Indicator based Sustainability Analysis of Future Energy Situation of Santiago de Chile

Volker Stelzer, Adriana Quintero, Luis Vargas, Gonzalo Paredes, Sonja Simon, Kristina Nienhaus, Jürgen Kopfmüller

Abstract—*Up to now, the Chilean Energy system has fulfilled the energy needs of Santiago de Chile considerably well. However, development trends of the current system impose significant future risks on the energy system. A detailed sustainability analysis of the energy sector of the Metropolitan Region of Santiago de Chile was conducted, using selected energy indicators and a distance-to-target approach. Risks for the sustainable development of the energy sector are detected, such as increasing concentration in the energy sector, import dependency for fossil fuels and increasing* CO_2 *emissions from energy production. Options towards a more sustainable development of the Megacity of Santiago within the national Chilean energy system are asssessed, such as the enhancement of energy efficiency and an increased use of renewable energies.*

Keywords—*future energy situation, indicators of sustainability, scenarios, sustainable development in developing countries*

I. INTRODUCTION

Chile's energy system is characterized by a strong growth as well as a high degree of privatization and economic concentration of energy service providers, which are controlled by the National Energy Commission (CNE) and the Energy Ministry. The total energy use in Chile (primary consumption) increased from 789 PJ (Petajoule) in 1999 to 1,593 PJ in 2012 [1], an annual average growth of 5.6%. This surge in energy consumption is for the most part a result of population growth, a highly dynamic economic development, and deficiencies in the effective use of energy resources. Approximately three quarters of the primary energy is based on fossil energy resources, which are almost completely imported from abroad.

The energy consumption of the Santiago Metropolitan Region (SMR) is dominated by the traffic sector accounting for 38% of final energy. This is followed by industry (27%), households (22%), and trade and services (13%) (data based in own calculation on [2]). By taking a closer look at the distribution of the final use of energy in terms of energy sources, it can be seen that – especially due to the energy use in the traffic sector – oil derivatives account for almost half of the final energy consumption. The other half is more or less equally distributed between gas and electricity.

The SMR can cover only 25% of its electricity demand on its own; therefore 3/4 of the electricity has to be imported. In the SMR 50% of the power is generated by fossil-fired thermal power plants, 50% by hydroelectricity.

Industry consumes the largest share of the electricity in the SMR (30%), followed by households (26%), and trade (22%). Mining accounts for 7%, agriculture for 2%, and the other sectors for 13% [3]. The power consumption per capita in the category "households" varies considerably in the different districts of Santiago. While people in Vitacura – one of the municipalities with the highest average household income – use around 1,200 kWh electricity per capita and year, people in the "poorer" municipalities Alhué and El Monte only consume less than 360 kWh [4].

II. ENERGY SCENARIOS

In a first step two framework scenarios for the years 2030 habe been developed and the interrelations between the framework scenarios and the energy sector were analyzed. This was the starting point for the development of energy scenarios (according to [5]).

The future development of the indicators was estimated and assessed in the framework of these energy scenarios, partly based on the MESAP/PlaNet model (see [6]). The parameters which were included in the modeling are presented in table 1.

Table 1 Role of selected energy parameters in the energy scenarios 2030 (source: based on [7])

Area	*BAU* (Business as usual)	*CR* (Collective Responsibility)	*MI* (Market Integration)
Role of hydropower	Realization of the large-scale plant HidroAysen	Focus on small hydroelectric power plants	Realization of the large-scale plant HidroAysen
Role of non-conventional renewable energy carriers	Implementatio n of agreed target values (5% for 2010 / 10% for 2024)	Strong increase of combined heat and power, wind, solar, geothermal energy, biomass	Intensified increase in power generation by wind and solar panels
Role of fossil fuels	Further investments in fossil fuel power plants	Gas as backup for renewable energies	Further investments in fossil fuel power plants
Transport sec-tor: share of electric vehicles in all cars registered	6%	10%	10%

III. STAKEHOLDER INVOLVEMENT

In the course of the framing project "Risk Habitat Megacity", a joint German-Chilean research initiative [8], 30 experts from research, federal and regional authoritities, and the industry were interviewed. These interviews provided important information on the data basis and the current situation, but also on the assessments of the future of the energy supply in Santiago and Chile and thus also for

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the further development of the scenarios.

A stakeholder workshop was held at the Economic Commission for Latin America and the Caribean (ECLAC) in Santiago. The aim of the workshop was to discuss indicators and target values as well as scenarios. During the workshop, the 20 participants from universities, authorities, and the industry entered into – in some cases very lively – discussions, especially concerning the indicators.

One of the results of the participation process was, that nuclear power is no option for Chile because

a. the high risk of disastrous earthquakes,

b. the huge investment and follow up costs of the technology and

c. the very high national potential on renewable energy with very low follow up costs.

The energy results were presented in a concluding workshop. Here especially the presented options for action were topics for discussion.

In addition, the results were included into the dialog of the regional government of the metropolitan region (GORE) for the development of a regional "politica de energies limpias".

IV. SUSTAINABILITY ANALYSIS IN THE ENERGY SECTOR

A comprehensive set of 44 indicators was compiled on this basis of an analyses of international literature (see [9]). Then 16 "core sustainability indicators" were chosen from this list, especially regarding the appropriate representation of the rules of sustainability of the integrative concept of sustainable development [10]. Finally the following 8 indicators for the assessment of scenario results were chosen primarily based on the criteria (a) possibility to determine target values for the indicators and (b) availability of SMR data:

1. Share of rural households with no access to electricity
2. Duration of electricity supply interruptions
3. Total primary energy consumption
4. Energy intensity estimatied as: Energy per GDP
5. Share of renewable energies in electricity production
6. Energy-related CO_2 emissions per capita
7. Energy import dependency estimatied as: Percentage of primary energy use based on imported energy
8. Degree of economic concentration in the energy sector

Where no sufficient data was available for the SMR, national or regional values were collected for the respective indicators. Target values were identified for all indicators based on existing local, regional, or national values; if this was not possible, scientific expertise was taken as a basis.

Table 2 Scenario results ☺ = target reached, ☹ = more to do

Indicator	Unit	Current value	Target value 2030	BAU 2030		CR 2030		MI 2030	
Share of rural households with no access to electricity in the SMR	%	0.4 (2008)	0.0	0.0	☺	0.0	☺	0.0	☺
Duration of electricity supply interruptions in SMR	h	2.8 (2008)	0.0	0.6	☹	0.2	☹	0.4	☹
Total primary energy consumption	PJ	497 (2007)	As low as posible	880	☹	680	☺	824	☹
Energy per GDP		85 (2008)	≤ 40	65	☹	50	☹	60	☹
Share of renewable energies in electricity production	%	55 (2007)	≥ 70	66	☹	75	☺	76	☺
Energy-related CO_2 emissions per capita	t	4.8 (2007)	2.5	5.3	☹	3.1	☹	4.6	☹
Percentage of primary energy use based on imported energy	%	77 (2007)	≤ 50	69	☹	52	☹	67	☹
Degree of economic concen-tration in the energy sector	%	90 (2003)	≤ 70	90	☹	86	☹	95	☹

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V. DISCUSSION OF RESULTS ACROSS SCENARIOS

The sustainability analyses of the current status and the scenario development of the indicators show a heterogeneous picture for the different scenarios. There are numerous positive developments, but also cases with large discrepancies from the target values have to be stated.

As an example, we will have a closer look at the indicator “percentage of primary energy use based on imported energy”.

One detected sustainability deficit for Chile (and the SMR) is the high dependency on fossil fuel imports, as this increases vulnerability to supply shortages and price increases. For many years Chile has been importing more than two thirds of the required energy resources. The import quota of primary energy increased from 50% in 1990 to more than 70% today. Reasons for this are the growing energy demand and the scarce reserves of conventional energy carriers in Chile.

Especially the import of natural gas from Argentina increased considerably in the past. In 2006/2007 Argentina dramatically reduced the export of natural gas to Chile by a breach of contract; this caused serious problems for Chile’s industry and private households. As a consequence, gas was to a large extent replaced by diesel and coal, which lead to a triplication of diesel imports. Also the import of oil and coal increased significantly during this period. Until 2010, approximately 1 billion US dollars were invested into two large international ports (Quintero and Mejillones) with a capacity of ca. 16 million m^3 liquid gas (LNG) per day to compensate for the gas supply shortage from Argentina.

The scenario results show that different developments are possible here. Indeed the percentage share of the dependency on imports is being reduced in the BAU and MI scenarios. But the growing energy demand raises the absolute amount of imported energy raw materials. An absolute as well as a relative decrease would only be possible in CR resulting from both the significantly smaller increase of the energy demand and the stronger use of domestic renewable energies (see fig. 1) without realizing the large-scale plant HydroAisen. In this scenario a reduction of the dependency on imports to 55 % could be nearly achieved.

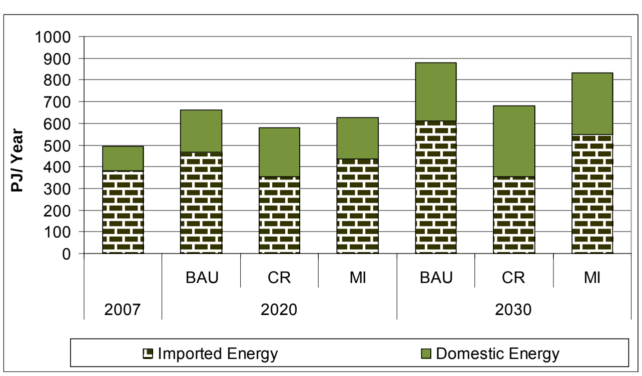

Fig. 1 Dependency of the RSM on foreign energy imports (based on [11])

VI. ENERGY POLICY FOR MORE SUSTAINABILITY

During the last years, Chile took some energy-political steps towards a more sustainable energy supply. An Energy Ministry was created on the national level, a program for energy efficiency was launched, and the regional government responsible for the SMR is working on a “politica de energía limpia” for the metropolitan region. In a future according to the CR scenario it would be possible to achieve some or come near to the sustainability target values for the selected indicators, e.g. for the indicator dependency on imports. In a world according to the BAU or MI scenario this would be different. From the foresight aspect it is therefore necessary to take further action.

One important measure is to enhance energy efficiency beyond the current activities in Chile to achieve the ojective of an efficiency increase of 20 % by 2020. In addition, in the course of the development of thermal energy production plants, gas-fired power plants should be preferred to coal-fired power plants since these can be controlled more flexibly and are therefore better suited for a continuous energy supply in combination with power plants which are based on fluctuating renewable energy carriers dependent on climatic conditions.

All in all, numerous studies conclude that non-conventional renewable energies (NCRE) in Chile have enormous potential for the future of the energy sector [12], [13] by far exceeding current policy targets. Univertsity of Chile and Technical University Federico Santa Maria estimate, that by 2025, non-conventional renewables could account for up to 30 TWh produced by almost a 6 GW installed capacity and provide more than 30 % of the total power generation [14].

The enormous potential for the use of energy from renewable sources is not equally distributed over Chile. The main reserves of energy potentials can be found for

- hydropower in the Andes
- biomass in the forests in the south, in the agricultural areas in the Central Region and the waste of the metropolitan region,
- wind power in the south,
- solar energy in the north,
- ocean energy in the west and
- geothermal energy all over the country.

To ensure that the energy from the different regions arrives in the SMR, the infrastructure of supply lines has to be improved. Concerning the large potential of solar energy available in the north, there is the possibility of producing hydrogen or methane from solar electricity and feeding these gases into the natural gas grid which supplies the different regions of Chile coming from Argentina but is not used to capacity due to the Argentine supply shortage.

The search for and analysis of potentials from renewable energies should be started in the SMR since transport-related line losses are increasing with growing distance to the energy source. An evaluation of the suitability of existing roof areas for generating solar energy based on data

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from an "overflight" of the SMR would be quite easy to realize, as it is currently done in Osnabrueck (Germany) [15], but also waste material and sludge from the SMR have high potentials for a regional supply with renewable energy.

To achieve the necessary goals of increasing both the energy efficiency and the share of renewable energies in the total energy production, not only technological measures are required but also the establishment of political framework conditions which hardly exist in Chile and the SMR today. Here especially the introduction of relevant taxes and charges for the use of fossil energy carriers has to be mentioned as well as the fact that the feed-in of renewable energies into the grid should be facilitated and given priority.

Another important measure will be the analysis of the local energy resources (hydro, biomass, solar, ocean, and geothermal) of the SMR area and the two neighboring regions V and VI and to public these information for free in the internet. This could be the basis for investors to plan their energy projects for the SMR.

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