Climate Change Impact on the Energy System at the Santiago Metropolitan Region

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Abstract — This paper describes the methodology and results from the analysis of climate scenarios and their impact on hydrometeorological variables and the energy system in the Metropolitan Region of Santiago, Chile´s capital city. Data are reported for historical and future scenarios. Meteorological data were obtained from meteorological stations and water resources administration, and GCM climate projections were obtained from globally available sources (A2-worst case and B1-best case scenarios). For future scenarios, a standard, simple downscaling methodology based on the probability distribution of each variable was used. A special study on the impact on the energy system was carried out. Overall results indicate that in the near future (2045-2065 period) Santiago will be a dryer, hotter city, with a high number of days with extreme temperatures, increased drought during the winter and summer, and lower life quality indexes derived from climate change effects. In the energy sector a decrease in the hydropower electricity is expected as well as a change in patterns of consumption with a shift in the peak demand, which will impose a growing stress on the longitudinal transmission network of the country.

Keywords—Energy System, Electrical Interconnected System, Global Circulation Model, Downscaling Methodology

1 INTRODUCTION

Climate change refers to any change in climate over time, whether due to natural variability or as a result ofhuman activity [1].Global Climate Change (CC) is characterized by a rise in average temperatures in most regions, changes in wind speed, humidity, precipitation, cloud cover, sea level rise and changes in the intensity and frequency of extreme weather events. Every day more studies about climate change are done; however, most of the initiatives are focusedonmitigatinggreenhouse gases and adaptation, but only a few analyze the effects on specific areas of the economy. This paper aims to study the impacts of CC on the Chilean's energy sector, specifically in the Electrical Interconnected System.

In general terms, it's expected that CC will induce changes in precipitation, which could affect hydropower generation [2]. Also, higher temperatures are expected to raise electricity demand for cooling and decrease demand for heating. In thermal power plants higher temperatures will reduce electricity production. In addition, extreme weather events could affect the transportation of electricity. Therefore, adaptation to CCwill require efforts for improvingtransmission and distribution systems.

In conclusion climate change will bring many direct and indirect effects, its necessary analysis the impacts to define appropriate adaptation policies.
The remaining of this paper is organized as follows: Section 2 presents an overview of the main trends of CC on the Chilean system and the region where Santiago city is sited; Section 3 describes the energy scenarios, which are classified as Business as Usual (BAU), Optimistic and Pessimistic; Section 4 and Section 5analyze the impact of CC on the main Chile´s interconnected system and the Metropolitan Region, respectively. Finally, Section 6 summarizes the main conclusions of this work.

2 CLIMATE TRENDS IN CHILE

In this section climate changes scenarios,thatwill affect Chilein themedium and longterm, are presented.The scenarios are based on Global Circulation Models, or GCMs [1]. GCMs are mathematical models where land, ocean and atmosphere processes are represented through mathematical relationships between variables. These calculations are performed on grid divisions of Earth's surface, each of them of dozens or even hundreds of kilometers of resolution.

2.1 Historical Data

In reference [3] Falvey and Garreaud (2009) analyzed historical temperature trends in central Chile (27.5°S – 37.5°S) for the 1960-2006 period. They found positive trends from 1975 to 2006 in stations located in the Andes and central valley. These trends exhibit an East-West horizontal structure pattern with a warming for the East-Central part of the country and negatives trends in costal stations.
The observed trends are presented in Fig1

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Thistrends are for the1979-2006 period and analize different regions: Andes East (Argentina); Andes West (Chile); Central Valley; Coast and Ocean.

In central and northern Chile (17°–37°S) the most notable feature is astrong contrast between surface cooling at coastal stations (0.2°C/decade)and warming in the Andes (+0.25°C/decade),only 100–200 km further inland.[3]

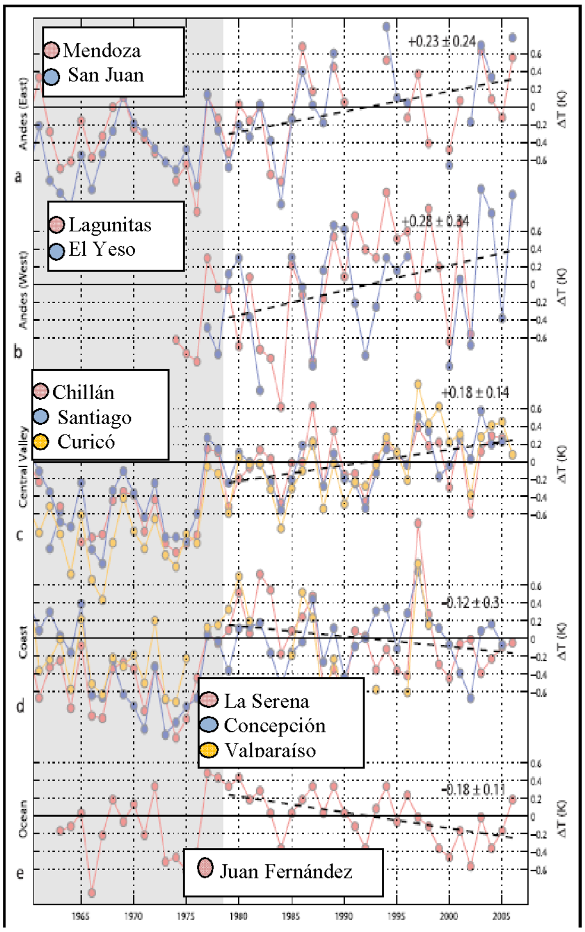

Fig1 - Temperature difference trends.

Different trends have been observed for maximum and minimum temperature, results show warming on both indexes for stations located near Santiago.Cooling patterns observed for coastal and low lying stations are also reproduced on the daily max and min temperatures, which have increased proportionally and according to the elevation of the measuring station.

The main conclusion of the study [3] is the presence of a warming trend in Andean regions of central Chile, and a less significant –yet still observable- warming trend in the valley regions. As the Metropolitan Region of Santiago is mostly located within the central valleys and close to the mountain range, according to the results by Falvey and Garreaudwarming trends are expected to continue in future scenarios.

Regarding precipitations, reference [2]evaluated data for the last 30 years finding negative (not significant) trends for central Chile and significant negative trends for southern Chile. Although there are uncertainties associated to the resultsdueto low frequency climate variations that influence the weather, such as El Niño southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO); negatives changes in annual precipitation for 33-34S on the order of 5% each decade where found.

2.2 Climate Trends in Chile

In reference [4] a study of climate scenarios in the Chilean territoryfor the period 2071-2100is reported. The study considers two emission scenarios A2 and B2, which are defined according to the IPCC [1]. These scenarios are studied by using PRECIS, a regional circulation model based on boundary conditions provided by Global Circulation models, in this case the English HadCM3 model [5]. PRECIS consists of a 25x25 km grid, a resolution far higher than GCMs, which present resolutions of hundreds of kilometers in magnitude. The advantage of using PRECIS is that coast and mountain features are better represented than GCMs, and these are key elements when analyzing Chilean climate.

Fig 2and **Error! Reference source not found.**presents an ensemble mean of projected changes for the middle (2040-2069) and late period (2070-2099), from different GCMs (Global circulation Models) for A2 scenario.

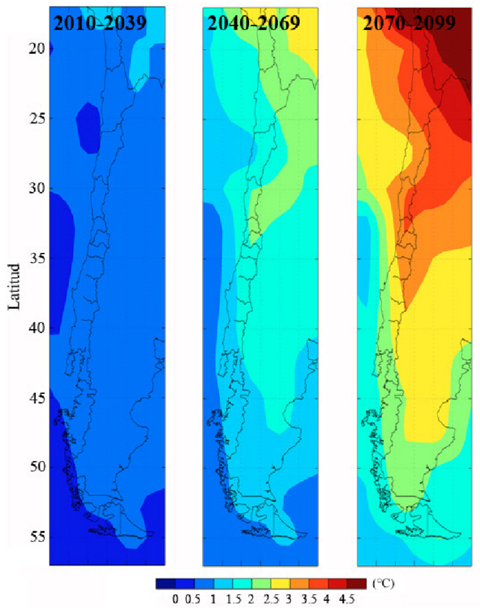

Fig 2Projected changes in temperature (°C), scenario A2. Early, middle and late period

Fig 2shows the projected changes in temperature in America Southern region. The color map represents the expected increase of temperature, from yellow to red colors higher increases are represented (2.5°-4.5°C). Blue colors are associate with smaller increase in temperature.

It's observed an approximate increase between 1-2.5°C for the middle period (2040-2069) and an increase between 2-4°C for late period (2070-2099). Results show a generalized warming for central Chile, with stronger warming on the Andean and central valley regions, and reduced precipitation.
Fig 3shows the projected changes in percentages of precipitations in the baseline period. Brown colors are related to decreases in precipitation while green colors are related to increases in precipitations.

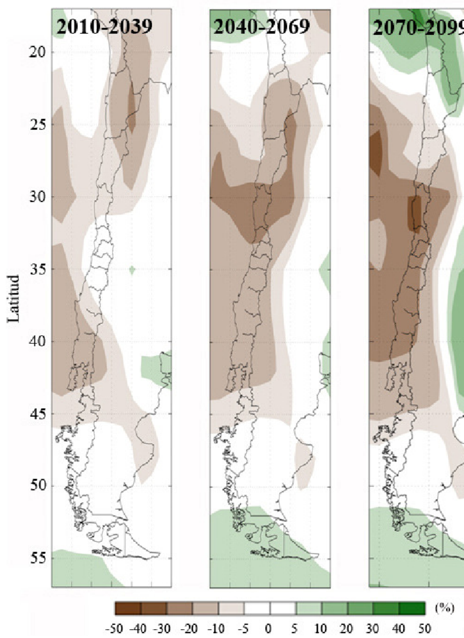

Fig 3Projected changes in precipitation (%), scenario A2. Early, middle and late period.

Results for central and southern regionsindicates a decrease of 10% to20% for precipitations in the period 2040-2070 and a decrease of 20% to 30% in the period 2070-2100.
Climate projections for the region show some variability in value, but mostly agree in the trends being projected: warming temperatures and decreasing precipitation is expected for the region according to the models.

2.3 Climate Trends for the Metropolitan Region (Santiago city)

Regarding climate future conditions at the Metropolitan Region, reference [4] makes projections for the period 2045-2065 based on direct downscaling of GCM projections (daily values) in two future scenarios A2 and B1.
The downscaling methodology is a standard methodology based on the probability distribution function of the variable. Downscaling was applied to model output from the Coupled Model Intercomparison Project (CMIP3) database, a database comprising more than 15 global coupled ocean-atmosphere circulation models used in the IPCC4 report on climate change [1]. Even though a high number of models are available, not all of them were used in data processing as a high number fail to clearly reproduce the climatic regime of the Santiago de Chile region. [5]
This downscaling methodology is intended to adapt the mean and the variability of the modeled time series to the historical data of the period. It assumes a lineal correspondence between both distribution curves and produces reliable results depending on the representativeness of the modeled values. If the model doesn't reproduce the observed climate patterns (for example, cold winter and hot summers), this downscaling methodology will not be reliable.
Regional meteorological historical data was obtained from meteorological stations owned by the DMC (Meteorological Administration) and DGA (Water Resources Administration).
Downscaled climate projections show approximately a 1 - 2 °C warming for the future period at most stations in the region. Additionally, days with maximum temperatures above 30 °C increase in the order of 25 – 45 days per year (A2 scenario) depending on the station being analyzed. Minimum temperatures also increase, but unlike the maximum temperature results, these increase more significantly at Pirque and El Yeso stations, which are located towards the mountain region of the area.
Precipitation projections are based on two indicators: average monthly values (climatology) and the distribution of number of days with precipitation in certain ranges. On average, precipitation decreases throughout the region. Models display a great deal of variability regarding the temporal patterns associated with this change, with specific months sometimes showing an increase in precipitation whereas most months evolve decreasingly.
The overall conclusion of the study [4] is that in the near future (2045-2065 period) Santiago will be a dryer, hotter city, with a high number of days with extreme temperatures, increased drought during the winter and summer, and lower quality of life associated with climate change effects. This result is independent of the scenario chosen, as both A2 (worst case) and B1 (best case) scenarios show similar responses.

3 ENERGY SCENARIOS

In order to analyze the impact of climate change in the Chilean energy system it is necessary to estimate the energy demand during the XXI century.There is a trade-off between energy and climate projections, as usually energy estimations are more accurate for short term periods (5-10 years), whereas climate models have better predictions in the long term (50-100 years).
In this paper the main goal is to obtain a general overview of the impact of new climate conditions on

the energy system. To accomplish this task, threeenergy scenarios are considered: BAU (Business as Usual), Optimistic and Pessimistic. Each energy scenario is associated to the evolution patterns used in IPCC scenarios [3]. A sample of these scenarios is presented in Fig 4

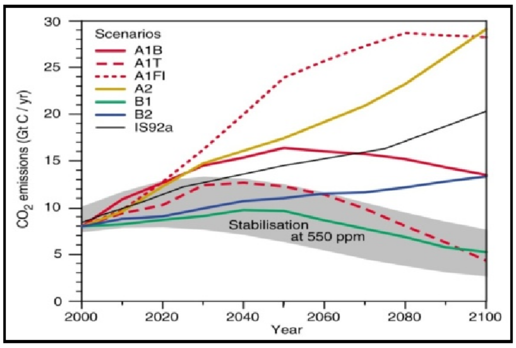

Fig 4 IPCC emission scenarios [6]

The pessimistic scenario, with high CO2 emissions, is related to the A2 scenario; while the Optimistic scenario, with less CO2 emissions, is related to de B2 scenario. The BAU scenario maintains the current socioeconomic trend and has the climatologically characteristics of B2.

The demand forecasting was made with the IAEA's model MAED (Model for Analysis of Energy Demand). MAED is an end-use-model which estimates the energy consumption in the following sectors: Industry; ACM (Agriculture, Construction and Mining); Manufacturing; Service; Residential and Transportation.[7]

3.1 Scenario Descriptions

The B2 scenario describes a world that prefers sustainable social economic solutions. It is a world with continuously increasing global population and economic development at a rate lower than A2. In contrast the A2 scenario represents a world that has less international cooperation; A2 world is more heterogeneous, consolidating into a series of economic regions, with disparities in productivity, income, energy use, and economic growth in general. Hence, in A2 global environmental concerns are relatively weak and it exhibits the largest GHG emissions of allscenarios by the end of the century.

In order to study separately the impact of the increase of Air condition consumption in the electric energy demand, and additional scenario, named BAU-AC, is included. This scenario maintains all the BAU parameters except those related to demand for cooling and heating (which are the same parameters used of the Pessimistic scenario).

It is worth to mention that current emission trends are above the pessimistic scenario already, so the future climate changes could be even more intensive. Fig 5shows an example of the different trajectories that emissions would follow given a different emission scenario.

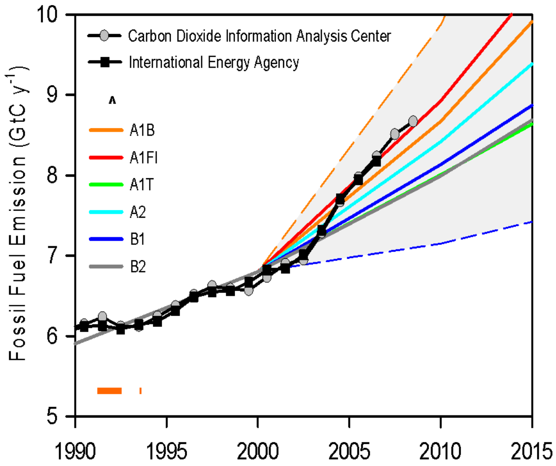

Fig 5Current and future emissions [6]

Toestimate energy demand is necessary to project socioeconomicparameters such as population and GDP, and technical achievements in energy efficiency.

Population
In Fig 7the population trend is presented.

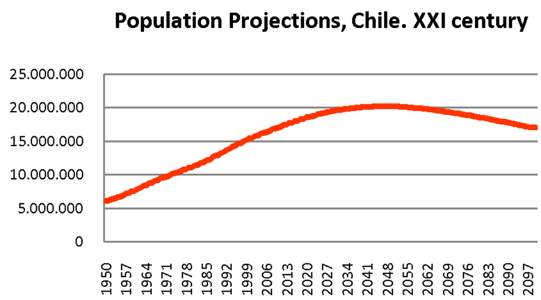

Fig 6Chilean population projections, XXI century

The population in Chile by the 2007 year was 16.598.074 inhabitants, 40% resided in the Metropolitan region. Considering the growth rates of National Statistics Institute (INE)[8] and Economic Commission for Latin America and the Caribbean (ECLAC) by 2050 the population will be, approximately, 20 millions of people. After that, the growthrateswill decrease. At the end of the century it's expected a population of nearly 17 million[9]. The same population trend is used for the three energy scenarios.

GDP
Regarding economic growth, in order to comply with the IPCC scenarios, the highest GDP per capita it is related to the Pessimistic (A2) scenario. On the other hand, the lowest GDP it is associated to Optimistic (B2) scenario. Figure 7 shows the GDP projections for all the scenarios.

The GDP is calculated in constants dollars of 2000 year.

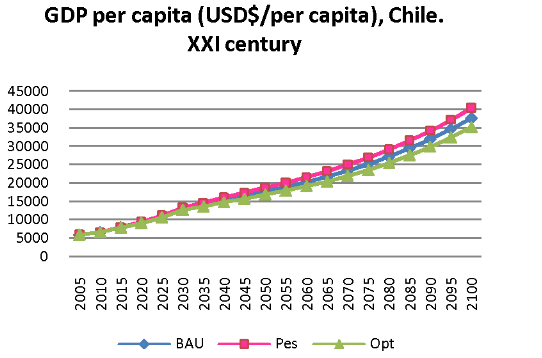

Fig 7 Chilean GDP per capita projection, XXI century

Energy Intensity

Energy intensity or energy consumption per dollar of real GDP—indicates how much energy a country uses to produce its goods and services. In Figure 8 projections for three scenarios are showed. As mentioned previously, the optimistic scenario has higher environmental and social awareness, therefore, this scenario considers higher efficiency of engines and less energy intensity per sector. On the other hand the pessimistic scenario has the highest energy intensity.

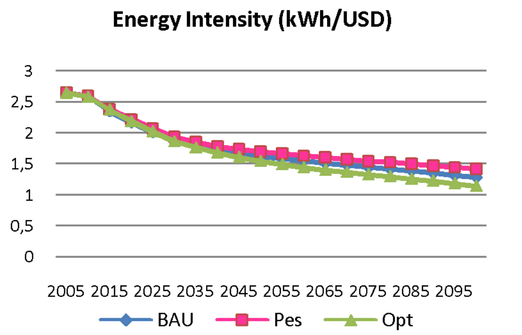

Fig 8Energy Intensity projections, XXI century

The decoupling of GDP growth from energy consumption growth led to a decline in energy intensity. Any change in energy intensity that does notresult from a change in efficiency is referred to as a structural change. Examples of structural change include energy conservation, a change in the mix of economic activity among the sectors of the economy, a change in the mix of activities within a sector, and a geographical change in population density. [10]

3.2 Energy Demand

This section shows the demand estimation for the country in the twenty first century period.

Total Energy Demand

Fig9 shows the result of the total energy demand estimation measured in annual GW (GWa).

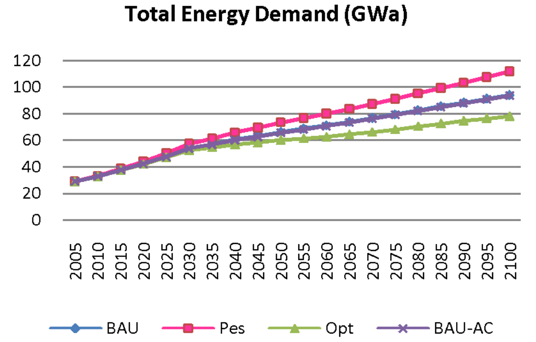

Fig9 Total energy demand, XXI century

From Fig9it is clear that all scenarios show the same pattern until 2025, which is coherent with the climate scenarios, because the effects of climate change begin to be noticeable from the middle period onwards.
As expected, the pessimistic scenario has the higher energy demand, at the end of century reachong 111.89GWa. Also, the scenario with less energy consumption is the Optimistic with 78.02 GWa in 2100.For the same year, the BAU scenario results in 94.21Gwa and the BAU-AC scenario reaches 93.73. The differences between these last two scenarios are about 0.5% and it is onlydue to air condition and calefaction consumption.

Total Electric Demand

Fig10shows the total electricity demand.

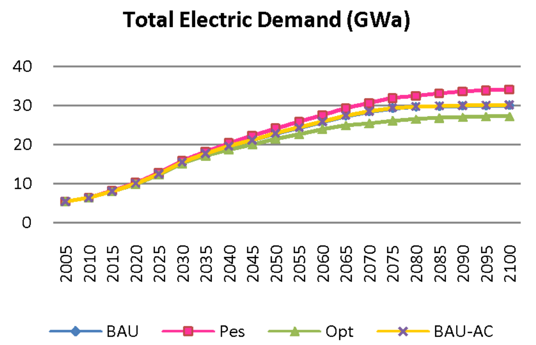

Fig10Total electric demand. XXI century

The electricity demand grows until mid-century, after that,it starts a saturation process.The pessimistic scenario has the higher electric demand, reaching 34.04GWa in 2100; this value is 25.18% higher than the electric demand in optimistic scenario, and 13.25% than the BAU scenario.
The scenario BAU-AC is a 0.36% higher than the BAU scenario; this is because in BAU-AC scenario the energy needs for air conditioning is higher.

The relation between electrical demand per capita and GDP per capita is shown in Fig11. This Figure shows that the highest electric demand per capita and GDP per capita are related to the Pessimistic scenario, and the lowest values to Optimistic scenario, which is consistent with the IPCC scenario description.

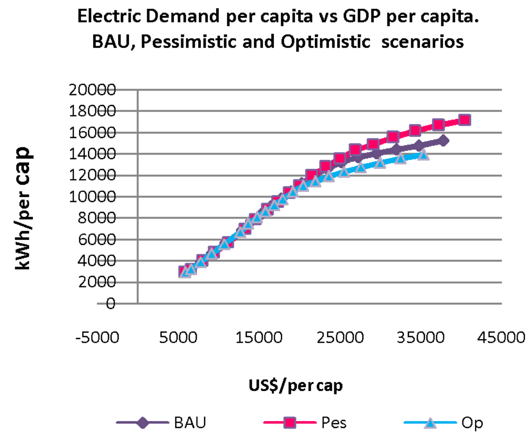

Fig11 Electric Demand per capita Vs GDP per capita.

Curves in Fig11indicate a close relation between electrical demand and GDP in the range 5-20 thousand dollars per capita. Saturation is reached for GDP per capita values above 20-30 thousand dollars, where the electric demand increasesat a very low grow rate.

Air Conditioning Demand

In Fig12the projected energy use in theservice sector due to air conditioning consumption is presented.

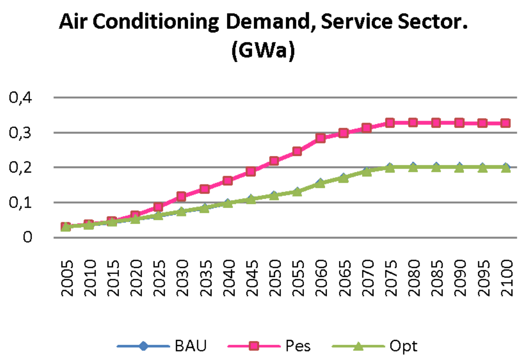

Fig12Air condition demand in service sector.XXI century

In Fig12 BAU and Optimistic scenarios have almost the same curve as both scenarios consider the same temperature increase. On the other hand, the pessimistic scenario shows a bigger increase, which is related to the temperatures and GDP per capita, both higher than in the other scenarios.
The saturation at the end of the century is related to the decline in the population. At the end of the century the pessimistic scenario reaches 0.32 GWaand for BAU and Optimistic scenarios, the consumption is approximate 20 GWa.
In Figure 13, similar results for the residential sector are presented.

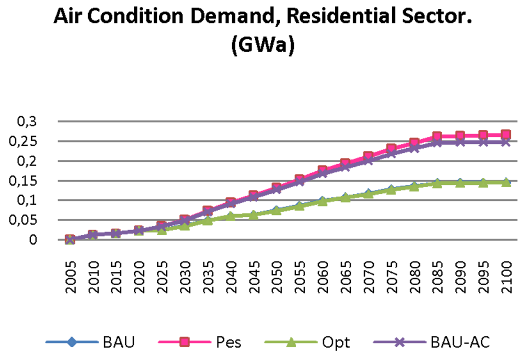

Fig13 Air condition demand in residential sector

Fig13showthat the electric demand related to the residential sector has the same pattern as in the service sector. The BAU-AC scenario has a 70.8% more demand than BAU scenario, but has 7% less of consumption than pessimistic due to the higher coefficient of performance(COP) considered in the BAU Air conditioner equipments.

Demand Forecasting

A summary of the maximum power consumption during the twenty-first century for three scenarios is presented in Table 1.

Table 1 Power demand (SIC). BAU, Pessimistic, Optimistic scenarios

MW	BAU	Pes	Opt
2010	7247	7250	7247
2020	11027	11152	10902
2040	20672	21441	19984
2070	29973	32166	27396
2100	33075	37240	30394

Table 1 shows that installed capacity in the Chilean electricity sector will increase nearly five times during this century.
The corresponding summary for the energy demand is presented in Table 2.

Table 2 Electric energy demand (SIC); BAU, Pessimistic, Optimistic scenarios

GWh	BAU	Pes	Opt
2010	47417	47440	47412
2020	73432	74527	72549
2040	138464	145103	132697
2070	199915	216821	179883
2100	213160	242940	192840

Similar to the power demand, the energy consumption will increase nearly five times until the end of the century.

3.3 Electricity Supply System

In this section,analyses of electricity supply for the Central Interconnect System (CIS) are presented.

Generation Mix
Results for the three scenarios under analysisBAU, Pessimistic, and Optimisticare shown in Tables 3-5.

Table 3: Installed capacity matrix, BAU scenario

BAU	Hydro (%)	Thermo (%)	Wind (%)	Solar (%)	Geo (%)
2009	47.41	51.85	0.73	0.00	0.00
2020	47.84	32.51	10.00	7.65	2.00
2030	45.45	30.56	11.00	10.40	2.60
2050	40.90	29.31	12.10	14.31	3.38
2080	35.24	28.82	13.34	16.90	5.71
2100	35.00	27.18	14.01	16.39	7.43

In Table 3 the current trend of using fossil fuel power plants leads to a share of nearly one third of the installed capacity. Renewable energy will reach another third and the remaining demand will be satisfied with hydro power plants.

Table 4 Installed capacity matrix, Pessimistic scenario

Pes	Hydro (%)	Thermo (%)	Wind (%)	Solar (%)	Geo (%)
2009	47.41	51.85	0.73	0	0
2020	39.35	40.65	9	8	3
2030	35	42	9.45	10.25	3.3
2050	30.8	44.2	9.92	11.45	3.63
2080	25.26	47.17	10.94	12.25	4.39
2100	25.15	45.19	11.49	13.34	4.83

In Table 4 the use of fossil fuel power plants is intensified, which is coherent with the pessimistic scenario (A2 in IPCC).

Table 5 Installed capacity matrix, Optimistic scenario

Opt	Hydro (%)	Thermo (%)	Wind (%)	Solar (%)	Geo (%)
2009	47.41	51.85	0.73	0	0
2020	50	30	10	7	3
2030	44	26	16	10	4
2050	42.75	22.35	18	12.1	4.8
2080	37.02	8.98	20	25.26	8.74
2100	37.1	5.9	21.9	25.1	10

Table 5indicates that the optimistic scenario has the highest percent of renewable energies and the lowest percent of thermal power generation. It is expected that electricity generation from coal plants will decrease due to CO2 mitigation policies and towards energy independence.

4 Effects of CC on the Central Interconnected System (CIS)

The CIS is the main electrical system of the country, delivering electricity to more than 92 % of the population. The Metropolitan Region of Santiago represents 42% of the electric demand [11] and it is supplied by power generation sources located in other parts of the country. Then, when studying the effects of climate change in the electricity sector in Santiago,it is important to understand the behavior of the entire electric system (CIS).
The following sections analyze the effects of climate change in generation and transmission facilities of the Central Interconnected System (SIC).

4.1 Hydropower

At present, hydropower represent nearly 47 % of the SIC install capacity.This type of generation is dependent on climate conditions and in drought periods it is strongly reduced.
The forecast of hydropower generation is focusedon two main systems, Maule and Laja [4]. This two systems represent more than 40% of hydropower generation in the entire system. In Fig 14 the Average energy production of these systems, in GWh, are presented.

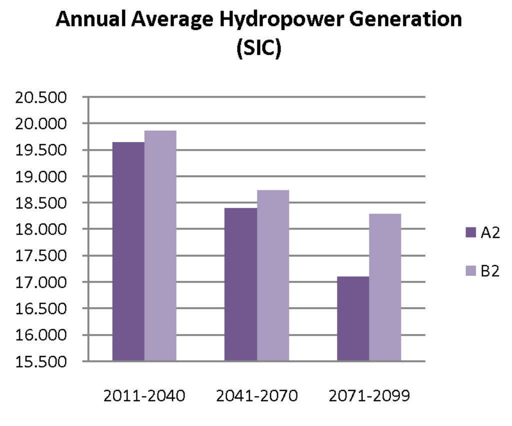

Fig14Annual Average Hydropower Generation (SIC).

The results show the same trend in both systems, moderate reductions in the first period 2011-2040, and strong reduction in the mid and late periods. In B2 scenario results show less decrease of hydropower generation than in the A2 scenario.
At the end of century the Maule system decreases 12% from the baseline period for the A2 scenario and 8% for the B2 scenario.The Laja System presents a decrease of 15% at the end of the century for A2 scenario and more than10% for B2 scenario.

The averagereductionsin hydropower energy, attributable toclimate changeare6%,12% and18% in A2 scenario forearly (2011-2040), middle (2040-2070) and late (2070-2100)period.The B2 scenario presents the same trends, but the percentages are 5%, 10% and 13% respectively.

4.2 Thermal Power

Currently, more than 51% of the SIC's installed capacity is thermal power.How efficient a plant is in transforming fuels into electric power depends upon the temperature differential between the machine and the external environment. The higher the temperature differential, the higher is the efficiency of conversion.

According to the projections presented in Section 2, climate change is likely to produce higher air and water temperatures. Therefore, the heat differential between the machine and the environment will decrease, thus reducing the net power generated from a given amount of fuel [12]. In fact, a 1°C increase in temperature reduces the power output of a nuclear plant at 0.8% and coal and gas plants by 0.6% [13].Other studies indicate that an increase of 1°C implies a decrease of approximate 0.63% in the output power of thermal plants [14].

By using these estimates, in the year 2009 the decreaseof thermal power caused by each Celsius-degree of increase in temperature is 109.71 GWh and 117.024 GWh, respectively.

4.3 Transmission System

The effect of rising temperatures will be an important factor in the transmission line design considerations. It is an inseparable aspect of the transmissionand distribution electricity sector, due to the Joule Effect caused by current flow in lines, which produces a power dissipation of RI^2. This indicates that heat losses, also called Joule Losses in a line, depend on the Ohmic resistance of the wires. In turn, the resistance depends on temperature almost in a linear way. Thus, an increase in temperature will prompt an increase in heat losses in the lines.

As a consequence, the effect of CC on the transmission system will worsen the current limit or thermal limit in the lines.

Nowadays, many studies regarding transmission capacity are run by considering 20°C as an operating temperature. CC will modify this temperature as shown in Table 6, wherethe operating temperatures for each period and scenario are depicted.

Table 6. Operating Temperaturesby Scenario

Scenario	2010-2040	2040-2070	2070-2100
A2	21.5°C	22.5°C	24°C
B2	21°C	22°C	23°C

Table 6 shows a higher temperatureincreasefor the A2 scenario.

The increase in operating temperature will reduce the transfer capabilities of all transmission equipment. This reduction is computed through a Derating factor (less than one), which represents the decrease in the transmission capability. Thus, the current limit multiplied by the derating factor is the future thermal limit. Table 7 show the Derating Factor for each scenario.

Table 7Derating factor by scenario and time period

Scenario	2010-2040	2040-2070	2070-2100
A2	0.97	0.95	0.92
B2	0.98	0.96	0.94

Table 7 indicates that the higher decrease is related to A2 scenario.

An average temperature increase, especially in the night temperature, will reduce the cooling cycle of transformers and other equipment; this will lead to a decrease in the average lifetime of equipment, more frequency of maintenance. Overall, this will imply early replacement of equipment by higher capacity equipment.

5 ELECTRICITY IN THEMETROPOLITAN REGION OF SANTIAGO

Santiago's climate is characterized by hot, dry summers and cold, wet winters (Mediterranean climate) [5]. Average summer high temperatures range from 28°C to 30°C, while minimum temperatures during winter range from 0 °C to 5 °C. Precipitation falls mostly during the months of June, July and August, with total precipitation amounts ranging from 200 to 500 mm each year.

Santiago is a growing city and the aggregate energy demand is increasing quickly, spurred by rapid population growth and an increasing GDP.

5.1 Transmission system in Santiago

To analyze the system a reducedfifty bus bar model of the SIC was used. Four expansion stages, defined for the years 2020; 2040; 2070; 2100, for each of the 3 scenarios studied in this paper (Pessimistic, Optimistic and BAU) are analyzed.

The analysis considers the following assumptions:

- All the loads grow at the same rate. This rate depends on the total demand projection considered by the year of study.

- The electricity generation matrices are those presented in Section 3.
- The expansion of the system it is done slowly, as the demand and generation are increased; by keeping the system reliability.
- The unit commitment economic dispatch it is done by using the merit order method.
- In the year 2020 three generic generators;solar, wind and geothermal generation; are incorporated.
- In the year 2040 an interconnection between SIC and SING (Interconnected System of Norte Grande) is considered. SING it is represented as a load of 300 MW.
- For the periods 2070 and 2100,SING load increasesof 20% and 30% percent are considered, respectively.

Santiago's consumption is represented by three bus bars: Alto Jahuel; Polpaico and Cerro Navia. Alto Jahuelreceives most ofthe south hydropower generation. After 2040, this bus receives the power from geothermal sources near Santiago.Polpaico is the bus bar that receives the thermal power generation from central coast and north of SIC. After 2020 wind and solar power will arrive from the north to this northern bar of Santiago(the major percent of radiation and wind velocity is located at the north side of Chile).Finally, Cerro Naviareceives the thermal power generation from Renca and Nueva Renca power stations.

The results are presented by year of study in the next sections.

5.2.1 Year 2020

Results for power flow studies are shown in Table 8.

Table 8CIS Power Flow results, year 2020

	Generation	Load	Grid Losses	Lines
	P (MW)	P (MW)	P (MW)	km
Opt.	10857.54	10363.84	526.55	9397.35
BAU	10993.72	10472.94	520.79	9220.55
Pess.	11324.72	10909.31	415.41	8537.97

The BAU and optimistic scenarios have a similar demand estimations for the year 2020, the difference its only 1.05%. Although these scenarios have the lowest generation and load values, they have the higher grid losses. In Optimistic scenario the major generation sources are hydropower and renewable energy. This result is consistent with other studies, which establish that future transmission systems will expand in order to grant access to remote points, commonly associated with renewable energy generation sources [16].

The last column in Table 8 shows the line extensions. It can be seen that the greatest number of line kilometers is related to Optimistic scenario.
The smaller extension is related to the Pessimistic Scenario. The major generation source for the Pessimistic scenario is thermal power, which is mostly located at central coastal zone very close to the higher consumption of the SIC, Santiago.

In Table 9 the results for Santiago are presented.

Table 9. Power Flow results for Metropolitan region, 2020

Santiago	Alto Jahuel	Polpaico	Cerro Navia	Total
BAU	2945.2	1495.2	854.9	5295.3
Pess.	3059	1507.8	990	5556.8
Opt.	3139.3	1228.7	842.1	5210.1

According to the results, Santiago represents between 47%-49% of total SIC's consumptions.

For Optimistic scenario 60 % of the Santiago's consumption comes from south hydropower and geothermal sources, which arrives to Alto Jahuel bus bar.For Pessimistic scenario the power related to this bus bar decreases to a 55%.BAU scenario is more diverse in terms of energy sources.

5.2.3 Year 2040

In this expansion stage the interconnection between SIC and SING is considered. Results are shown in Table 10.

Table 10CIS Power Flow results year 2040.

	Generation	Load	Grid Losses
	P (MW)	P (MW)	P (MW)
Opt.	20006.87	18845.82	1161.05
BAU	20945.27	19664.02	1281.25
Pess.	21539.92	20482.22	1057.7

Table 10 shows the same pattern that the 2020 results (Table 8) but in this case BAU scenario has greater losses. This is due to the generation mixand a higher demand associated to BAU scenario.

For 2040 an increase of 1.5°C (Pessimistic scenario) and 1°C (BAU and Optimistic scenarios) is expected; that implies a decrease in 3% (Pessimistic) and 2% (BAU and Optimistic) of the current limit.
The final result is that in Pessimistic scenario is necessary to increase the grid capacity (lines km) in 3.39% and for BAU and Optimistic scenario an increase of 2.62% and 0.12% is needed. Thus, climate change starts to be noticeable as a reduction in the current capacity of lines is observed.

In Table 9 the results for Santiago are presented.

Table 11Power Flow results for Metropolitan region, 2040.

Santiago	Alto Jahuel	Polpaico	Cerro Navia	Total
BAU	4458	4128.4	1358.2	9944.6
Pess.	3386	6049.9	1607	11042.9
Opt.	4595.9	3636.3	1135.7	9367.9

Table 11 shows an intensified behavior of Table 9. In Pessimistic scenario 55% of power use in Santiago comes from Polpaico while in Optimistic scenario the major percent comes from Alto Jahuel, 49.06% only a 38.82% comes from Polpaico.

5.2.4 Year 2070

The generation results are presented in Table 12.

Table 12Power Flow results, year 2070.

	Generation	Load	Grid Losses
	P (MW)	P (MW)	P (MW)
Opt.	27118.88	24905.94	2212.94
BAU	30121.8	28178.73	1943.06
Pess.	31318.63	29542.4	1776.24

In this expansion stage a higher difference between Optimistic and BAU scenarios is observed. The BAU generation is 12% higher than the BAU scenario. Also, a higher increase of renewable energies is seen in the Optimistic scenario. As these energies are more distant than other power plants, they imply higher grid losses (see Table 12).

In this expansion stage an increase in temperature in 2.5°C (Pessimistic) and 2°C (BAU and Optimistic) is observed. This increase in temperature will produce a decrease in current limits in 95% and 96% respectively (see **Error! Reference source not found.**). The expected decrease in current or thermal limit will trigger an increase of the grid extension (line km) in 1.33% for Optimistic scenario; 1.46% in BAU scenario and 1.95% in Pessimistic scenario.

Table 13 Power Flow results for Metropolitan region, 2070.

Santiago	Alto Jahuel	Polpaico	Cerro Navia	Total
BAU	6328.3	6341.1	1778.7	14448.1
Pess.	4622.5	8615.3	2166.9	15404.7
Opt.	5887.6	5657.5	1155	12700.1

The results of power flow in Santiago show the same pattern than the ones observed in Table 11, except for Optimistic scenario.
In the Pessimistic scenario 55.93% of the Santiago consumption provides from Polpaico. BAU scenario has a more diverse generation matrix, where 44% of the power comes from Polpaico, 44% from Alto Jahuel and a 12% from Cerro Navia. The optimistic scenario has a different behavior due to the increase of renewable energies, 44.5% of power to Polpaicocomes mostly from solar and wind energies (together represent 40% of the generation matrix).

5.2.5 Year 2100

The generation results are presented in Table 12.

Table 14 Power Flow results, year 2100

	Generation	Load	Grid Losses
	P (MW)	P (MW)	P (MW)
Opt.	29893.25	27390.54	2502.71
BAU	32565.63	30390.6	2175.04
Pess.	36989.33	34754.32	2235.01

It's observed that the power requirements at the end of century are approximate three times the requirements at 2020.
The same pattern than in 2070 stage is observed, higher grid losses for Optimistic scenario even though has less demand and generation.
At the end of century an increase in temperature in 4°C (Pessimistic) and 3°C (BAU and Optimistic)is expected. This increase in temperature will mean a decrease in current limits in 92% and 94% respectively (see **Error! Reference source not found.**). The expected decrease in current or thermal limit will mean an increase of the grid (line km) in 1.9% for Optimistic scenario; 1.47% in BAU scenario and 2.84% in Pessimistic scenario.

Table 15Power Flow results for Metropolitan region, 2100.

Santiago	Alto Jahuel	Polpaico	Cerro Navia	Total
BAU	6799	7118.5	1778.5	15696
Pess.	5827.7	9628.9	2657.3	18113.9
Opt.	6187	6792	1035	14014

In Table 15 it is observed that more generation comes from Polpaico in the three scenarios. The expected decrease of hydropower and an increase in renewable energies mostly located in the north of the SIC produce this pattern change. In this stage 48.47% of the Santiago's consumption for Optimistic scenario comes from Polpaico, which is mostly renewable energy.

7 Conclusion

This paper presents CC impacts on the Chilean Central Interconnected System and the Santiago city.

First, climate historic and future trends are analyzed. Results for central and southern regions (where is mostly located the SIC) project an increase between 1-2.5°C for 2040-2069 period, and an increase between 2-4°C for 2070-2099 period. The results also indicate a decrease of 10% to20% for precipitations in the period 2040-2070 and a decrease of 20% to 30% in the period 2070-2100.Warming temperatures and decreasing precipitation is expected for the region according to the models. In particularly, for Metropolitan region is expected that in the near future (2045-2065) Santiago will be a dryer, hotter city, with a high number of days with extreme temperatures, increased drought during the winter and summer.

Scenarios are defined in order to project energy demand and to analyze the impact of climate change in the Chilean energy system. Three scenarios are considered: BAU (Business as Usual), Optimistic and Pessimistic.
The main results for the pessimistic scenario show that this scenario has the higher Chilean total energy demand, reaching 111.89 GWa at the end of century. The scenario with less energy consumption is the Optimistic with 78.02 GWa in 2100. The BAU scenario has a middle consumption of 94.21Gwa.

Regarding the electric demand, the pessimistic scenario has the higher value, reaching 34.04 GWa in 2100. This value is 25.18% higher than the electric demand in optimistic scenario, and 13.25% higher than the BAU scenario.

In the power supply sector a reduction in hydropower energy is expected. The reduction is due to a decrease in precipitation. The hydro power decreases are 6%, 12% and 18% in A2 scenario forearly (2011-2040), middle (2040-2070) and late (2070-2100) period. And for the B2 scenario the decrease has the same trend, but is less intensive, with percentages of 5%, 10% and 13%, respectively.

It is expected that the generation from coal plants will decrease as this energy type is affected by temperatures. How efficient a plant transforms fuels into electric power depends upon the temperature differential between the machine and the external environment. If the external temperature increases the efficiency decreases.

In the future for Santiago are projected higher temperatures, therefore it is expected that the temperature demand pattern will change and the highest electric demand will be in summer months (December, January and February) due to air conditioning systems. This change could adjust the load maximum peak behavior.
The main conclusion observed from the power flow analisisis that,despite the Optimistic and BAU scenarios have the lowest generation and load values, they have the higher grid losses. This is because the transmission system will expand to grant access to remote points, which are associated with renewable energy generation sources. In Optimistic scenario the major generation sources are hydropower and renewable energy. In other hand the Pessimistic scenario has the lower losses the main reason is that the major generation source for this scenario is thermal power, mostly located at central coastal zone very close to the higher consumption of the SIC, Santiago.
The power flow results for Santiago show that the demand increase during the XXI century, at the end of the century the increase is slowly for the saturation electric demand-GDP pattern. The consideration that all the loads increase in the same rate is a strong consideration and could be some source of errors. Despite that the results do not intend to be accurate the main gold is to reflect the Santiago electric demand trend.
Since 2040 the effect of climate change isobserved in the thermal capacity of the lines. The increase in temperature will decrease the current limits. At the end of century is expected an increase in temperature in 4°C (Pessimistic) and 3°C (BAU and Optimistic). This increase in temperature will induce a decrease in current limits in 92% and 94% respectively. The expected decrease in current or thermal limit will produce an increase of the grid (line km) in 1.9% for Optimistic scenario; 1.47% in BAU scenario and 2.84% in Pessimistic scenario.

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