demand of energy, due to estimates of the CNE (2008), in 2020 there

[320] Even in comparison of an inefficient bus in New Delhi with the latest hybrid SUV, that is less effective in providing energy services per kilometer driver or per capita, see Haas et al. (2008).

[321] Another factor is the more intense competition for land, which results in higher prices around the MR, energy production is 'outsourced' to other parts of the country, like the 2000 kilometers distant Hidroaysen project, principally contracted to fulfill the electricity requirements of the MR.

are 24,000MW of installed capacity required. Despite of a little very recent success in decoupling the economic growth from the energy demand, the government has to intensify efforts to decouple economic growth from energy consumption. This could be achieved by more, in spite of remarkable successes in the implementation of the quite broad energy efficiency program of 2005,[322] efforts in energy efficiency measures, where not yet applied and with especially sector specific targets definitions for the new energy efficiency program running in 2010-2020. Here, the government has to send clear long-term signals to investors, to attract private capital, that is urgently needed considering the large amounts of infrastructure investments that have to by realized until 2030, in order to guarantee an uninterrupted energy supply. CORFO plays an important part in supporting measures and in establishing preconditions for a good investment climate. Here, the focus should be on technologies, with large potentials and that have not been in focus and supported by the Chilean government, taking into account international developments and technological improvements and potentials for future cost reductions, as energy prices are one of the highest in the region. Here, RET represent a notably contribution in order to get the country less energy independent, considering the current imports share of around 70 percent of the total primary energy supply. The energy requirements are estimated with 24,000MW in 2020, according to a study of the CNE (2008). The installed capacity by early 2011 was around 16,000MW, so that there is an additional capacity of around 8,000MW needed to fulfill the energy requirements. The remaining gap can be fully covered by RET and energy efficiency measures. The overall RE potential is, in a conservative estimate, 15,500MW but in case of optimal utilization of RET with potential of 43,000MW.[323] Here, solar and ocean energy as well as second and third generation biofuels are not included in the potential, due to insufficient studies, missing irradiation data or difficulties in calculating the development of third generation RET like ocean energy or osmotic power. The additional potential of energy efficiency measures is estimated with 11 percent of the 2020 installed capacity or equivalent 1,600MW. In conclusion, with conservative estimates of RET implementation and utilization of the full energy efficiency potential an additional capacity of more than current capacity could be added without the nuclear power option.[324] Furthermore, three important aspects and developments have to take into consideration. RET are in an initial stage[325] of their development, in opposite to the scarce fossil fuels, that already experience these learning cost effects, etc. Second, the government should consider the negative externalities[326] when

[322] Until this year energy efficiency has not played any role in the Chilean energy policy.
[323] This estimates are a compendium of the potentials for each RET in chapter 4.
[324] It has to be stated, that some RET are intermittent tecs and need additional equipment to work as base load.
[325] Depending on the RET, but cost reduction potential is given for all form of REs.
[326] These costs are caused by a third party or a company that is not responsible to pay the negative effects like pollution, cancer or the contamination of a river that fossil fuels might cause. For example the average of the EU 27 that internalizes the costs of coal production are between 0.02 and 0.15 €/KWh, see Owen (2006).

installing new capacity. And thirdly, the potential for a new green industry could create several thousands of new employment opportunities. A typical construction of a hydroelectric facility creates between five and seven times the jobs of coal plants of equal costs.[327] In the case of China, biomass and concentrated solar power have created the highest employment with 197,000 and 117,000 per one USD billion investment, respectively.[328] This is an opportunity, especially considering a feed-in tariff in order to stimulate initial investments and feasibility studies for CSP and the so far not considered forms of energy from the ocean.

The electricity sector has the longest running electricity reform process in the world. Here, privatization and deregulation of the former governmental controlled service has benefited the consumer and the electricity companies. But, due to insufficient regulation and to the provision of financially bad equipped regulators in Chile as well as a highly inelastic demand of electricity markets, there has been formed a quite strong market concentration or a market situation with strong oligopolies.

Finally, as the most vital aspect and to be understood as general conclusion, the government has to continue[329] to develop and to establish a strategic view of energy policy. Chile urgently needs, as well with respect to the recent sharp price increases, to ensure and to cope with a comprehensive national energy policy framework for the long term, that includes strategic goals for energy policy an energy efficiency alike. The recent efforts to explore more indigenous fossil resources could serve as a transition technology in order to establish a functioning framework and a national policy for RET and energy efficiency, that could cover the energy necessities in the year 2030, under the assumption that the economy is continuing the growth path of the recent decades. The implementation would also co-benefit the 2008 program to fight climate change lower the greenhouse gas emissions and pave the way into a more sustainable future development.

The understanding the importance of urban settlements has to be implemented in a sustainable master plan not only with respect to the question of energy consumption and technological progress, but as well as in the context of a more sustainable growth with a lower energy intensity and becoming aware of the increasing importance and future challenges to of cities, where Curitiba serves a good example to follow.

In this case, the humankind can learn from the ancient Greeks and Romans that where aware of the power that is provided by the sun. If the Chilean government follows this track, energy security and the sustainable development challenge will be one of the next positive achievements of the country, serving as a model for sound and sustainable policy making for the decades to come.

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[327] Schwartz et al. (2009) for more details; In a CDEC-SIC (2010) document, that recommends plants expansion between June 2010 to October 2020, includes 3065MW of hydropower out of 3,725MW additional capacity in RET, which would result in a large job creation opportunity.

[328] Strand/Toman (2010).

[329] In this context, the CNE (2008) new guideline are an initial step to an integrated energy policy approach.

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7. Appendix

Table 2: Benefits and disadvantages of megacities

Dimension	Positive Consequences	Negative Consequences
Social	Improved health care	Spatial separation
	Better educational offers	Unequal income conditions
	Cultural variety	Higher criminality
	Political participation	Less control of governance
Economic	Expansion of infrastructure	Decline of urban buildings
	Higher income opportunities	Increased traffic problems
	Growth in productivity	More informal work places
	Technological innovation processes	Low wages for dwellers
Ecological	Less use of space per capita	Air pollution
	Public transport opportunities	Water pollution
	Efficient planning of space	Increased health problems
	(integrated) recycling cycle	(Toxic) Waste removal

Source: Adaptation to World Development Report 2003 and Kötter/Friesecke (2007).

Table 3: Current market shares and trends in OECD electricity generation for 2004 and WEO Reference Scenario projection for 2030

	2004 Generation (TWh)	Share (%)	2030 Generation (TWh)	Share (%)	Growth rates (% p.a.) 2004-2030
Coal	3842	38	5391	37	1.3
Oil	527	5	297	2	-2.2
Gas	1854	18	3345	23	2.3
Nuclear	2319	23	2382	16	0.1
Hydro	1267	13	1519	11	0.7
Combustible renewables and waste	196	2	485	3	3.6
Other renewables	115	1	1049	8	8.9

Source: OECD/IEA (2007), p. 21.

Table 4: SOS indicators and their relationships to different SOS dimensions

Indicator	Rationale for position in SOS-spectrum	Main dimension of SOS			
		Av	Acs	Aff	Acp
Simple indicators					
Resource estimates	Physical existence of resources forms the basis for potential availability. If a classification based on economic feasibility is made, then a slight shift towards affordability.	X			
Reserve to production ratios	Physical availability and consumption translated into time frame of availability.	X			
Diversity indices	Depending on the application either accessibility (fuel div., supp. Div.) or affordability (supply concentration)		X	X	
Supply market concentration	See above		X	X	
Import dependence	A large determinant in accessing resources is the fact whether these are domestic or not.		X		
Net energy import dependency	A combined measure of 2 elements related to accessibility (import and fuel diversity) will most likely end up in the same realm		X		
Political stability	The political situation (including the alignment of political orientation between supplier and consumer) is an important determinant in the access to resources.		X		
Oil price	The affordability of energy is in its strictest interpretation almost similar to its (monetary) price.			X	
Mean variance portfolio	Relates the unit generating cost (affordability) to the variance therein.			X	
Non carbon	The negative consequences of energy consumption may hinder its societal acceptance.				X
Market liquidity (CET)	The (un)willingness to trade translates to price movements and thus the affordability of energy.			X	
Market liquidity (IEA)	When defined as own consumption in relation to amount available on the market, it is an indication of the vulnerability to price movements.			X	
Energy or oil intensity	These demand-side indicators provide an indication of the potential impacts of a disruption, be it physical or economical. As such they can be placed between availability and affordability.	X		X	
Oil/energy expenditures				X	
Energy or oil use per capita		X			
Share of oil in transport sector		X		X	
Share of transport sector in total oil use		X		X	
Aggregated indices					
Jansen et al. (2004)	With fuel and import diversity at its roots, and a political stability parameter, this indicator mainly focuses on the accessibility element, although the inclusion of a depletion function introduces an element of availability.		X		
IEA's ESI_{price}	Focusing on the root causes of market power and resulting uncompetitive pricing, this indicator can be placed in the affordability quadrant. Including political stability introduces an element of accessibility to the indicator, whereas including depletion (suggested in IEA, 2004a,b,c) introduce an element of availability.			X	
S/D index	Although very elaborate, the emphasis of this indicator is on accessibility, with import shares determining the supply score, and conversion and transport included. Including demand moves introduces an element of availability/affordability, but given the weight of this element it stays predominantly access-oriented.		X		
Bollen (2008) MERGE	This function translates SOS concerns into monetary terms, and as such can be placed in the affordability quadrant.			X	
OVI (Gupta 2008)	Predominantly monetary indicators and thus affordability, but also supplier diversity, political risk and reserves i.r.t imports. Based on the weights as described in Gupta (2008), pp1206 more towards acceptability than availability		X	X	

Source: Kruyt el al. (2009), pp. 2179-2180.

Table 5: Index of market concentration for power-sector generation

Country/region	No. firms	Share of largest firm (%)	HHI	Equivalent equal-size
Argentina	38	14	0.06	16.7
California	40	23	0.11	9.1
Australian NEW	11	18	0.12	8.3
Colombia	26	24	0.14	7.1
Brazil	14	25	0.15	6.7
England and Wales	32	28	0.16	6.3
New England	16	32	0.18	5.6
Bolivia	6	26	0.19	5.2
Hungary	10	27	0.19	5.3
Peru (SICN)	8	35	0.23	4.3
Sweden	8	52	0.32	3.1
Chile (SING)	4	43	0.33	3.0
N. Ireland	4	48	0.33	3.0
Spain	8	46	0.34	2.9
Alberta	12	55	0.38	2.6
Chile (SIC)	4	60	0.43	2.3
New Zealand	6	68	0.53	1.9
Czech Rep.	6	75	0.60	1.7
Queensland	2	76	0.64	1.6
Portugal	3	93	0.86	1.2

Source: Bacon/Besant-Jones (2001), p. 348.

Table 6: Biogas plants in Chile

Name/ Location	System/Type waste	LGF application
Comuna de Teno	Residues of the wine producing industry	Electricity generation
San Felipe, V Región	Organic residues of the agro-industry	Energy generation
Coltauco, VI Región	Organic residues	Energy generation
CEPADE, VII Región	Organic residues	Energy generation
Proyecto BioEiberger: Planta AgroEnergía Los Ángeles	Organic residues	Energy generation
Energía Verde Opuntia	Organic residues	Energy generation
San Antonio biogas plant	Organic residues	Burned in flare
Quillota biogas plant	Organic residues	Burned in flare
Puerto Montt biogeneration plant	Organic residues	Burned in flare

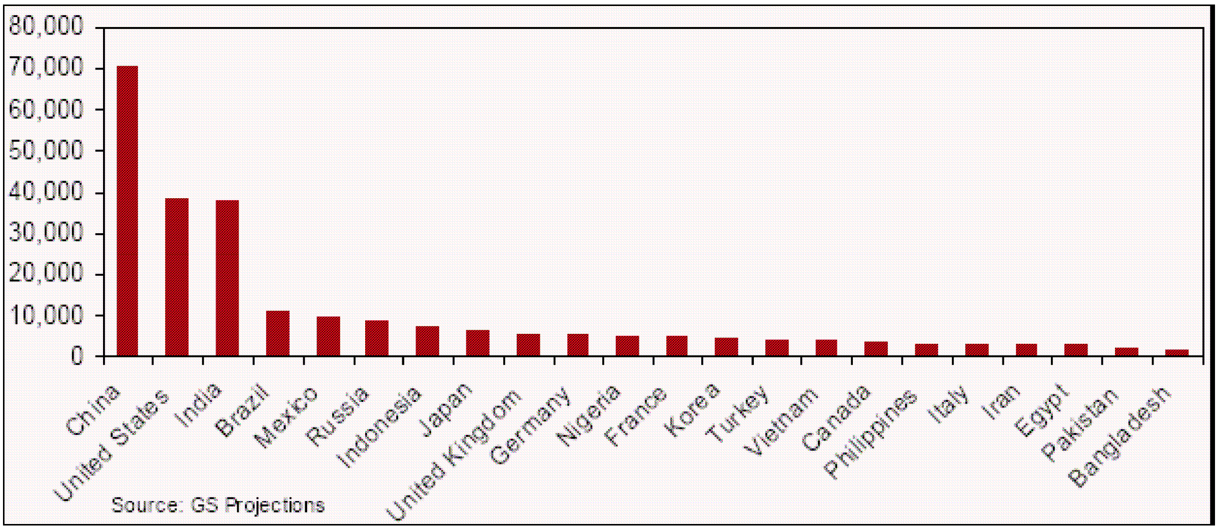
Source: BTG (2009), p. 18.

Table 7: Market barriers and implementation solutions for RET

Barrier	Key characteristics	Typical measures
Uncompetitive market price	Scale economies and learning benefits have not yet been realised	• Learning investments • Additional technical development
Price distortion	Costs associated with incumbent technologies may not be included in their prices; incumbent technologies may be subsidised	• Regulation to internalise 'externalities' or remove subsidies • Special offsetting taxes or levies • Removal of subsidies
Information	Availability and nature of a product must be understood at the time of investment	• Standardisation • Labelling
Transactions costs	Costs of administering a decision to purchase and use equipment(overlaps with "Information" above)	• Reliable independent information sources • Convenient & transparent calculation methods for decision making
Buyer's risk	• Perception of risk may differ from actual risk (e.g. 'pay-back gap') • Difficulty in forecasting over an appropriate time period	• Demonstration • Routines to make life-cycle cost calculations easy
Finance	• Initial cost may be high threshold • Imperfections in market access to funds	• Third party financing options • Special funding • Adjust financial structure
Inefficient market organisation in relation to new technologies	• Incentives inappropriately split—owner/designer/user not the same • Traditional business boundaries may be inappropriate • Established companies may have market power to guard their positions	• Restructure markets • Market liberalisation could force market participants to find new solutions
Excessive/inefficient regulation	Regulation based on industry tradition laid down in standards and codes not in pace with developments	• Regulatory reform • Performance based regulation
Capital stock turnover rates	Sunk costs, tax rules that require long depreciation & inertia	• Adjust tax rules • Capital subsidies
Technology-specific barriers	Often related to existing infrastructures in regard to hardware and the institutional skill to handle it	• Focus on system aspects in use of technology • Connect measures to other important business issues (productivity, environment)

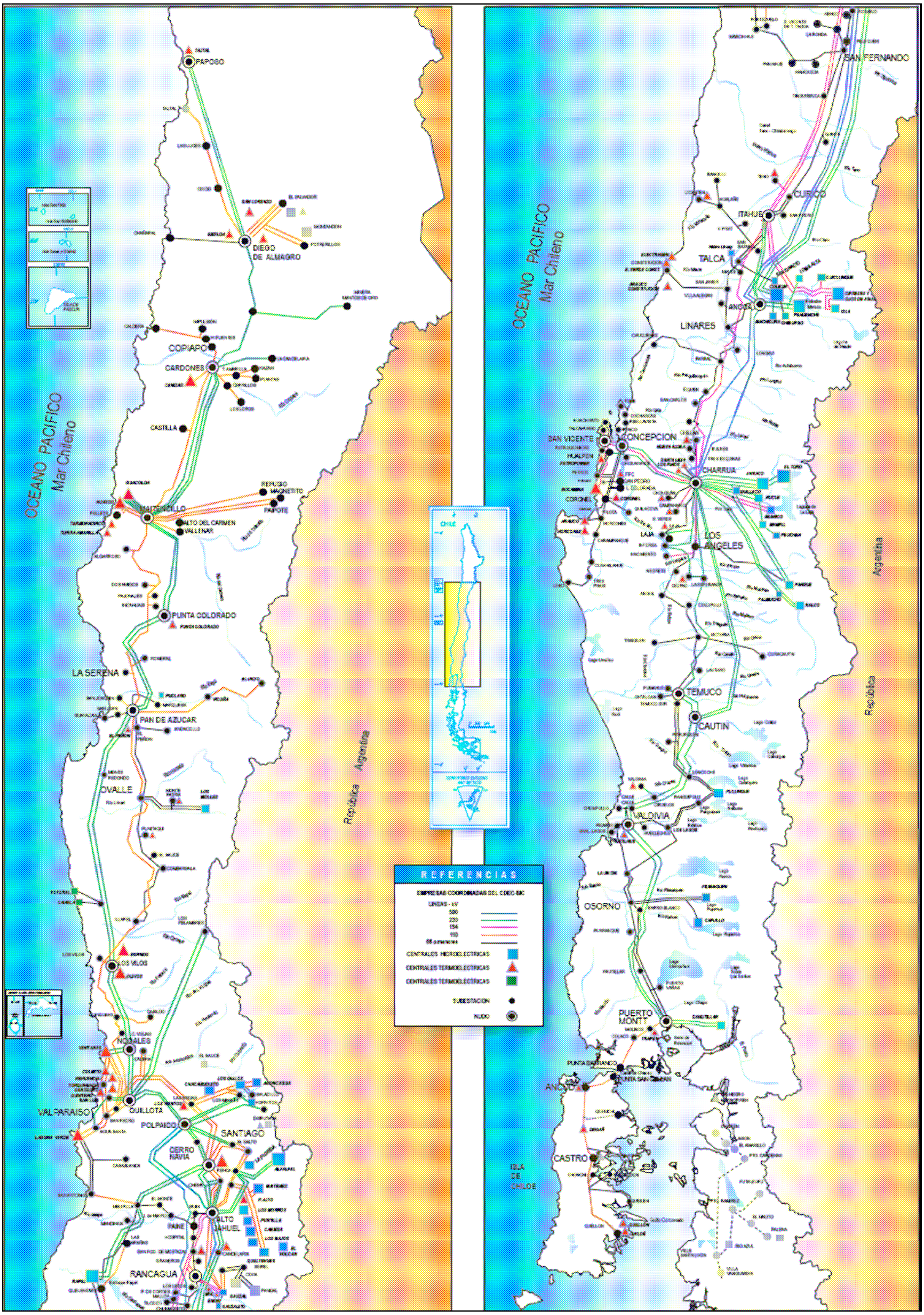
Source: Owen (2006), p. 633.

Figure 7: Expected World GDP growth until 2050 with BRIC focus



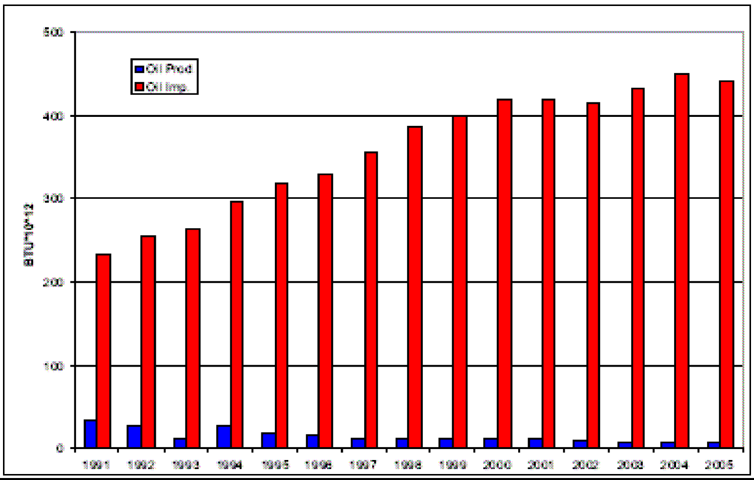
Source: Goldman Sachs (2007), p. 154.

Figure 18: SIC grid and its connection (update July 2010)



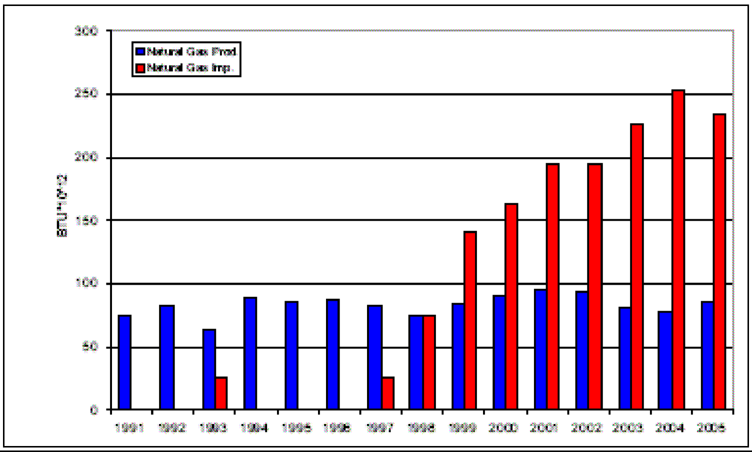
Source: CDEC-SIC (2011), (accessed April 20th 2011), (www.cdec-sic.cl)

Figure 19: Crude Oil Production and Imports (1991-2005)



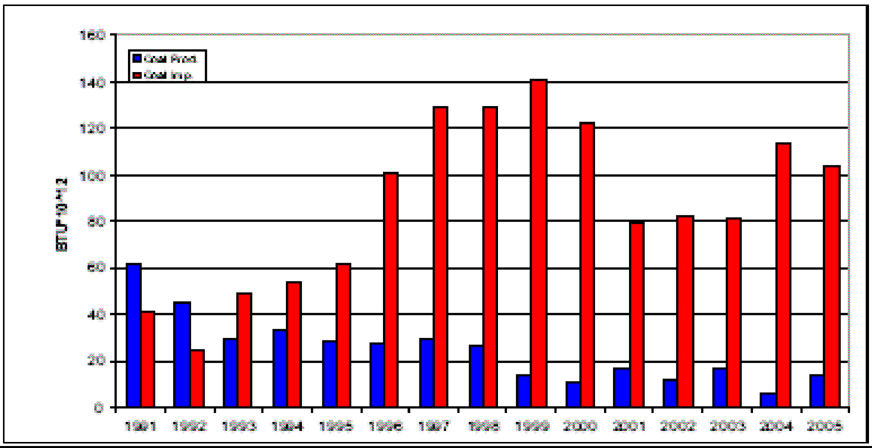
Source: Raineri (2007), p. 28.

Figure 20: Natural Gas Production and Imports (1991-2005)



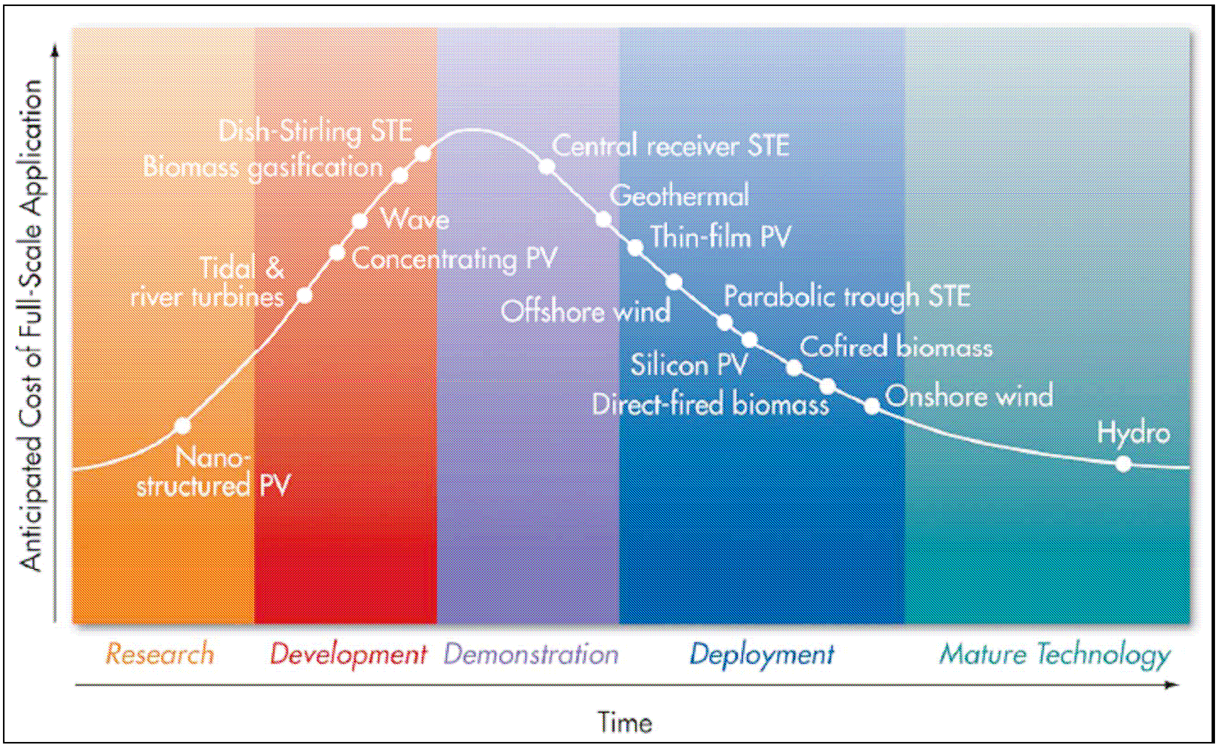
Source: Raineri (2007), p. 28.

Figure 21: Coal Production and Imports (1991-2005)



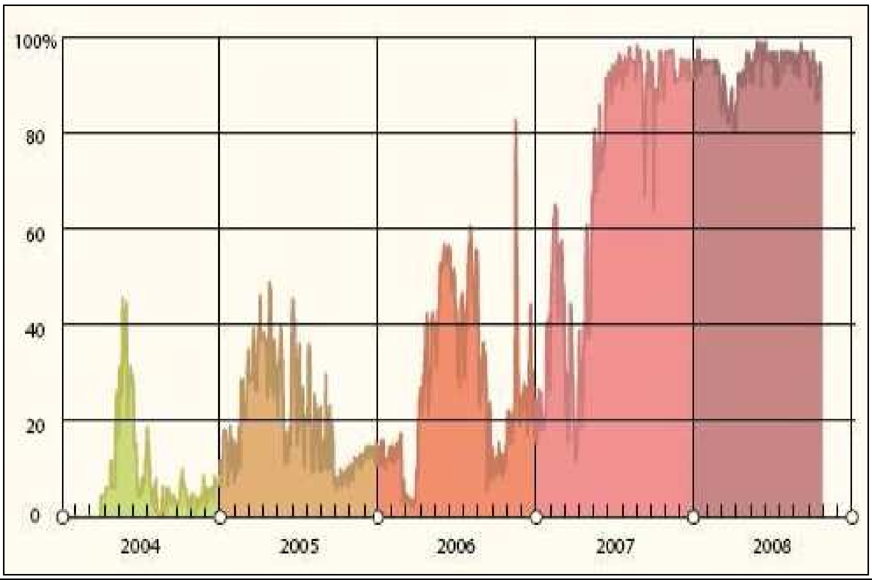
Source: Raineri (2007), p. 28.

Figure 22: Renewable technology development stages



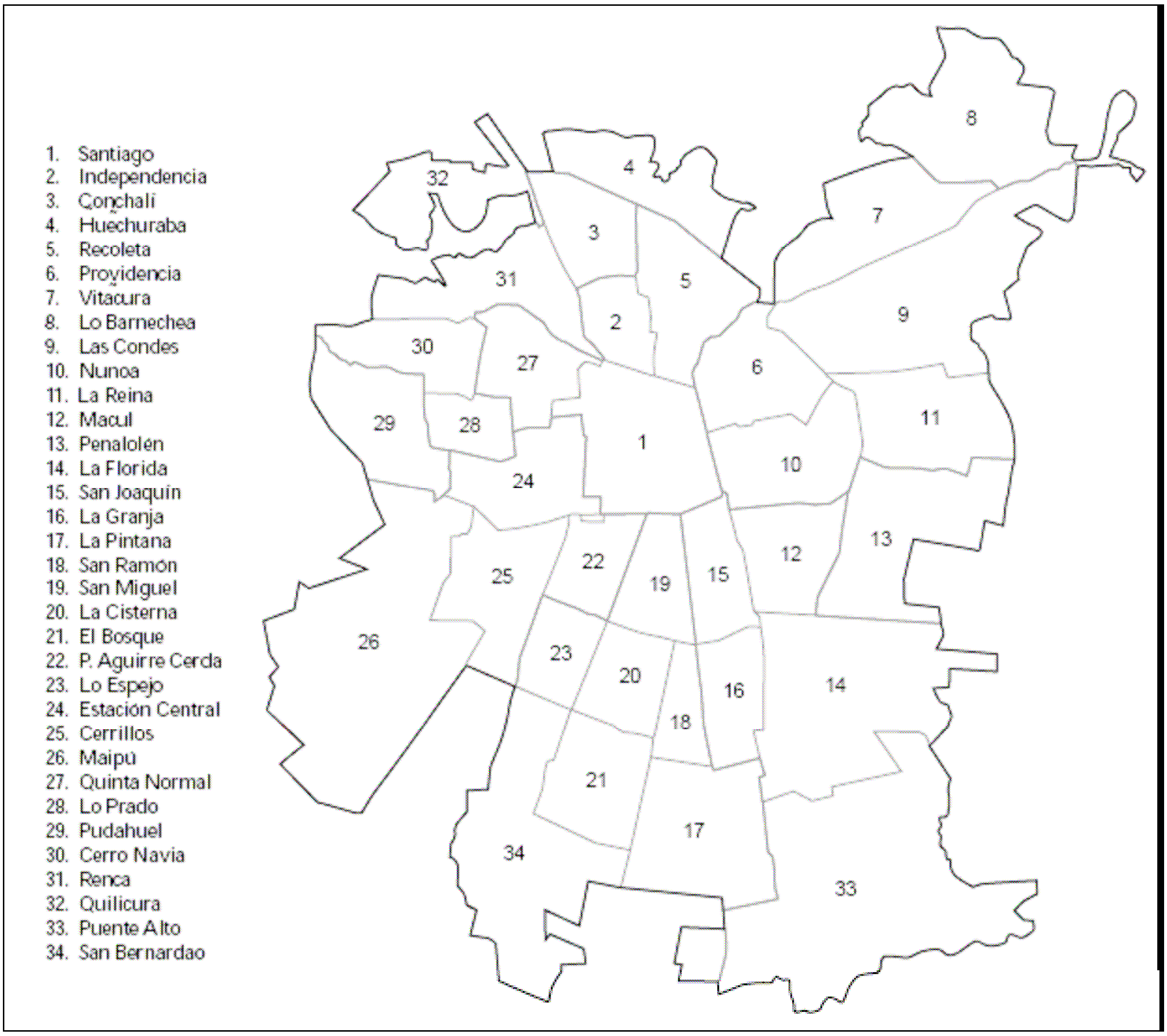
Source: Hearps/McConnell (2011), p. 6.

Figure 23: Restrictions on gas from Argentina in percent of normal requirements



Source: Méndez (2009), p. 6.

Map 1: The *Comunas* of Greater Santiago

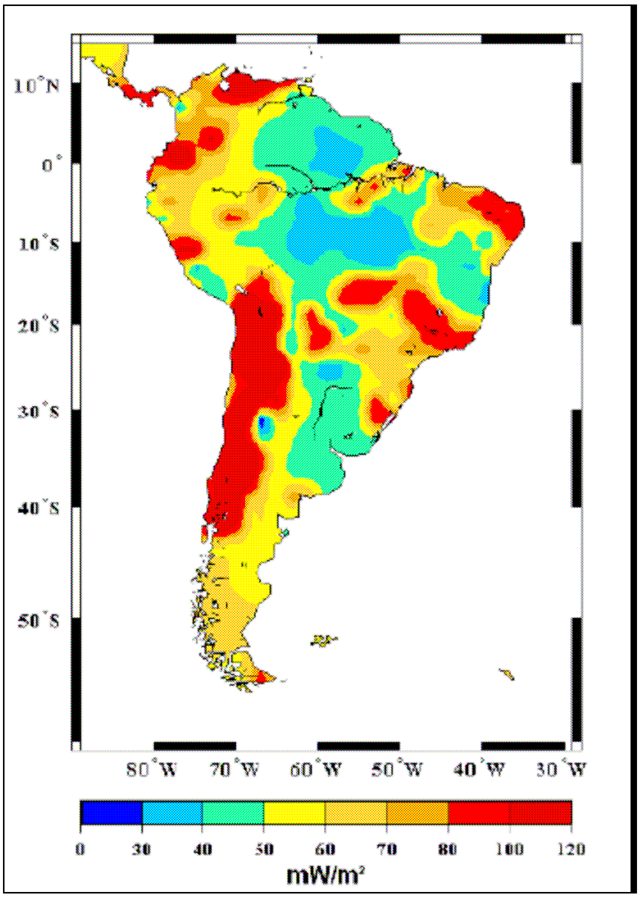


Source: Dockemdorf et al. (2000), p. 177.

Map 4: Geothermal areas in Central and Southern Chile

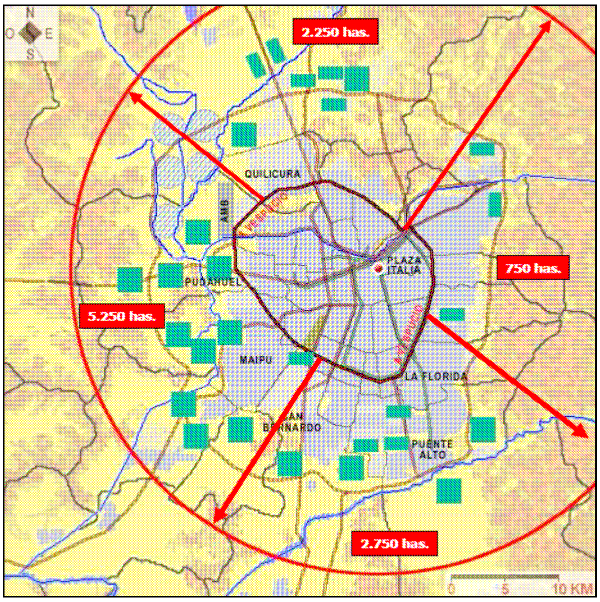
Source: Lahsen et al. (2010), p. 3.

Map 5: Heat flow map of South America



Source: Haraldsson (2011), p. 3.

Map 6: Expected Urban Expansion in 2002-2012



Source: Curuma (2006), p. 12.