GENI Global Energy Network Institute

Renewable Energy Potential of Chile

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Abstract

The Republic of Chile has energy shortages and needs energy. Key factors have contributed to this shortage throughout the past decade, including limited indigenous fossil fuels, droughts and a natural gas shortage from Argentina in 2004. The quickest and easiest path to regain the energy lost from Argentina was to resort directly to fossil fuels. Diesel and coal replaced the natural gas shortages, which not only raised electricity prices; it also raised greenhouse gas emissions due to its greater carbon footprint. In addition to energy shortages, Chile is experiencing economic and population growth. The situation that Chile is encountering is unfavorable in the direction of a world that is attempting to reduce greenhouse gas emissions with an optimism to help stop climate change. The investment in a renewable energy mix is a high priority to provide a more secure energy supply, to reduce greenhouse emissions and to supply sustainable and healthier energy.

1 Overview of Chile

1.1 Chile Background

1.1.1 Introduction

Chile, a republic located in South America borders the Andes Mountain range to the Pacific Ocean. The size of Chile is roughly twice the size of Montana at 756,102 square kilometers, however its long and narrow shape gives it a unique geography. Its length spans 6,435 km of coastline and at its widest point is 240 km wide. The climate varies upon longitude. Northern Chile is an arid region, and is the location of one of the world's driest desert: the Atacama Desert. Central Chile is a Mediterranean climate, and it is home to the majority of the Chilean population. Southern Chile is a cold and wet climate that embraces beautiful landscapes including the diverse and famous Patagonia region. The Andes Mountain range is active to over

Key	Region name	Capital
XV	Arica and Parinacota	Arica
I	Tarapacá	Iquique
II	Antofagasta	Antofagasta
III	Atacama	Copiapó
IV	Coquimbo	La Serena
V	Valparaíso	Valparaíso
VI	Libertador Bernardo O'Higgins	Rancagua
VII	Maule	Talca
VIII	Bío Bío	Concepción
IX	La Araucanía	Temuco
XIV	Los Ríos	Valdivia
X	Los Lagos	Puerto Montt
XI	Aysén del Gral. Carlos Ibañez del Campo	Coyhaique
XII	Magallanes y Antártica Chilena	Punta Arenas
RM	Metropolitana	Santiago

Figure 1: Map of the 15 regions in Chile. Note: RM is the 13th Region.

three dozen volcanoes and it supplies the origin of substantial rivers that flow into the Pacific Ocean. Politically, the country is sectioned into 15 administrative regions.

Chile is rich in natural resources such as copper, timber, nitrates, precious metals and molybdenum. It is the world's largest producer and exporter of copper; mining is a major industry and an essential part to the Chilean economy. Even though Chile has an abundance of copper and mining resources, it has limited indigenous fossil fuels. Today, the energy and electricity for the 16,888,760 million population of Chile primarily depends on imported fossil fuels.[1]

1.1.2 World Organization Affiliations

Chile has access to various fossil fuels due to their economic relations with other countries, primarily with Argentina. Chile is a member of several worldwide organizations that include, but are not limited to, the Asia Pacific Economic Corporation (APEC), Organization of American States (OAS), World Trade Organization (WTO), the Inter-American Bank Development (IADB), Old Dominion Electric Corporative (ODEC), and Organization for Economic Cooperation and Development (OECD).[2] The membership to these organizations allows Chile to collaboratively seek solutions, create policies, as well as supplement growth and prosperity. Sustainable development and growth for Chile is more accessible with these ties to international organizations and other countries. The Organization of American States works to achieve sustainable development and an environment. Chile is in the process in becoming a member of OECD, and new public-policy expertise will be given access to Chile once they become an official member.[3] Overall, the integration of international relations enables Chile to become more accessible to foreign partnerships and economic investment.

1.1.3 Government Industries

The Chilean government consists of 17 ministries including the Ministry of Health, Justice, Economy, Agriculture as well as Energy. The National Energy Commission (CNE) is a branch of the Ministry of Energy. Other institutions that are linked to the Ministry of Energy include, but are not limited to, the Superintendency of Electricity and Fuels (SEC), National Environmental Commission (CONAMA), Panel of Experts of the General Law of Electricity Services, and Economic Load Dispatch Centers (CDEC). There is an approximated 70 companies that participate in the electricity industry that consist of generation, transmission, and distribution companies.[4]

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[1] "Chile." *The World Factbook*. Central Intelligence Agency, 5 July 2011 https://www.cia.gov/library/publications/the-world-factbook/geos/ci.html>.

[2] "Global Energy Network Institute." http://www.geni.org

[3] "Chile." *International Energy Agency (IEA)*. 2011. http://www.iea.org/

[4] Behnke, Dr. Rodrigo P. *Renewable Energy in Chilean Electricity Market*. http://www.cne.cl/cnewww/export/sites/default/05_Public_Estudios/descargas/ERNCMercadoElectrico_Bilingue_WEB.pdf

1.2 Background with Renewables

1.2.1 Hydropower

Chile has a prolonged history with hydropower and it is a still a major source of energy for the country today. In 1897, the Chivillingo Hydroelectric plant was the first hydropower plant to be built in Chile. The plant initially supplied energy for a local coalmine as well for the small city of Lota. The Chivillingo power plant halted production in 1990 and it is now a national monument.[5] Hydropower has developed since the Chivillingo plant was first built. Figure 2 demonstrates that hydropower has continued to increase production throughout the past decades. Today, Chile has abundant types of hydropower technologies including small hydropower plants, large hydroelectric reservoir power plants and run-of-river hydroelectricity. As of 2007, approximately 38% of the electricity supply was derived from hydropower.[6] Hydropower has supplied Chile with an abundance of energy throughout the past century, however environmental controversy and climate change does not favor this renewable energy as a future primary energy supply for Chile.

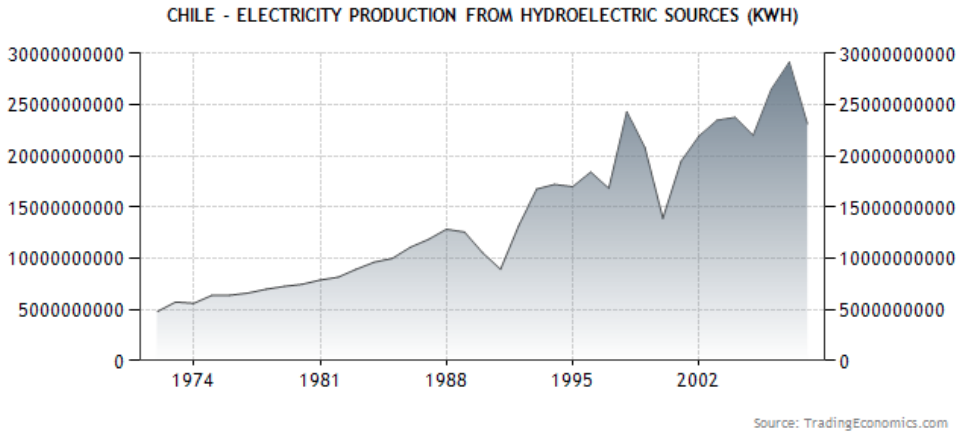

Figure 2: Electricity production from hydroelectric sources, 1974-2002

1.2.2 Wind and Biomass

Chile has limited wind and biomass development which is currently supplying less than 1.5% of the total energy supply. Several corporations and organizations are attentive to the Chilean renewable energy supply. One of which is the Center for Renewable Energy (CER). CER is a Chilean organization that works to develop renewable energy throughout Chile. Their mission is to "to ensure optimal participation of renewable energies in the energy matrix of Chile to contribute to the sustainable development of the country."[7]

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[5] Sulzberger, Carl. "Early Hydroelectric Power in Chile." *IEEE Power Engineering Society*. IEEE. Web. http://www.ieee.org/organizations/pes/public/2008/jul/peshistory.html

[6] *CNE – National Commission of Energy*. Government of Chile. http://www.cne.cl/

[7] *CER - Center of Renewable Energy*. Government of Chile. http://cer.gob.cl/

Other worldwide companies have also taken interest such as an Australian based company, Pacific Hydro, and a Spanish based company, Endesa, to install wind farms and hydropower facilities. It is proposed that Chile should begin to urgently explore and consider the massive potential of solar, wind and possible geothermal and ocean energies in order to tranition towards a carbon-free country.

1.3 Importance of Renewable Energy

Renewable energy is an important aspect of the 21st century as part of the "green revolution," which has evolved into a worldwide phenomenon. Renewable energy will significantly reduce the amount of greenhouse gases into the atmosphere, be more sustainable for the environment, provide a constant energy supply without drastic price fluxes, and it will take the dependence off of imported fossil fuels that can be expensive. Renewable energy, such as solar, wind, geothermal and hydropower release nominal carbon emissions and have a limited impact on the environment. These abundant renewable energies are the ideal energy supply for the world. Renewable energies decrease the amount of greenhouse gases, pollutants, ecological footprint and are a major step towards sustainability.

1.4 Possible for Chile in 10 Years?

To have the Republic of Chile a 100% renewable energy country by the year of 2020 is a difficult challenge worth contemplating. Al Gore stated in his speech in 2008, *"To those who say ten years is not enough time, I respectfully ask them to consider what the world's scientists are telling us about the risks we face if we don't act in ten years. Ten years is about the maximum time that we as a nation can hold a steady aim and hit our target."*[8] Vice-President Gore suggested that America should move towards 100% renewable energy in 10 years. Climate change is impacting our earth , and humans fossil fuel usage are causing this. Besides Mr. Gores critical remarks for American renewable energy, is it possible in Chile?

1.5 Concluding Thesis

A strategic energy plan for Chile is necessary in order to ensure that it transitions from thermal power plants to renewable energy power plants. In order to provide the most secure and diverse energy supply, the system will run most efficiently between equal government and private industries. Chile's current agenda includes the challenge of environmental objectives, energy security, and balancing economic growth.[9]

Figure 3 shows that by 2030, only 8.5% of the energy capacity supply is projected to come from renewables in the trajectory that Chile is currently going with renewables. This is a very low percentage considering the 26-year time span (beginning in 2004). Chile could be headed towards a more aggressive commitment of installing greater renewable energy capacity considering the potential that it is available.

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[8] Gore, A., Jul 17, 2008, "A Generational Challenge To Repower America by Al Gore", Al Gore.org, http://www.algore.org/generational_challenge_repower_america_al_gore

[9] *Chile Energy Policy Review 2009*. Paris: Organization for Economic Co-operation and Development / International Energy Agency, 2009. Print.

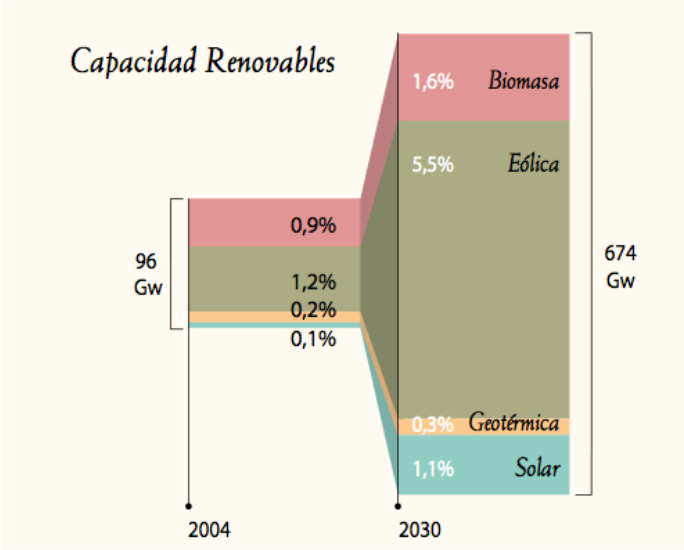

Figure 3: Renewable capacity 2004 compared to predicted 2030

2 Chile's Current Use and Emissions

2.1 Energy Demand

The energy deficit during the past decade, primarily due to the shortage of natural gas from Argentina in 2004, raised several proposals to make up for this energy shortage. Not only has the shortage of natural gas caused concern to the energy sector in Chile, there have been droughts in 1998-1999 and 2007-2008 that have had a impact on the hydroelectric supplies. In order to quickly regain the lost supply, various implications transpired: diesel-fired generation, switch to diesel oil from natural gas, flexible use of water in reservoirs and reductions in transmission voltage.[10] There have been suggestions such as importing natural gas from Indonesia, building nuclear power plants and building additional hydroelectric power plants in order to increase the energy supply.[11] Due to the potential of further oil, gas, coal and water shortages in the future, renewable energy should be seriously considered to replace these shortages rather than the installation of new thermal plants.

[10] *Chile Energy Policy Review 2009*. Paris: Organisation for Economic Co-operation and Development / International Energy Agency, 2009. Print.
[11] Aspey, P., and S.M. Vinko. *Expedition Proposal to the Atacama Desert, Chile*. Publication. 11 Feb. 2008. http://renovables.pbworks.com/f/proposal.pdf

The electricity demand is projected to increase an average 5.5%-6.5% per year from 2008-2025. The national system of electricity includes 31 generating companies, 5 transmission and 34 distribution firms -- to a total of 70 companies.[12] Hydropower accounts for the majority of electricity, however coal, gas and oil necessitate the remaining amount of electricity generation. In figure 5, even though hydropower constitutes a considerable amount of electricity generation, it accounts for a very small portion, approximately 8%, of the total primary energy supply.

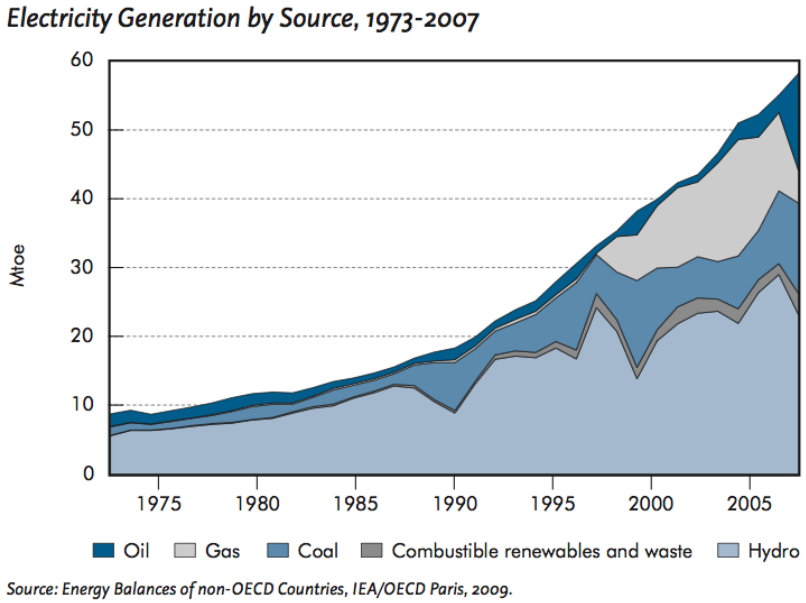

Figure 4: Electricity generation by source, 1973-2007

2.1.1 Energy Sources

Sources of the current energy demand include coal, oil, gas, combustible renewables (biofuels) and waste, hydropower, wind and minimal electricity trade. See figure 5. Chile imports 80% of its oil, gas and coal. The majority of the natural gas comes from Argentina. Imports of natural gas to Chile drastically decreased in 2004 due to Argentina's own energy shortage. This impact can be observed in figure 4. In 2009, Chile began importing liquefied natural gas from Argentina.

In 2007, Chile imported crude oil at a rate of 230,000 barrels/day -- primaril from Brazil, Ecuador, Angola, and Colombia. They imported 5.8 million tons of coal predominantly from Colombia, Indonesia, Australia and Canada.[13]

[12] *CNE – National Commission of Energy*. Government of Chile. http://www.cne.cl/

[13] *Chile Energy Policy Review 2009*. Paris: Organisation for Economic Co-operation and Development / International Energy Agency, 2009. Print.

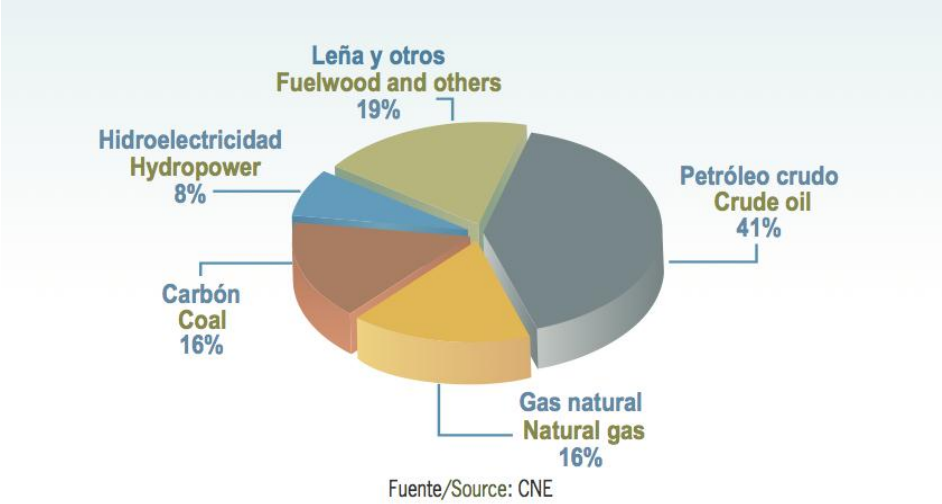

Figure 5: Primary energy supply, 2007

2.1.2 Energy Demand

In 2008, Chile consumed 56.35 billion Kilowatt-hours of electricity, 7.379 million short tons of coal, 297.65 thousand barrels of oil per day. The total primary energy that Chile consumed in 2008 was 1.215 quadrillion Btu.[14] Chile has approximately 13,000 MW installed power capacity, which is expected to rise 6% annually and may increase to 8%.[15] Chiles electricity generation is consumed and distributed throughout various sectors including, transportation, commercial, residential, industry and mining. Alone, the mining and industry sectors consume 68% of the total electricity generation. See figure 6.

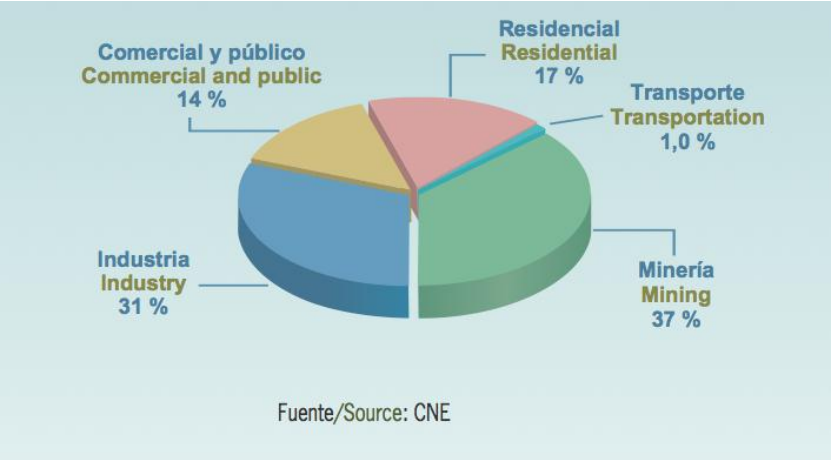

Figure 6: Electricity consumption by economic sector, 2007

[14] "Chile." *EIA*. U.S. Energy Information Administration, 30 June 2011. http://www.eia.gov/countries/country-data.cfm?fips=CI

[15] Cruz, J., M D Thomson, and E. Stavroulia. "Preliminary Site Selection-Chilean Marine Energy Resources." Garrad Hassan, 15 May 2009. http://www.cne.cl/cnewww/export/sites/default/05_Public_Estudios/descargas/estudios/texto10.pdf

2.2 Energy Policy

Chile's energy policy for the past 30 years has been *"founded on the principles of free market competition between private companies, regulation of natural monopolies and limited role of the state…"*[16] The premise of Chile's energy policy consists of competitive markets between private corporations of which there is minimal contributory role from the state.[17] The transition from state to private industries began in the early 1980's under the 1982 General Law of Electric Services. The law proclaims, *"recognized generation, transmission and distribution as separable activities; introduced a pool-type market in generation and third-party access to the transmission network; and set up a system operator to co-ordinate the operations of competitive generators*." In 1998, the last state utility was sold. The energy sector was also founded on, *"to rely competition between privately owned entities wherever possible; to regulate where it is not; and to limit the role of the state in entrepreneurial activities."*[18]

2.3 CO_2 Emissions

The dependency on fossil fuels for energy has steadily been increasing since the 1980's. Oil, in particular has nearly tripled. Renewable energy is almost absent on the graph and hydropower consists of less than one-ninth of the total primarily energy supply. Therefore, the large amount of fossil fuels burned correlates to a considerable output of carbon dioxide. By looking at figure 7, the transportation, energy and manufacturing industries are largely responsible for the majority of the carbon dioxide emissions. From 1984, these three industries have been steadily on the rise, resulting in increased emissions. The Kyoto Protocol is an international agreement established in 1997 that sets targets for greenhouse gases. Even though Chile signed the Protocol, it did not have an obligation to reduce their greenhouse emissions.[19]

[16]"Chile." *Global Wind Energy Council (GWEC)*. http://www.gwec.net/index.php?id=171
[17] "Chile." *International Energy Agency (IEA)*. 2011. http://www.iea.org/
[18]*Chile Energy Policy Review 2009*. Paris: Organisation for Economic Co-operation and Development / International Energy Agency, 2009. Print
[19] *Chile Energy Policy Review 2009*. Paris: Organisation for Economic Co-operation and Development / International Energy Agency, 2009. Print

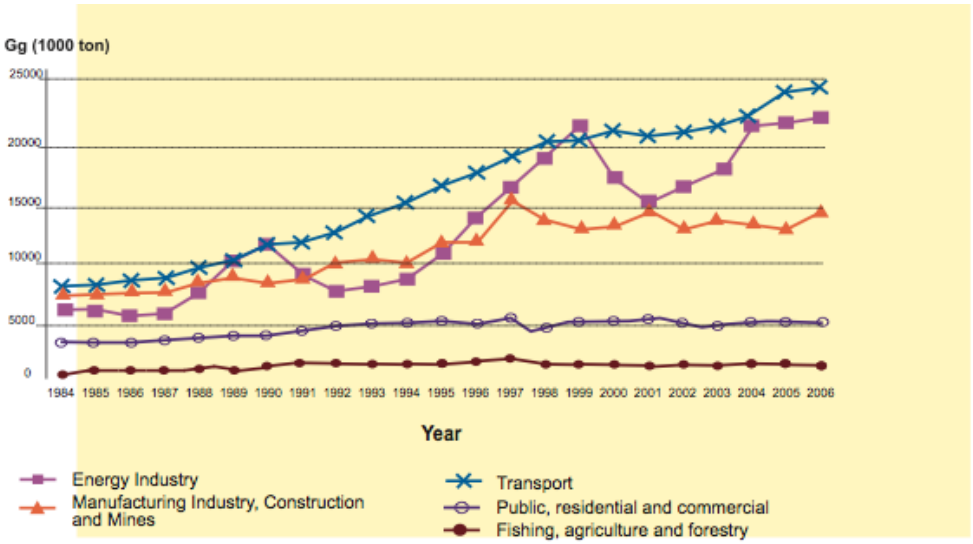

Figure 7: Carbon dioxide emissions by energy sector, 1984-2006 (in Gg)

Chile's rank in carbon dioxide emissions from the consumption of fossil fuels is 50th in the world. In 2009, Chile emitted 62.55 million metric tons of carbon dioxide. The world emitted 30,400 million metric tons.[20] Compared to the world, Chile as a country has an acceptable standing on carbon dioxide emissions, however it has a high ranking of carbon dioxide emitted per capita. 4.3 tons of carbon dioxide per person is emitted, which is the 5th highest emission rate per capita in the Americas.[21] In order to reduce the amount of carbon dioxide there needs to be strict measures and a strict emissions reduction policy.

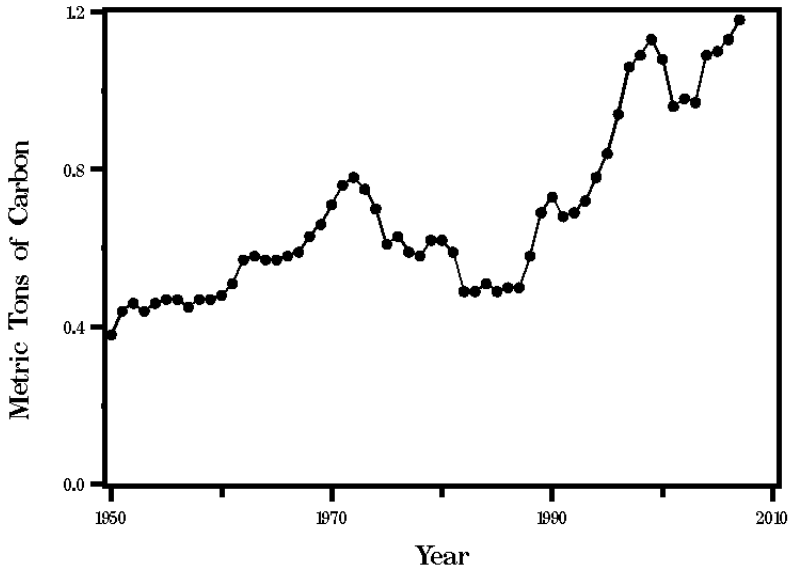

Figure 8: Carbon dioxide emissions, 1950-2006 (in metric tons)

[20]"Chile." *International Energy Agency (IEA)*. 2011. http://www.iea.org/
[21]*Santiago Times.* http://www.santiagotimes.cl/

Chile is not in alignment with the world goal to reduce carbon dioxide emissions. Since 1950, the release of carbon dioxide into the atmosphere has been increasing. Emissions of carbon dioxide nearly tripled from 0.3 metric tons in 1950 to 1.1 metric tons in 2006. See figure 8. This is the four highest emissions of greenhouse gases include electricity generation, transport, mining, and agriculture according to the National Action Plan on Climate Change (PANCC).[22]

In particular, the greenhouse gas emissions from copper production have increased annually from 2004-2008. The copper industry emissions during those years increased from 11.5 million tons to 17 million tons, despite that copper production decreased. Due to the natural gas shortage from Argentina in 2004, the mining industry adopted coal and diesel to replace natural gas. Coal and diesel have a 2x greater carbon footprint than natural gas, thus raising the amount of greenhouse gases. *"Clear future GHG emission reductions in the copper mining industry will, to a large extent, hinge on GHG-efficient grid policies."*[23]

2.4 Energy Demand in 2020

2.4.1 Population

The population and economic growth rate in Chile has been increasing. The population in Chile is increasing at a growth rate of 0.836% annually.[24] With the current population at 16,888,000 people in 2011, the population in 2020 is estimated to be at 18,208,000 people.

2.4.2 Mining

The energy consumed by the mining industries is also increasing. Chile is the world's largest producer and exporter of copper. The mining industry is a major consumer of energy and electricity. The copper industry alone consumes 11% of the total country's use of energy, 32% of total electricity and 6% of total fuel. The Northern Interconnected System (SING) supplies 73% of energy to copper mining and 66% of copper production.[25] The copper industry is continuing to grow, along with its energy demand. From 2004-2008, copper production fell 2%, however the energy consumption rose 21%.[26]

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[22]"National Climate Change Action Plan." Government of Chile, 2010. http://www.mma.gob.cl/1257/articles-49744_Plan_02.pdf

[23]*Ministry of Mining*. Government of Chile. http://www.minmineria.gob.cl/574/w3-channel.html

[24]"Chile." *The World Factbook*. Central Intelligence Agency, 5 July 2011. https://www.cia.gov/library/publications/the-world-factbook/geos/ci.html

[25]*CNE – National Commission of Energy*. Government of Chile. http://www.cne.cl/

[26]"Energy Consumption and Greenhouse Gas Emission in the Chilean Copper Mining Industry." *Ministry of Mining*. Government of Chile, 2008. http://www.cochilco.cl/english/productos/doc/energy_consumption_and_greenhouse.pdf

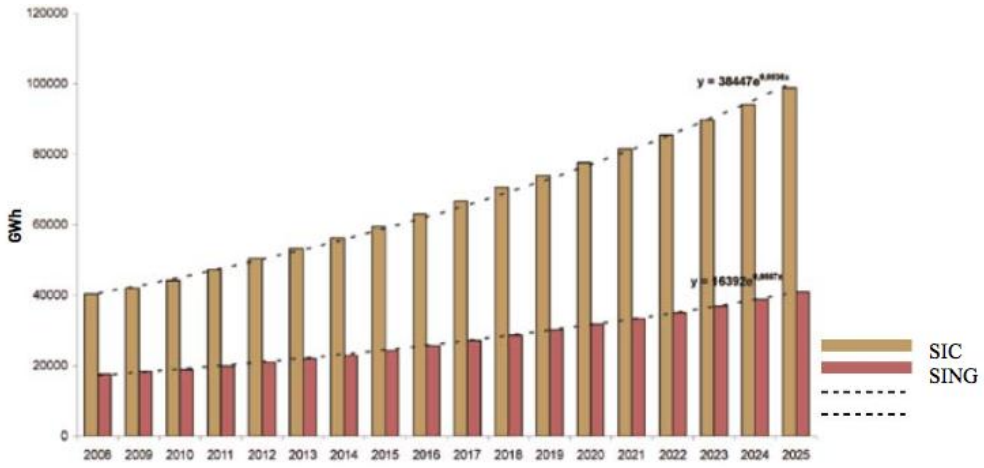
2.5 Seasonal Electricity Demands

The population increase and the expansion of the industrial sector will lead to a substantial growth in the demand for energy. The gross domestic product (GDP) is expected to rise 4.9% annually from 2002-2030. As a whole, the final energy demand is expected to rise 4% annually. 1n 2030, the final energy demand is projected to be: 41% industrial, 40% transport, 16% residential and 3% commercial. It will be essential to focus on getting renewable energy to the industrial and transport sectors as they are projected to consist of 80% of the energy demand.

The energy demand for the industrial sector is projected to grow 4.2% annually. The copper industry is the major contributor to the industrial sector.[27] Even though copper production fell 2% from 2004-2008, the total energy consumption rose 21%. The copper industry consumes 11% of the Chile's total use of energy, 32% total use of electricity and 6% of the total fuel. The SING system primarily supplies energy for copper mining and production.[28] The demand for electricity, natural gas, petroleum and diesel are all expected to increase.

The energy demand for the transport sector is expected to increase at an annual rate of 4.9% annually. Ownership of the passenger vehicle and freight transport is expected to increase.

The energy demand for the residential sector is expected to increase 2.3% annually. Electricity alone is projected to increase 5.9% per year between 2002-2030. The energy demand for the commercial sector is expected to increase 3.6% annually. Electricity is projected to increase 3.7% per year.



Source: PRIEN (2008) from FFLA report "Opciones parala Matriz Enérgtica Electríca: Insumos para la Discusión"

Figure 9: Projected electricity generation in Chile, 2008-2025

Similar to carbon dioxide trends, energy generation has also been on the rise. Figure 9 predicts the increase in electricity generation through the year 2025 for two of the electricity grids in Chile. The overall electricity demand in Chile is projected to increase at a 5% yearly rate. Electricity generation from natural gas is expected to quadruple between 2002-2030 from 3 GW to 14 GW.[27]

[27]"Chile Energy Demand and Supply Outlook 2006." *APEC*. 2006. http://www.ieej.or.jp/aperc/2006pdf/Outlook2006//ER_Chile.pdf

[28]*CNE – National Commission of Energy*. Government of Chile. http://www.cne.cl/

2.6 Electricity Grids

The Chilean electricity grid is based on four separate systems that are situated based upon the geography of Chile. Within each system there are three segments: generation, transmission and distribution. The generation segment involves the production of electricity. Thermoelectric power plants and hydroelectric power plants are examples of the generation segment. Transmission segments include power lines and thirdly distribution segments include the stepped-down voltages to where the power is consumed.[29] The four electricity grids are unbalanced and fragmented due to regional demands, the geographical distribution of the population as well as the cost limitations to connect the systems. Since the SIC system primarily depends on hydroelectric supplies, it is a concern in times of draught in order to maintain a substantial supply of energy.[30]

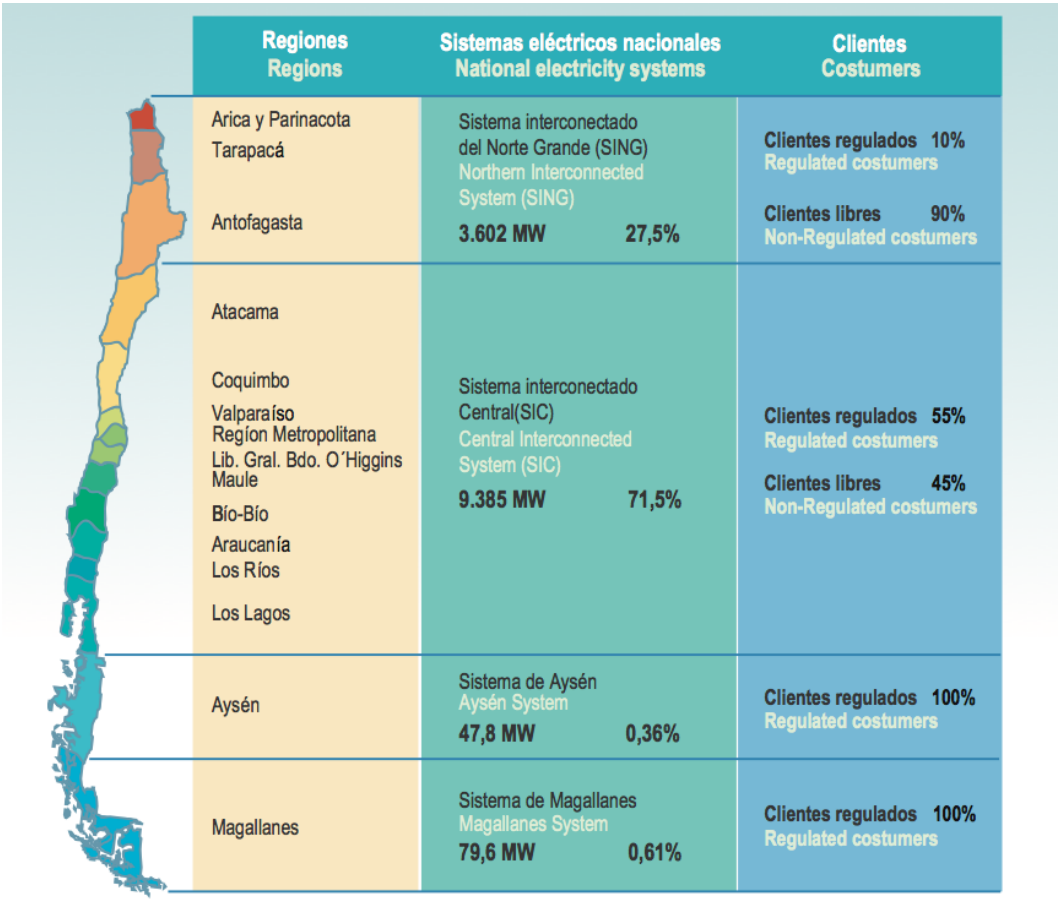


Figure 10: Grid of 4 electricity systems

[29] *CNE – National Commission of Energy*. Government of Chile. http://www.cne.cl/
[30] "Chile Energy Demand and Supply Outlook 2006." *APEC*. 2006. http://www.ieej.or.jp/aperc/2006pdf/Outlook2006//ER_Chile.pdf

The Interconnected System (SING) and the Central Interconnected System (SIC) supply 99% of the total electricity supply in Chile. SING provides 27.5% of the country's energy supply. This system supplies 90% of the total mining and manufacturing industries in Chile. Approximately 99.64% of the generation is derived from thermoelectric power and 0.36% is from hydroelectric power. SING supplies power to 270,000 clients.

SIC provides 71.5% of the country's energy supply. This system supplies 90% of the total population supplying 4,640,000 customers. 53.46% of the generation from SIC is derived from hydropower, the other half derives from fossil fuels, and 0.2% comes from wind power.

The Aysén system and Magellan system account for just 1% of the country's total electricity supply. These two systems are very small, yet they provide energy to 76,000 clients.[31]

Fuente/Source	SIC	SING	Magallanes	Aysén	Total/Total
Hidráulica > 20 MW Hydro > 20 MW	4.771	0	0	0	4.771
Combustibles Fósiles Fossil Fuels	4.035	3.589	80	26	7.729
Total Convencional Total Conventional	**8.806**	**3.589**	**80**	**26**	**12.500**
Hidráulica < 20 MW Hydro < 20 MW	104	13	0	20	136
Biomasa Biomass	191	0	0	0	191
Eólica Wind	18	0	0	2	20
Total ERNC Total NCRE	**313**	**13**	**0**	**22**	**347**
Total Nacional Total Country	**9.118**	**3.602**	**80**	**48**	**12.847**

Fuente/Source: CNE

Figure 11: Installed capacity by system, 2007 (MW)

3 Current Renewable Energy

There has been an effort towards the movement of renewable energy. On Aril 1, 2008, Law 20.57 passed requiring that from 2010-2014, 5% total energy supply sold by electricity companies must come from renewable energy. After 2014, there must be a yearly 0.5% increase. Therefore by 2020, there must be an 8% increase in the renewable energy supply. The law also addresses that if an energy provider has an installed capacity greater than 200 MW to sell, 10% of what the utility sells must be derived from renewable energy.[32]

[31] *CNE – National Commission of Energy*. Government of Chile. http://www.cne.cl/

[32] Behnke, Dr. Rodrigo P. *Renewable Energy in Chilean Electricity Market*. Rep. Commission of National Energy, Oct. 2009. http://www.cne.cl/cnewww/export/sites/default/05_Public_Estudios/descargas/ERNCMercadoElectrico_Bilingue_WEB.pdf

Figure 12 categorizes that fossil fuels, coal, natural gas and diesel represent approximately 58% of the electricity generation, and hydropower delivers 38%. Even though hydroelectricity reservoirs are not emitting greenhouse gases, this electricity generation is not considered a renewable energy source because its capacity is not less than 20 MW in size. Thus in 2007, approximately 3% of the capacity for electricity generation was derived from biomass, wind and small hydro sources.[33]

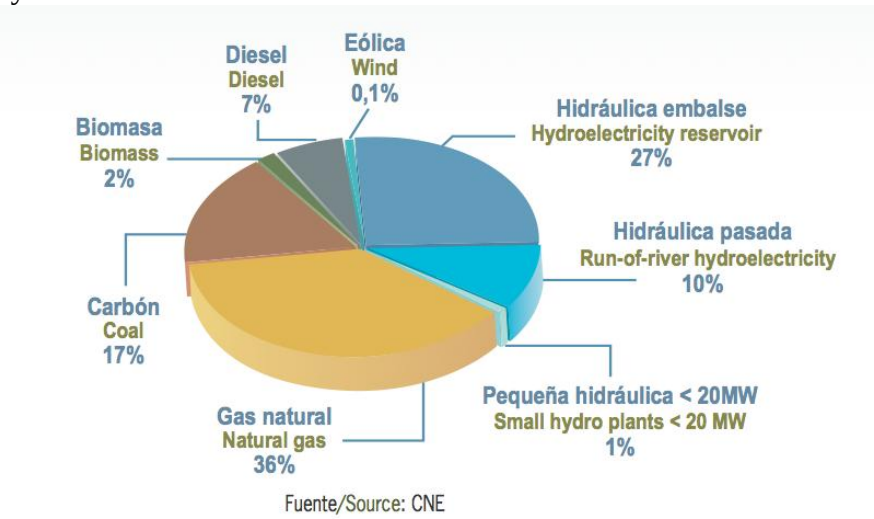


Figure 12: Installed capacity by generation, 2007

3.1 Hydropower

Hydropower accounts for nearly 38% of the electricity generation in Chile. The rivers that flow from the Andes Mountains have been dammed to create a reservoir for potential energy. The majority of the hydropower that is generated is connected to the SIC power grid.

As seen in figure 13, there are 24 hydroelectric facilities in Chile. According to figure 5, in 2007, nearly 5,000 MW of final energy demand was consumed from hydropower.

3.2 Other

Currently, there is a capacity of 561 MW of non-hydro renewable energy; of that 172 MW is wind. Wind power was first introduced in 2001 with a 2 MW farm installed in Asyén; however it was not until 2007 when Chile's second wind farm was installed. Since then, several wind farms have been installed to add to a total of six installations. See figure 13. With the addition of a strict energy policy to develop wind power and the expansion of the grid system, wind development in Chile will increase.[34]

[33] *CNE – National Commission of Energy*. Government of Chile. http://www.cne.cl/
[34] "Chile." *Global Wind Energy Council (GWEC)*. http://www.gwec.net/index.php?id=171

Figure 13: Current renewable energy generation sites

4 Renewable Energy Potential

4.1 Background

The Chilean government describes Renewable Energy as: *"Electrical energy generate through renewable primary energy sources such as biomass, wind, geothermal, solar and hydropower that has a capacity less than 20 MW."*[35] There are various objectives in order to achieve the full potential of renewable energy. Implementation about the importance of an energy mix is key to renewable energy. This includes research about renewable resources and the creation of instruments for investment than renewable energy investment.[37]

[35]Duffey, Annie. "Opportunities and Domestic Barriers to Clean Energy Investment in Chile." *IISD*. June 2010. http://www.iadb.org/intal/intalcdi/PE/2010/05903.pdf

In order to incorporate renewable energy from research into production, there are series of development stages:
1. Evaluation of Energy Sources
2. Selection of Technology and Technical Economic Evaluation
3. Financing
4. Engineering/Construction
5. Integration into the Market
6. Operation into the Market
7. Exit from the Market[36]

4.2 Hydropower

The environmental issues, economic, and political disagreement are major concerns for the hydroelectricity industry. A project called HidroAysén proposes to build four major dams in the Patagonia region. Patagonia is a remote region in the south shared by Argentina and Chile. The rivers from the Andes are short and steep that allow for ideal hydroelectric potential. This project has been approved by the state. These HidroAysén dams may put ecosystems in jeopardy and could endanger lives at the end of a 2000 km transmission line. The majority of the Chilean population disapproves of the project and there were 30,000 demonstrators protesting against the dams in May 2011. The population cherishes the Patagonia region and it is a precious natural resource.[39]

Other than the controversy by political, economical and environmental concerns, climate change is an additional factor that could affect the future of hydroelectric power. There are three water climate change concerns: the reduction of rainfall in south-central Chile, less snow pack accumulation in mountains correlates to less glacier melting and increased frequency of La Nina/El Nino ocean conditions that reduce the amount of water supply for generation.[37] It is predicted that the temperature and rainfall patterns will change over the next forty years. It is projected that there will be a temperature increase from 1°C to 1.5°C, yet rainfall will decrease by 10-15%. The drop in precipitation correlates to a decrease in the water level of dams. Droughts can produce a major impact on hydroelectric supplies that can produce energy shortages.[40]

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[36]Behnke, Dr. Rodrigo P. *Renewable Energy in Chilean Electricity Market*. Rep. Commission of National Energy, Oct. 2009. http://www.cne.cl/cnewww/export/sites/default/05_Public_Estudios/descargas/ERNCMercadoElectrico_Bilingue_WEB.pdf

[37]*Chile Energy Policy Review 2009*. Paris: Organisation for Economic Co-operation and Development / International Energy Agency, 2009. Print.

[38]"Chile Facts." *National Resources Defense Council*. May 2011. http://www.nrdc.org/international/files/chilecostofenergy_eng.pdf

[39]Barrionuevo, Alexei. "Plan for Hydroelectric Dam in Patagonia Outrages Chileans." *The New York Times*. 16 June 2011. http://www.nytimes.com/2011/06/17/world/americas/17chile.html?pagewanted=all

[40]Painter, James. "Chile Faces Climate Change Challenge." *BBC News*. 23 May 2009. http://news.bbc.co.uk/2/hi/8058080.stm

Chile has recently experienced draughts and dry spells during the summers of 2007, 2008, and 2010.[41] It is projected that in 2065, there could be as much as a 70% decrease of water in the Maipo River.[42] Water shortages are also a concern regarding thermal power plants, as water is necessary to run and cool these plants.

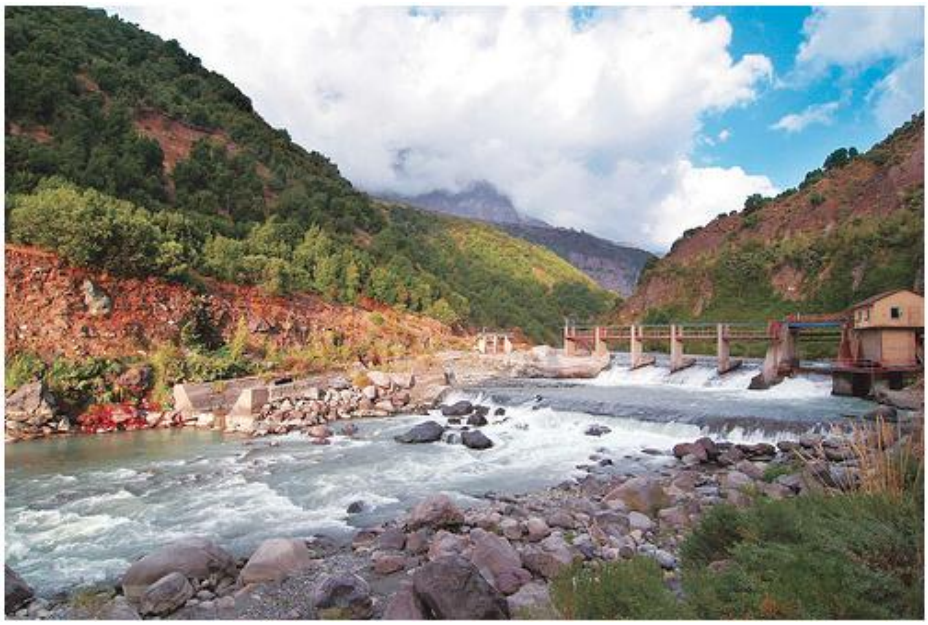


Figure 14: Coya and Pangal hydropower plant

Future hydroelectric plants need to be built with these expected climate change factors. Smaller hydropower plants and run-of-the-river hydropower plants are classified as renewable energy are a more sustainable option to produce carbon-free energy.

Hydropower is a promising renewable energy resource with various locations along Central and Southern Chile. 60 small hydro projects that are less than 20 MW are currently being studied. According to the National Energy Commission and National Irrigation Commission, rivers show potential throughout 290 channels and small dams of at least 850 MW.[44] Figure 14 is a photograph of the Coya and Pangal Hydro project that has the the capacity of 76.3 MW, which supplies 250,000 Chilean homes. It is located in the 6th region of Chile.[43]

[41]"Wind Energy in Chile-Lianquilhue wind farm." *REVE.* http://www.evwind.es/noticias.php?id_not=11306

[42]Painter, James. "Chile Faces Climate Change Challenge." *BBC News*. 23 May 2009. http://news.bbc.co.uk/2/hi/8058080.stm

[43]"Chile Projects." *Pacific Hydro*. http://www.pacifichydro.com.au/en-us

[44]"Renewable Energy." *InvestChile*. Chilean Economic Development Agency. http://www.investchile.cl/opportunities/renewable_energy/renewable_energy

4.3 Wind

Wind is produced by uneven temperature and pressure differences in the atmosphere. The motion, or kinetic energy, from the wind can be converted into mechanical energy in order to produce energy. Wind is a viable and promising renewable energy source for Chile. There are currently over 45 wind projects currently under development or being considered, and 126 MW of wind projects under construction in addition to the 172 MW that is in current use.[45]

The Global Wind Energy Council estimates that there is 40 GW, or 40,000 MW of wind potential in Chile.[46] A wide selection of locations are ideal to harness wind energy. These locations include Northern Chile, along the coast and various valleys in the regions of IV, VII, VIII, XI and XII.[45] Specific areas include the coast of Atacama, Coquimbo, Maule, Calama, and the plateaus in Antofagasta.

The installment of wind farms will significantly reduce the amount of carbon dioxide into the atmosphere. The Totoral wind farm in Coquimbo has the capacity of 46 MW. At its complete potential the wind farm could supply electricity for approximately 50,000 homes. The Totoral wind farm will offset 65,000 tons of carbon dioxide emissions per year, which is equivalent to the removal of 15,000 cars off of the road.[47] With these figures as a template, since the wind potential in Chile is predicted at 40,000 MW, if all of this energy was harvested and converted to electrical energy then it could power 43,478,000 homes. This would reduce 56,521,400 tons of carbon dioxide emitted into the atmosphere per year, which would be equivalent to taking 13,043,000 cars off of the road. However, Chile is nowhere near to using 40,000 MW of electricity per year. Current power demand is 13,000MW. Due to investment and land limitations it is very unlikely that the entire wind potential will be harnessed in Chile.

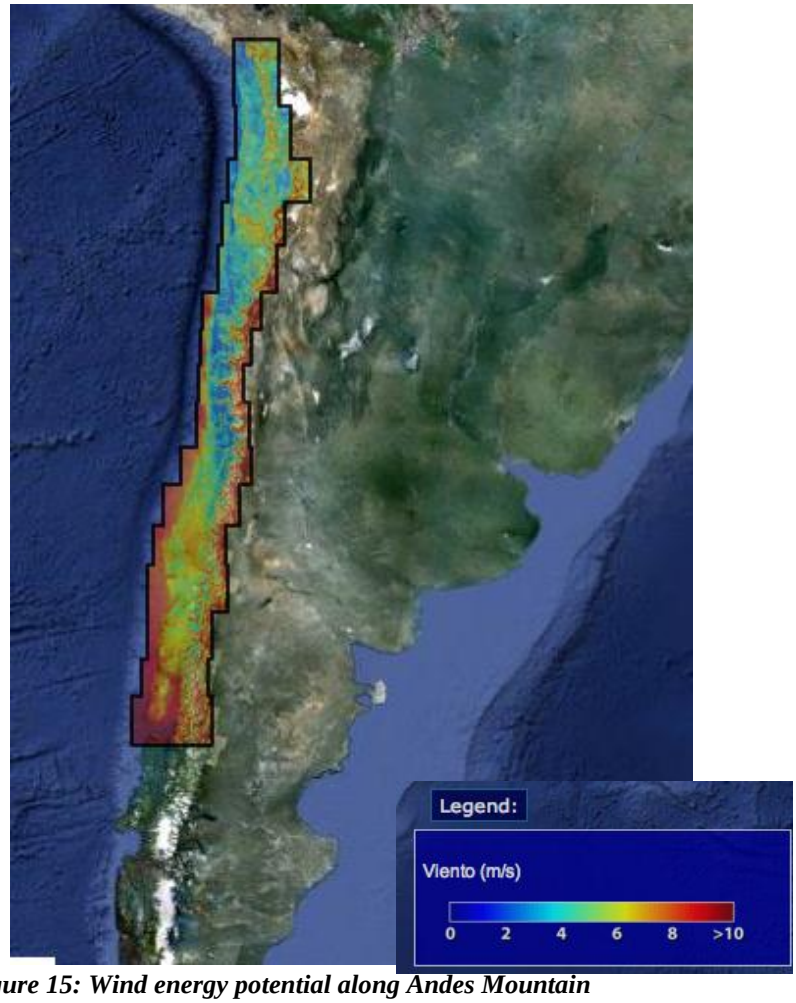


Figure 15: Wind energy potential along Andes Mountain range and Southern Chile

[45]"Renewable Energy." *InvestChile*. Chilean Economic Development Agency. http://www.investchile.cl/opportunities/renewable_energy/renewable_energy
[46]"Chile." *Global Wind Energy Council (GWEC)*. http://www.gwec.net/index.php?id=171
[47]*CER - Center of Renewable Energy*. Government of Chile. http://cer.gob.cl/

4.4 Solar

Similar to wind potential, there is opportunity for solar energy in Chile that has not been developed at all. The climate in the Atacama Desert has ideal conditions for solar energy potential. The Atacama Desert is 600 miles long that stretches from Southern Peru throughout Northern Chile. See figure 16. It receives an annual 0.6 mm of rainfall, which defines it as one of the driest places on earth. Some regions in the Desert have no recorded rainfall.[48] Some of the highest solar radiation in the world is received by the Atacama Desert, and the plateau can receive up to 9.28-kilowatt hours of sun per square meter per day.[49] Its minimal cloud cover and high solar radiation are supreme conditions to harvest solar energy.

Figure 16: In yellow: Atacama Desert

According to figure 17, the Atacama Desert is 139,860 km^2 and can receive up to 275 W/m^2 of solar irradiance, which is equal to 275 MW/km^2.[50] 1 km^2 is equivalent to 200 football fields. If the entire country of Chile were dependent on solar energy, only 47.27 km^2, or about 9,454 football fields would be needed to fulfill the electricity demand of 13,000 MW.

Location / Desert	Desert size km^2 [2]	Required area km^2	Irradiance W / m^2
Africa, Sahara	9,064,960	144,231	260
Australia, Great Sandy	388,500	141,509	265
China, Takla Makan	271,950	178,571	210
Middle-East, Arabian	2,589,910	138,889	270
South America, Atacama	139,860	136,364	275
U.S.A., Great Basin	492,100	170,455	220

Figure 17: Chart of the most solar irradiant regions in the World

[48]Vesilind, Pritt. "The Driest Place on Earth." *National Geographic Magazine*. http://ngm.nationalgeographic.com/ngm/0308/feature3/

[49]Nielsen, Stephan. "A Solar Mother Lode for Chile's Mines." *Bloomsberg Businessweek*. 10 Feb. 2011. http://www.businessweek.com/magazine/content/11_08/b4216012473761.htm

[50]Aspey, P., and S.M. Vinko. *Expedition Proposal to the Atacama Desert, Chile*. Publication. 11 Feb. 2008. Web. http://renovables.pbworks.com/f/proposal.pdf

Figure 17 and 18 determines six locations around the world that would be able to supply the world's total primary energy demand using 8% efficient cells. The Atacama has the highest irradiance in the world of 275 W/m^2. In figure 18, the size of the black dots represents the surface area that would be needed to produce 3 TW from each location.[51]

The solar potential in the Atacama is enormous and as photovoltaic cells will become cheaper in the upcoming decade, solar will be a more cost affordable investment. Photovoltaic cells involve the excitement of electrons, which generates a flow of electricity. *"In 5 to 10 years, solar options will be cheaper than HidroAysén,"* Roberto Román, mechanical engineer at the University of Chile.[52] Besides photovoltaic, other types of solar technology includes concentrating solar power and solar thermal energy. By concentrating solar power, the solar energy heats up a liquid, which is then channeled through a steam turbine to generate electricity. Solar thermal energy heats up a liquid as well in order to provide heating for homes, businesses or other industrial uses such as agriculture.[53]

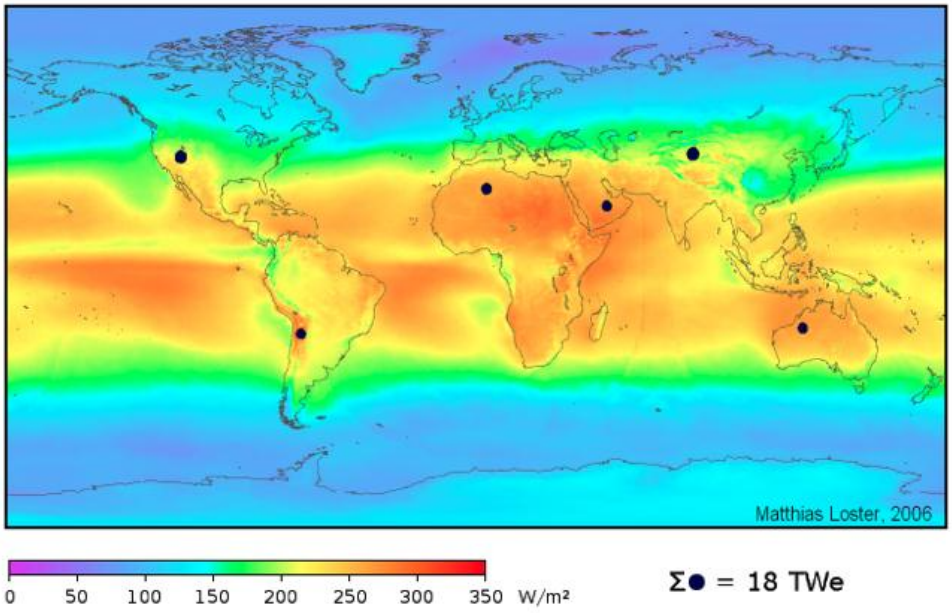


Figure 18: Map of the world's solar energy

Various barriers determine the potential of solar farm locations. There are three protected areas in the Atacama Desert: one national park and two national preserves. The Pan de Azucar National Park, La Chimba National Reserve, and Pampa del Tamargual National Reserve consume a total of 1,491 square kilometers of the total 139,860 square kilometer desert region.

[51]Loster, Matthias. "Total Primary Energy Supply-From Sunlight." 2010. http://www.ez2c.de/ml/solar_land_area/

[52]Barrionuevo, Alexei. "Plan for Hydroelectric Dam in Patagonia Outrages Chileans." *The New York Times*. 16 June 2011. http://www.nytimes.com/2011/06/17/world/americas/17chile.html?pagewanted=all

[53]*CER - Center of Renewable Energy*. Government of Chile. http://cer.gob.cl/

[54] Armstrong, Sean. "Atacama Desert (NT1303)." *World Wildlife Fund (WWF)*. http://www.worldwildlife.org/wildworld/profiles/terrestrial/nt/nt1303_full.html

4.5 Geothermal

Geothermal energy is derived from the heat within the earth. Geothermal energy exists within the Earth's core, however it is most accessible on the surface of the earth among areas with high volcanic activity and geological faults. Chile is located on the "Pacific Ring of Fire," a line of faults that has intense volcanic and seismic activity. Chile is blessed geothermal potential as it contains 10% of the most active volcanoes in the world.

There are an abundance of sources for geothermal energy throughout the 11 regions of Chile, and there are approximately 120 locations for potential geothermal activity.[55] The National Petroleum Company estimates that there is potential to produce 3,350 MW of electricity from geothermal.[56] Another study estimated that there is potential of 16,000 MW in the next 50 years.

In-depth geothermal exploration and investment will expand more geothermal energy possibilities and potential. Geothermal exploration is similar to the exploration of oil reserves, thus it requires time and investment. The government agency, Ministry of Mining, is responsible for receiving geothermal exploration applications and permits under Law N 19.657. Exploration is granted by the state.[57]

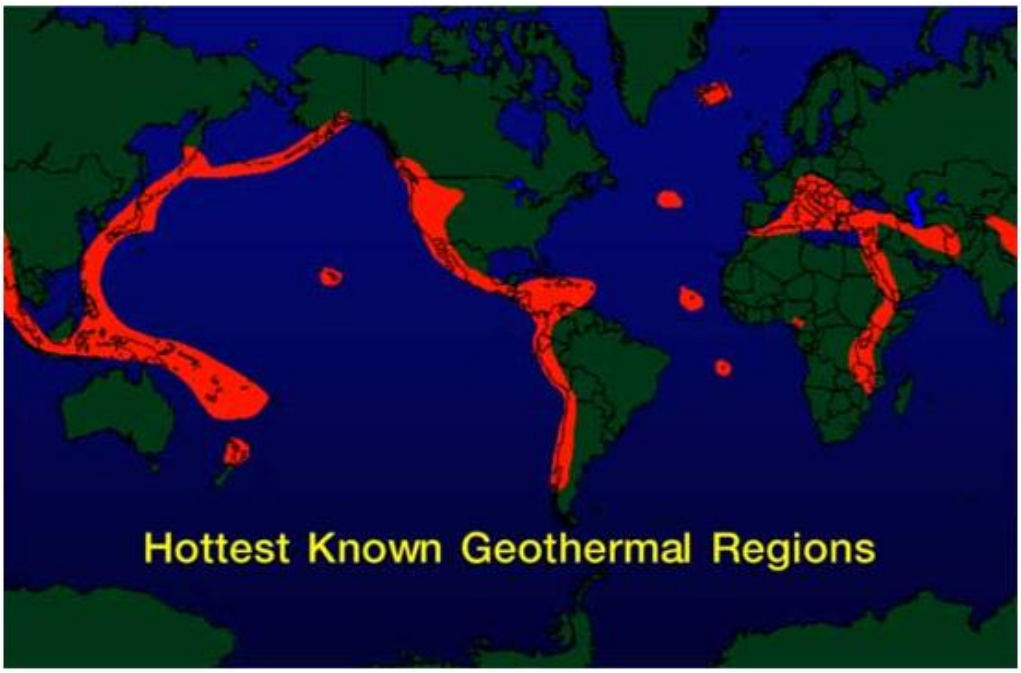


Figure 19: World's geothermal potential

[55]"Probable Sources Identified Regulation Geothermal Energy." *National Commission of Energy*. Government of Chile, 28 June 2000. http://www.cne.cl/cnewww/export/sites/default/08_Normativas/02_energias/descargable_renovables/regla_geotermia_xDoc_7x.pdf

[56]"Chile." *International Energy Agency (IEA)*. 2011. Web. http://www.iea.org/

[57]"Renewable Energy." *InvestChile*. Chilean Economic Development Agency. Web. http://www.investchile.cl/opportunities/renewable_energy/renewable_energy

4.6 Ocean

The ocean and tidal energy potential in Chile is enormous, especially along the Southern coast. British engineering consultant Baird & Associates reported that, *"Chile is the country with the highest wave energy potential in the world."*[58] A study approximated that there is 164,000 MW of energy potential along Central and Southern Chile.[59] Since ocean, tidal and wave energy is an emerging renewable energy source, the installation and construction costs of ocean turbines is still to be developed.

Another factor to illustrate that Chile has potential for ocean and tidal energy is the Chacao channel in Chile's 5th region – which has been determined to have the 3rd strongest energy currents in the world.[60] Alexander Gorlov calculated that there is approximately 2,000 MW of potential within this channel. This potential is huge considering that the proposed five HidroAysen dams would have an installed capacity of 2,750 MW.

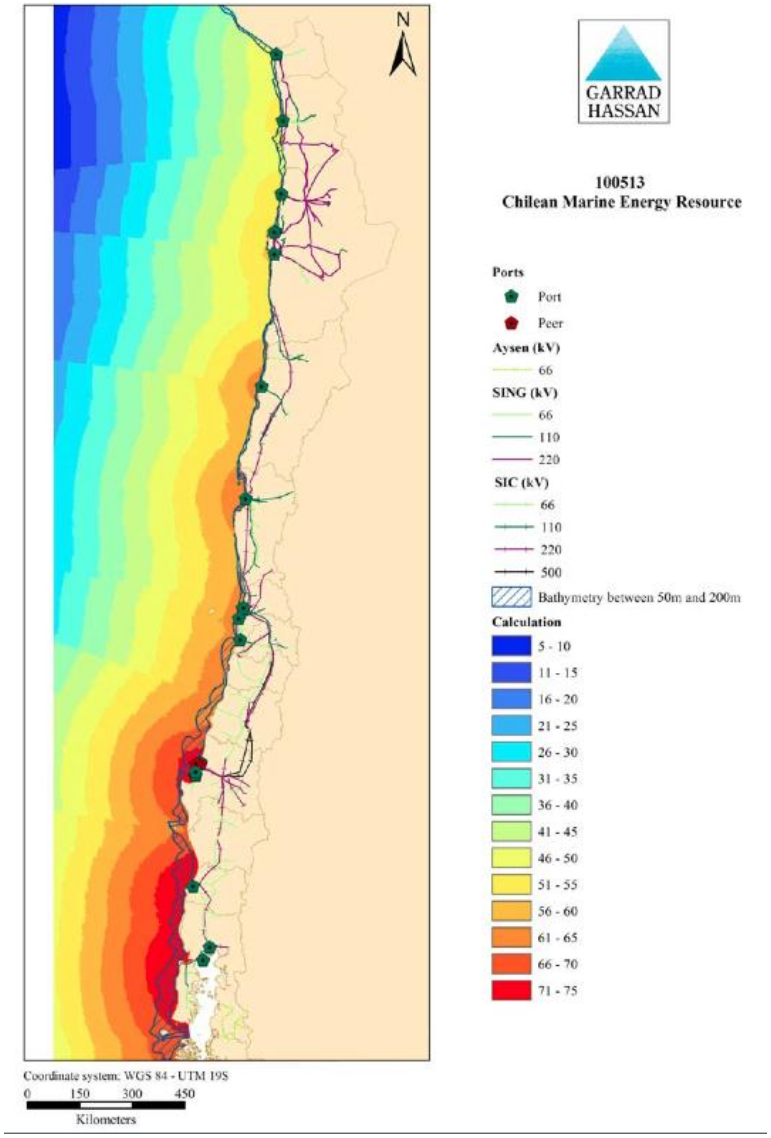


Figure 20: Chile's ocean energy: overall classification (weighted average)

[58]"Chile Is the Country with the Highest Wave Energy Potential in the World." *Ocean Energy Council*. 10 Apr. 2008. http://www.oceanenergycouncil.com/index.php/Wave-Energy-News/Chile-is-the-country-with-the-highest-wave-energy-potential-in-the-world.html

[59]*Santiago Times*. http://www.santiagotimes.cl/

[60]*CER - Center of Renewable Energy*. Government of Chile. Web. http://cer.gob.cl/

"An initial study on Chile's tidal energy capacity confirms the country has "unique global potential" for this renewable energy source. According to the report, published by Chile's National Energy Commission (CNE), even if only 10% of this renewable resource is harnessed, it would exceed the existing installed capacity of Chile's central electricity grid, or SIC."[61]

4.7 Biomass

In 2007, 191 MW of energy from biomass was produced into the SIC system (see figure 11). Biomass is not yet at its full potential either. The by-products from the logging industry have the potential to produce 470 MW of energy. The by-products from the industries between the Maule and Los Lagos region have the potential to produce 900 MW of energy.[62] There are current studies evaluating electricity generation from waste produced by forest management and harvesting.

Biogas and biofuels is another alternative energy source derived from plants and animals. In October 2008 began the operation of a biogas plant from sewage. This plant can provide for up to 4% of the fuel/gas consumption in Santiago.[63] Biogas and biofuels cannot only be derived from plants, but also from landfills and sewage plants. There is approximately 150 MW of potential biogas from existing sewage treatment plants and landfills.[62]

4.8 Overview

Chile's installed capacity is approximately 13,300 MW, which could be expected to rise 6%-8% annually.[64] According to figure 10, in 2008, the total capacity was at 13,275 MW of energy. At a 6% annual growth rate, in 2020 the MW of electricity required is estimated at 22,800 MW.

	Small-Hydro	Solar	Wind	Ocean	Geothermal	Biomass
Estimated Potential	10,000 MW (at least)	275 MW/km^2	40,000 MW	164,000 MW	16,000 MW (over 50 yr period)	1,370 MW

Figure 21: renewable energy source estimated potential

[61]Wynne-Hughes, Antonia. "Chile Ponders Tidal Energy Potential in Magellan Strait." *Merco Press*. 17 Aug. 2009. http://en.mercopress.com/2009/08/17/chile-ponders-tidal-energy-potential-in-magellan-strait
[62]"Renewable Energy." *InvestChile*. Chilean Economic Development Agency. http://www.investchile.cl/opportunities/renewable_energy/renewable_energy
[63]*Chile Energy Policy Review 2009*. Paris: Organisation for Economic Co-operation and Development / International Energy Agency, 2009. Print.
[64]"Chile Is the Country with the Highest Wave Energy Potential in the World." *Ocean Energy Council*. 10 Apr. 2008. http://www.oceanenergycouncil.com/index.php/Wave-Energy-News/Chile-is-the-country-with-the-highest-wave-energy-potential-in-the-world.html

5 Transition to Renewable Energy

5.1 Transition

There are various development stages in order to incorporate renewable energy into the electricity grid. Depending on the scale, the renewables will either connect at the distribution or transmission level. There are detailed phases in order to connect the renewables to the electricity grids. The company of the NCRE must report an intention to the distribution company, and if the distribution company approves: a series of applications, requirements, standards and technical tests must be approved. These phases can be found in detail in a report approved by the Ministry of Energy.[65]

The renewable energies of solar and wind do not produce a constant supply of energy. Since they are intermittent sources, the electricity grids must be ungraded to a "smart grid" to accommodate these resources and establish a more steady flow of energy to the consumer. The flexibility of the electric system should increase in order to improve grid management and planning.[66]

5.2 Barriers

There are a series of barriers that would prevent renewable energy from entering the market. These include economic, technological, regulatory and financial barriers. Two major barriers include improving the electricity market framework and the lack of investment conditions to produce direct support for renewable energy.

Other barriers include, but are not limited to:[67]

1. Weak infrastructure
2. Lack of
    - -Information on energy resources
    - -Geothermal exploration, which requires large investments
3. Difficulty accessing credit
4. Uncertainty regarding technological options
5. Distance to electricity grids
6. Geographical Features
    - -National protected areas

[65] Behnke, Dr. Rodrigo P. *Renewable Energy in Chilean Electricity Market*. Rep. Commission of National Energy, Oct. 2009. http://www.cne.cl/cnewww/export/sites/default/05_Public_Estudios/descargas/ERNCMercadoElectrico_Bilingue_WEB.pdf

[66] "Chile." *International Energy Agency (IEA)*. 2011. Web. http://www.iea.org/

[67] "Renewable Energy." *InvestChile*. Chilean Economic Development Agency. http://www.investchile.cl/opportunities/renewable_energy/renewable_energy

Small Hydro	Wind	Solar
-Delay processing permits **-Absence of unified criteria for** environmental impact assessment	-Efficiency from wind patterns	-Only during the day -Abundance of land needed-spacious

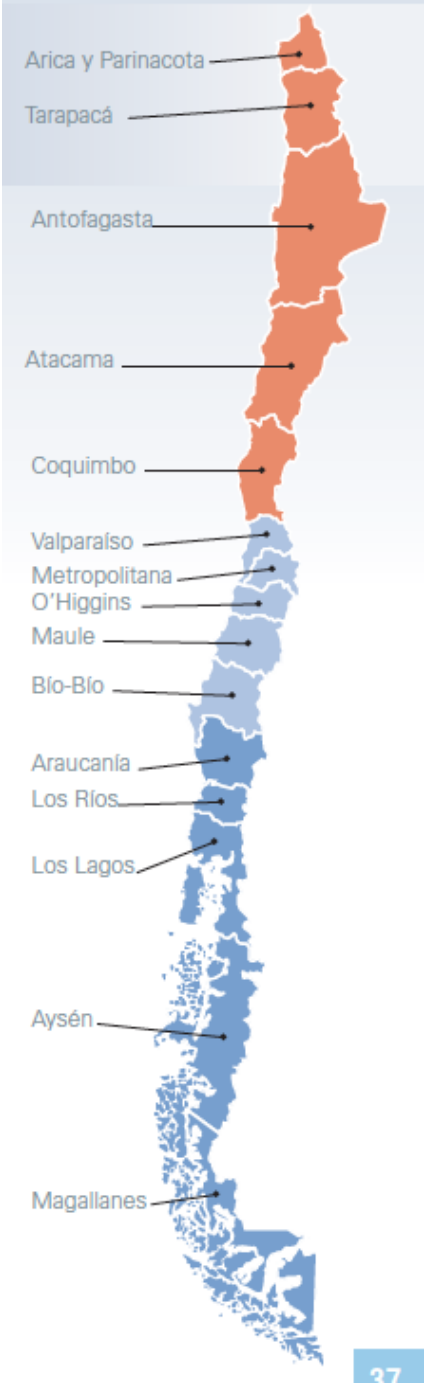
Geothermal	Biomass	Ocean
-Low identification spots **-Need registry of available** sources **-High investment costs**	-Conversion of efficiency -Availability & transportation of biomass -Lack of policies support -Risk associated with intensive agriculture (such as fertilizers)	-New technology -Requires intense research assessment -Very expensive

Figure 22: renewable energy source barriers [61&62]

5.3 Solutions

The potential for renewable energy is enormous. A myriad of renewable energy sources are located in Chile including wind, solar, ocean, geothermal, biomass and hydropower. As one of the main barriers: the electricity market and the connection of NCRE to the electricity grid must be redesigned. The SING and SIC are the two major grids in Chile that remain separate. However, if the potential of renewable energy is exploited near the Aysén and Magellan Systems, it may be recommended to link these two grids to SIC: the Santiago region. There is enormous wind and ocean energy in Southern Chile. Because there are limited industries and population in regions XI and XII, the energy not consumed by the region could then be transferred to the Santiago region where it could be used by the this dense metropolitan area.

[68]"Renewable Energy." *InvestChile*. Chilean Economic Development Agency. http://www.investchile.cl/opportunities/renewable_energy/renewable_energy
[69]*CER - Center of Renewable Energy*. Government of Chile. Web. http://cer.gob.cl/



Northern Zone
*Geothermal
*Solar
*Wind

Central Zone
*Biomass
*Small Hydro
*Wind

Southern Zone
*Small & Medium Hydro
*Biomass
*Wind
*Geothermal
*Ocean

←Have grid connections available from Aysén & Magallanes to SIC & SING Grids

Figure 23: Renewable energy sources with most potential by region

A second solution is to amend the law of 20.257, which is to develop the integration of renewable energy into the market. The law requires 5% of energy generations to come from NCRE by 2014, and from then on there should be a 0.5% increase each year. By 2020, there will be 8% of renewable energy integrated to the energy market. With the addition of the 2.4% renewables today, only 10.4% of renewables will be in the generation in 2020. Even though there is not a cap on the amount of renewable energies that can be produced, it could be amended in order to strictly enforce the action of government and private markets to quickly invest in renewable energies.

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6 Conclusions

Chile has potential to become a world leader in renewable energy with its wide variety of potential sources given its unique geography. The Atacama Desert in the north has enormous solar potential due to its large size and intense solar irradiance. This solar energy should be harvested, either using photovoltaic or concentrated solar thermal to provide energy to the mining industries located in the north. Mining industries, especially copper mining, consumes 4,911 MW of electricity. Only 18 square kilometers, or 3,600 football fields in the Atacama Desert would be able to supply their full demand. Hydropower found from the rivers throughout central and southern Chile could supply energy to the metropolitan region in Chile, where most of the population resides. Due to the massive controversy over the five proposed hydroelectric dams in the Patagonia region, small hydro plants, less than 20 MW, should be built to reduce the environmental impacts and to preserve the land. Wind, found throughout all regions in Chile could supply energy to both electricity grids. Geothermal, ocean and biomass could provide thousands of megawatts to the four electricity grids with the proper integration and investment.

There are three main factors guiding renewable energy, and more specifically renewable energy that will influence the Chilean economy and have an overall benefit for the country. One factor is that renewable energy will positively influence the economy by creating more jobs. These jobs include project managers, engineers, construction workers, and many others. If more people are put to work, it will correlate to a more productive economy.

A second factor is that Chile will no longer be dependent of foreign countries for fossil fuels. The risk of an energy shortage would be non-existent if a myriad of renewable resources are installed among each electricity grid. The Chilean government sectors will have full control over the energy that is produced, correlating to regulated prices to consumers. Since prices rise and fall in the global market, the importing of potentially expensive foreign oils and gases will also be dramatically reduced.

A third factor is that renewable energy resources will bring to Chile is a more sustainable country. Renewable energy resources emit little or no greenhouse gases. Global warming due to human effects is a major concern all over the world. To not burn fossil fuels and to have a carbon neutral country is a step closer to achieving a healthier and more sustainable world.

The population is expected to continue growing as well as the copper industry. A strategic plan for Chile's energy supply would be beneficial to secure a constant supply of energy. In order to secure this constant supply of energy, diversification between renewable

energy sources is essential. Laws need to be passed to increase the amount of renewable energy as quick as possible, including strengthening the renewable energy law, Law 20.257.

Is it possible for Chile to be 100% renewable by 2020? If the need for energy were a desperate situation, there are enough renewable resources in Chile to contribute to its electricity supply. Renewable energy will significantly reduce the amount of greenhouse gases spewed into the atmosphere, be more sustainable for the environment, give constant energy without drastic price fluctuations, and it will take the dependence off of expensive, imported fossil fuels. However, these projects involve large financial investments, deliberate planning and construction phases. It is undetermined when the final transition from fossil fuel production to renewable energy production will take place. The costs and benefits of renewable energy will drive the energy development in the world in this decade. It is time for renewable energy to have a larger impact in Chile and on the world's energy supply.

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