Towards a sustainable electricity system in Chile.

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Current situation and assessment methodology

Carlos Gaete[1,5], Alejandro Gallego[2,5], Laurence Stamford[3,5] and Adisa Azapagic[4,5]

ABSTRACT

Achieving sustainable development is a priority nowadays, and electricity systems play an especially relevant role. In 2014, Chile consumed 70.4 TWh of electricity generated mainly from hydropower and thermal plants. Since 2008 Chile has experienced consistently high prices of electricity affecting the national economy. In addition, society is not inclined to support new power plants due to distrust of the environmental assessment system and the lack of public discussion. On the other hand, the electricity sector is considered the largest contributor to climate change, and therefore a plan is required to reduce its greenhouse gas emissions. Considering the economic, social and environmental challenges, this article presents a methodology for assessing the sustainability of electricity production in Chile. The sustainability of the electricity system will be assessed considering future scenarios and using tools such as life cycle Assessment (LCA), social life cycle assessment (SLCA) and life cycle costing (LCC).

Keywords: Life Cycle Assessment (LCA), electricity generation, environmental social and economic evaluation, sustainability.

I. INTRODUCTION

1.1. Sustainable Development

In 1987, Sustainable Development was defined for the first time by the United Nations (UN) as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

In achieving this sustainability, electricity plays a major role. On one hand, electricity helps to bring about efficient industrial development and social progress. On the other, current electricity systems are shaped by technologies which have negative impacts on the environment, and can generate economic and social problems. For that reason, electricity systems should be designed to overcome these issues and contribute to sustainable development.

1.2. The electricity sector in Chile

The electricity sector in Chile had, in 2014, an installed power capacity of 20,265 MW which is mainly composed of fossil fuels followed by hydropower with shares of 61.3% and 31.7% respectively [1] (see Table 1).

The generation of electricity in 2014 totalled 70.4 TWh produced by 4 electricity systems: i) Central Interconnected System (SIC by its acronym in Spanish), ii) Interconnected System of Norte Grande (SING), iii) Aysen and iv) Magallanes. The first two – SIC and SING – are the major systems, while the latter two are located in southern Chile and provide less than 1% of the electricity produced in the country.

SING is located in the northern part of the country, an area with a predominantly desert climate. It covers close to 25% of the Chilean mainland surface area yet only 6% of Chile's population lives there. The quantity of energy produced by this systems is 15.8 TWh, 67.8% of which is consumed by mining companies [1]–[3]. Electricity in SING is mainly produced by thermal power plants located on the coastline.

Table 1. Electricity generation and power capacity by source in Chile in 2014 [1], [4], [5].

Sources	**Installed Capacity**		**Electricity**	
	Gross capacity [Mw]	***Share [%]***	***Gross supply [TWh]***	***Share [%]***
Coal	4,519	22.3%	28.4	40.3%
Natural Gas	5,059	25.0%	10.3	14.6%
Oil	2,828	14.0%	3.4	4.8%
Hydro	6,430	31.7%	23.7	33.6%
Biomass	453	2.2%	2.7	3.9%
Wind	734	3.6%	1.4	2.0%
Solar	224	1.1%	0.5	0.7%
Cogeneration	18	0.1%	0.1	0.2%
Total	20,265		70.4	

The second main system (SIC) is located in the central area of the country and is the largest electrical system as it supplies power to 90% of Chile's population and extends over 2,100 km. This system is mainly composed of hydropower and thermoelectric power plants and reached an electricity generation in 2014 of 47.3 TWh [1], [2], [6].

1.2.1. Economic aspects

In the case of the SIC system, the hourly average marginal cost in 2013 was US$151/MWh and in 2014

[1] e-mail: carlos.gaetemorales@postgrad.manchester.ac.uk
[2] e-mail: alejandro.gallegoschmid@manchester.ac.uk
[3] e-mail: laurence.stamford@manchester.ac.uk
[4] e-mail: adisa.azapagic@manchester.ac.uk
[5] School of Chemical Engineering and Analytical Science, University of Manchester, C16, the Mill, Sackville Street, Manchester M13 9PL, UK.

US$135/MWh [1]; this compares to around US$50/MWh in the USA [7]. Underlying these high prices are some structural deficits. In the case of the mentioned SIC system, during the 1990s electricity was mainly produced by hydropower causing a high volatility of prices because of variability of hydrologic conditions from one year to the next [6]. From 1996 to 2004 the use of natural gas power plants fed by Argentinian gas reduced the volatility of electricity prices, reaching a US$24.78/MWh 'node price' (the softened price developed for consumers in order to protect them from the higher variability of wholesale price). However, the curtailment of Argentinian gas started in 2004 reaching almost the total reduction of supply in 2007 leading to a rising of node prices up to US$103.75/MWh in 2008 [2], [8], [9]. Due to these circumstances, gas power plants had to be replaced by coal power plants. The hydropower and coal generation allowed a reduction in price volatility, but since 2008, electricity prices in SIC have remained high [8].

This may be explained by the following factors: i) High volatility of fossil fuel prices [2]; ii) The occurrence of three years of drought between 2010 and 2012 [10], iii) Lack of investment in new energy projects caused by difficulties experienced in obtaining certifications, mainly explained by environmental and public opposition in spite of less interest in investing [10] and iv) the exertion of market power ("ability of an agent to influence the price of the market" [11]), due to the existence of a highly concentrated electricity market in which three companies have historically owned up to 89% of total SIC capacity (and currently own about 76% including subsidiaries) [1], [10], [12], [13]. Several authors have established that liberalized markets can allow companies with high market share to exert market power in different ways (e.g.: through reduction of investment; over-investing in peaking technology and under-investing in base load technology) [11], [12], [14]–[16].

As SIC represents a high percentage of Chile's electricity demand, high electricity prices become an important national issue affecting individual consumers and production sectors. Empirical results confirm that Chile's high electricity price has affected negatively the economic activity, consumption, private investment, employment, and the export sector to the industry which compete with imports and productivity [17]. The capacity of meeting personal needs is affected and production sectors become less competitive, affecting deeply the economic growth [18].

1.2.2. Social concerns

On the other hand, the electricity sector has been facing social opposition since 1992 when indigenous leaders disapproved the construction of Pangue and Ralco hydropower plants and were requested to leave their ancestral territories [19], [20]. In 2011 the Ministry of Energy conducted a study to identify the difficulties experienced by electricity projects in progressing to commissioning. In total, 13 projects (predominantly hydropower dams and thermal power plants) were identified that had received 117 administrative or legal objections [21], demonstrating high social opposition. This is in part explained by Mundaca [9] who stated that Chile's environmental framework law permits private companies to choose the information to be presented in the Environmental Impact Assessment (EIA) system, and, therefore, allows manipulation, lessens transparency and suppresses opportunities for public discussion in the assessment process. Similarly, Berdegue [22] stated that society's continuous opposition to new power projects is due to the lack of legitimacy of the evaluation process which does not provide an effective space for discussion; additionally, the distribution of costs and benefits for affected communities is inadequate.

1.2.3. Environmental impacts

As a member of UN, Chile has committed to creating a new international climate agreement to be presented in the U.N. Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP21) that will be held in Paris in December 2015. For that reason, in December 2014 the Chilean government presented a public consultation to decide national strategy for reduction of greenhouse gas (GHG) emissions. The reduction will vary from 25% in 2025 up to 45% in 2030 in relation to 2007 emissions. Considering that the main contributor to GHG emission is the energy sector (75% in 2010), the mitigation plan will focus in the reduction of emissions generated by the electricity system.

Chile will face important challenges in the coming years associated with economic, social and environmental aspects, where the electricity sector will play a relevant role. All the issues mentioned in previous sections justify the development of a study that assesses sustainable future scenarios for the electricity system in Chile through the application of a specific methodology.

II. SELECTED METHODOLOGY

Santoyo-Castelazo and Azapagic [23] developed recently a methodology to assess the sustainability of energy systems. These authors developed a generic framework that can be applied to a variety of energy systems and enables the integration of sustainability assessment with future scenarios using a life cycle approach. This methodology has been selected to be applied to the Chilean electricity system.

2.1. Sustainability assessment methodology

As can be observed in Figure 1. this methodology consists of several consecutive steps: i) selection of sustainability indicators, ii) selection and specification of technologies, iii) definition of scenarios, iv) environmental, economic and social assessments and v) multi-criteria decision analysis.

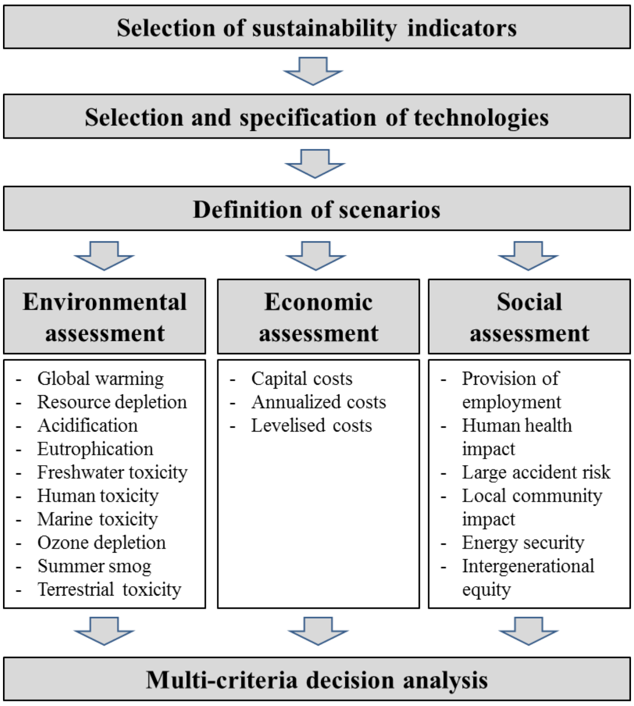

Figure 1. Sustainability assessment methodology [23].

2.1.1. Selection of sustainability indicators

Several environmental, social and economic indicators can be chosen to assess the sustainability under a life cycle approach [23]. For environmental issues, Life Cycle Assessment (LCA) is a methodology that explores the potential environmental impacts caused by a product during its whole life cycle (raw material extraction and production, infrastructure commissioning, products or services production, use and final disposal). It has been used for more than 35 years and has become a well-known tool which has been useful in several sectors, including energy generation [24]. The life cycle assessment (LCA) methodology is regulated by the International Standards Organization (ISO) through the ISO 14040 standards. Based on LCA, the following environmental impacts can be considered in the mentioned sustainability methodology: global warming, abiotic depletion, acidification, eutrophication, freshwater aquatic ecotoxicity, human toxicity, marine aquatic ecotoxicity, ozone depletion, photochemical ozone creation and terrestrial ecotoxicity [23].

Social life cycle assessment focuses in the social effects of the life cycle of a product or process. This methodology shares similarities with environmental LCA, including the following challenges: acquiring site-specific data; addressing location- or scale-specific information; and achieving standardised techniques [25]. Social indicators can be considered in the assessment methodology according to their relevance to the sector, such as provision of employment, human health impact, large accident risk, local community impacts, energy security and intergenerational equity [23], [26].

For the economic evaluation, life cycle costing (LCC) will be applied. LCC is defined as "an economic evaluation of different design options taking into account every significant cost to obtain assets along the economic life of each option expressed in present currency". For energy systems, LCC is used to estimate and compare all costs associated with the production of electricity in different scenarios. The economic indicators that may be considered are: capital costs, total annualized costs, and levelised costs, where the latter represents total costs per unit of energy [23].

2.1.2. Selection and specification of technologies

The aim of this step is to identify all technologies that could be included in the analysis according to availability in the present or future and territorial conditions [23]. For example, renewable, nuclear or conventional technologies may be considered in this analysis.

2.1.3. Definition of scenarios

Scenario analysis is included to find alternative energy situations and assess their sustainability implications. Several factors can be considered for the development of scenarios, such as economic growth, security of supply, mitigation of climate change and future technological development [23].

2.1.4. Environmental, social and economic assessment

Each scenario must be assessed with the purpose of estimating its potential impacts. The indicators selected previously are applied in this step [23].

2.1.5. Multi-criteria decision analysis (MCDA)

Robust decisions involving a range of options must consider a range of environmental, economic and social criteria. Often, there is no single best option in relation to all criteria: decisions may lead to an improvement in some criteria and a decline in others. In order to support improvements and solve these problems, MCDA provides various structured techniques for decision makers [27].

MCDA methods address problems that involve multiple criteria based on preferences or weights for each criterion. This is particularly useful in energy systems because of the various sustainability issues that have to be considered and a diverse range of stakeholder perspectives [14]. For that reason, MCDA had been used extensively in relation to sustainable energy [27].

Generally, the first step in MCDA involves identification of options or scenarios to be considered and sustainability indicators which will be used as decision criteria [27]. This is followed up by decision makers expressing their preferences for different decision criteria by assigning weights of importance. Various methods can be used for this, including the analytical hierarchy process or utility function [28]. This could be carried out by consultation with decision makers [27] in which they are asked to compare different indicators, or in a wider consultation with other stakeholders, such as the public [28]. The indicators are then aggregated into a single score based on the weights of importance so that the alternatives or scenario can be compared more easily, thus facilitating identification of the most sustainable option [28], [29].

III. CONCLUSIONS

Electricity systems are highly complex involving many environmental, social and economic aspects. The case of Chile is not an exception and the results of implementation of the proposed sustainability methodology will give support to decision and policy makers. One of the major challenges will be to find, select and develop information that is correct and appropriate in the context of Chile's characteristics.

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