Renewable and Sustainable Energy Reviews 94 (2018) 154–167

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Environmental impact profile of electricity generation in Chile: A baseline study over two decades

Mabel Vega-Coloma*, Claudio A. Zaror

Department of Chemical Engineering, University of Concepcion, P.O. Box 160-C, Correo 3, Concepción, Chile

ARTICLE INFO

Keywords:
Life cycle impact assessment
Chilean electricity generation

ABSTRACT

Chile is one of the world largest copper producing countries, housing significant mineral reserves, and accounting for over 30% of national electricity consumption. Currently, the total installed electricity generation capacity amounts to over 20 GW and is expected to double within the next two decades. Since electricity generation is a well-known source of environmental impacts throughout its lifecycle, there is a permanent need to evaluate potential environmental burdens of alternative courses of action. Unfortunately, systematic information on the environmental performance of current electricity generation in the country is lacking. Therefore, this paper reports the potential environmental burdens of the Chilean electricity generation system over the last two decades, to account for temporal effects and serve as a baseline to which compare different strategies, following a cradle-to-gate approach based on ISO 14.040–44:2006 standards. The system limits included fuels extraction and transportation processes, and construction materials, as well as electricity generation, considering as a functional unit 1 kWh.

Plant operation, thermal efficiency and infrastructure requirements were modelled based on primary data, whereas fuels extraction, refining, and manufacturing of construction materials were obtained from Ecoinvent databases.

Changes in water availability, commercial constrains in natural gas supply, investment in renewable energy technologies, among others, have led to significant changes in the environmental profile along time. Results obtained here show stricter environmental legislation and more efficient environmental control technologies need to be introduced to promote improvements in environmental performance, with particular focus on human health and ecotoxic effects in coal-fired power plants.

Finally, new electricity generation capacity based on solar, wind, and other renewable sources should be encouraged to reduce the environmental footprint of electricity generation, thus fostering the competitiveness of Chilean exports.

This work provides a sound baseline for the assessment of future development scenarios, constituting an interesting case study for comparative studies.

1. Introduction

Since the early 90's the Chilean economy has experienced significant growth rate, particularly due to the expansion of mining, forestry, manufacturing, agricultural, and marine products. Currently, Chilean exports amount to nearly US$ 80,000 million, with important contributions to the world market; particularly, in copper, salmon and cellulosic products, with Chilean exports meeting 30%, 24%, and 12% of total world demand, respectively.

As environmental and social performance becomes a key factor for competitiveness, scientists, engineers and investors are pressed to include those criteria in decision-making. As a member of the OCDE countries since 2010, Chile has embraced international agreements to improve environmental and social performance in line with sustainable development goals.

In this respect, electricity usage and its associated primary energy consumption and emissions are important contributors to the life cycle environmental impacts of many products and processes, and also a significant component of the carbon footprint of products, institutions, and geographic regions.

In Chile, most electricity is generated and distributed in two hitherto independent electricity networks, namely the Interconnected Greater Northern Network (SING) and the Interconnected Central Network (SIC), with a total installed capacity of 20,285 MW.

* Corresponding author.
E-mail address: mabvega@udec.cl (M. Vega-Coloma).

https://doi.org/10.1016/j.rser.2018.05.058
Received 18 October 2017; Received in revised form 29 March 2018; Accepted 25 May 2018
1364-0321/

Historically, the SING network is mostly composed of thermoelectric power plants, whereas the SIC network features a significant share of hydroelectric plants. During the last 20 years, Chilean electricity consumption has doubled in line with economic growth, reaching over 70,000 GWh/year in 2015, with around 75% contribution from the SIC network. This trend is expected to continue, despite great efforts to improve energy efficiency in all economic sectors, that has led to a 50% reduction in electricity intensity during the last two decades, to a present 250 MWh/MM $US GDP. Moreover, since 1995 the SING and SIC systems have experienced important changes in the mix of primary energy sources, mainly due to economic incentives, climate change effects, as well as restrictions in the availability of natural gas from neighbouring Argentina.

Recently, an Energy 2050 strategic roadmap has been developed with the participation of key public and private stakeholders, with view to meeting long term energy scenarios [1]. This strategy establishes alternative courses of action to improve safety and quality of energy supply, environmental sustainability, and energy efficiency, among other key factors. Given the unique solar, hydro, wind, and geothermal energy potential in Chile, those policies are likely to trigger new investments in electricity generation capacity with a significant impact on the electricity mix. Moreover, the SING and SIC networks will be fully interconnected within the next couple of years and plans to link the Chilean grids with the rest of South American neighbours within the next two decades are already underway, opening the way to interesting environmental and technological challenges.

Unfortunately, very little systematic information on the environmental implications of present and future energy scenarios in Chile are currently available, affecting decision making at both private and public levels. Indeed, most decisions so far have been taken on the basis of information from international experience. Nevertheless, electricity cannot be considered as a homogeneous commodity, since potential environmental and human health impacts associated to specific electricity generation processes are determined by the nature of primary energy sources, site specific conditions, among other factors [2–5].

There is widespread consensus that potential environmental and human health impacts associated to electricity generation extend upstream to the very extraction of natural resources, refining processes and materials transport; involving also power plant construction, and end of life. Therefore, a Life Cycle Assessment (LCA) approach constitutes an appropriate and widely used methodological framework to assess the environmental performance of electricity generation systems [2,6]. As a result, LCA has become instrumental in policy-making in the energy sector, and there is a growing body of literature reporting LCA for electricity production in several contexts [2,6–10]. Previous studies have reported on the environmental performance of electricity networks at country levels [11–18], including the temporal factor [4] and future projections scenario [3,5,10,19–24].

Environmental burdens associated to specific generation technology have been widely reported [25–29], with emphasis on land use [30], greenhouse gases emissions [31,32], and freshwater consumption [33,34]. Those results have been used in the assessment of eco-efficiency of electricity mixes at top European economies, providing targets to less efficient countries [35].

In the Latin American region, life cycle assessment for electricity generation was carried out in Brazil at country level by Coltro et al. [11], and at technology level focussed on hydropower plants [36], coal based power plants [37] and electricity generation from sugarcane bagasse [38]; whereas in Mexico a life cycle assessment was developed for electricity production taking as base the year 2006 [39].

In Chile, just a few examples of LCA application could be found, mainly in context of the quantification of the environmental burdens of primary copper production [40,41].

The lack of systematic studies on the past and present environmental life cycle impact of Chilean electricity production reduces the capacity to make rational policy and investment decisions. Within this context, the goal of this LCA is to fill such information gaps, providing an environmental life cycle assessment of electricity generation in Chile based on primary data, over the period 1995–2015. Thus, the effect of climate change and technological evolution could be accounted for, providing a basis for the environmental assessment of future scenarios and decision-making of public and private stakeholders. Results from this study are expected to serve as a robust baseline for the assessment of future scenarios in electricity generation.

2. Methodological framework

The ISO 14040:2006 [42] and 14.044:2006 [43] standards were used as the methodological framework to conduct this LCA study.

As mentioned above, this study included all significant inputs and outputs related to electricity generation in the Chilean SING and SIC networks, including major materials and energy inputs, air and water emissions and solid wastes. A hybrid LCA approach to describe the system was followed [44], focussing on cradle-to-gate boundaries for each electricity technology and grids. Hybrid LCA is a combination of the economy wide Input/output (I/O) and Process models. The first uses simplifications such a linear relationship among I/O and the process can only be aggregated into limited number of sectors. On the other hand, the process model assessment typically consists of a detailed inventory of resource inputs and environmental outputs converting this approach in a very data intensive and time-consuming exercise [45,46]. This hybrid LCA approach has been widely used in previous research for electricity production [5,9,10,23] and provide a well proxy of real environmental profile.

2.1. Goal and scope definition

Within the scope of the study, the system function is the generation of electricity and its delivery at point of connection to the electrical distribution system (ie. busbar) at the SING and SIC networks. The functional unit, which enables the system inputs/outputs to be quantified and normalised, is one kilowatt-hour (kWh EE) delivered at the busbar, as suggested by Curran et al. [7] and UNEP [10]. As mentioned above, this study covers the period 1995–2015, and 99.3% of the Chilean electricity generation capacity.

This is a cradle-to-gate LCA study, considering all production steps from raw material extraction to the high voltage electrical current delivered at the busbar. The system boundaries and the main unit processes modelled here are illustrated in Fig. 2, shown in following sections.

2.2. Environmental impact assessment models

There is a wide range of impact assessment models, including mid-point and end-point approaches [46]. In this study, the updated version of CML 2 Baseline 2000 v2.05/World, 1990 [47] environmental impact assessment was used to describe the environmental performance of the electricity Chilean matrix. This includes ten mid-point indicators that account for climate change, natural resources depletion, and emissions to soil, water, and air, among others. Additionally, the Eco-indicator 99 end-point impact assessment model was used for comparison's sake. That model considers three end-point indicators related to damage to human health, ecosystem quality, and resources use, each related to a number of impact sub-categories. Both impact models have been widely reported in LCA applied to electricity generation [3,14,18,35,39].

The software package Simapro v.7.3.3 [48] was used to model the systems and calculate environmental impacts, on the basis of primary data complemented with the Ecoinvent v. 2.2 database.

2.3. The Chilean electricity generation system

The SING network covers the Northern part of Chile, extending