Environmental impacts of lack of hydropower planning in Chile: 110 years

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1. Summary

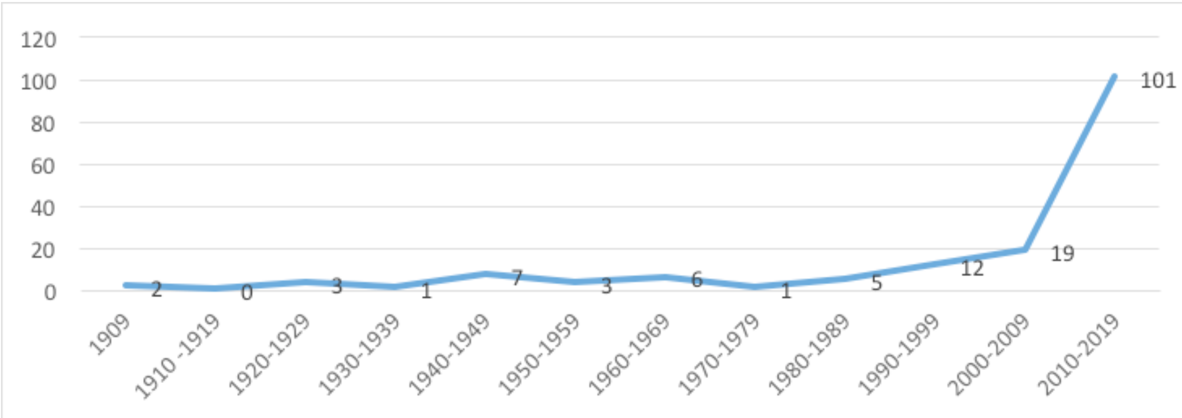
A comprehensive review was made regarding hydropower development in Chile during the last 110 years. From 1909 to 2019, a number of hydropower projects have been developed without any systematic strategic planning, based mainly in a project to project evaluation. Despite the development of an environmental regulation in 1994, impacts have not been significantly minimized mainly because of the lack of planning, generating a number of cumulative impacts along the country. This research presents the results and lessons of this review, using IHA Hydropower Sustainability Protocol framework, focused mainly on the impacts on rivers and those related to transmission lines. Some recommendations are also proposed for the future of hydropower in Chile or other countries.

2. Introduction

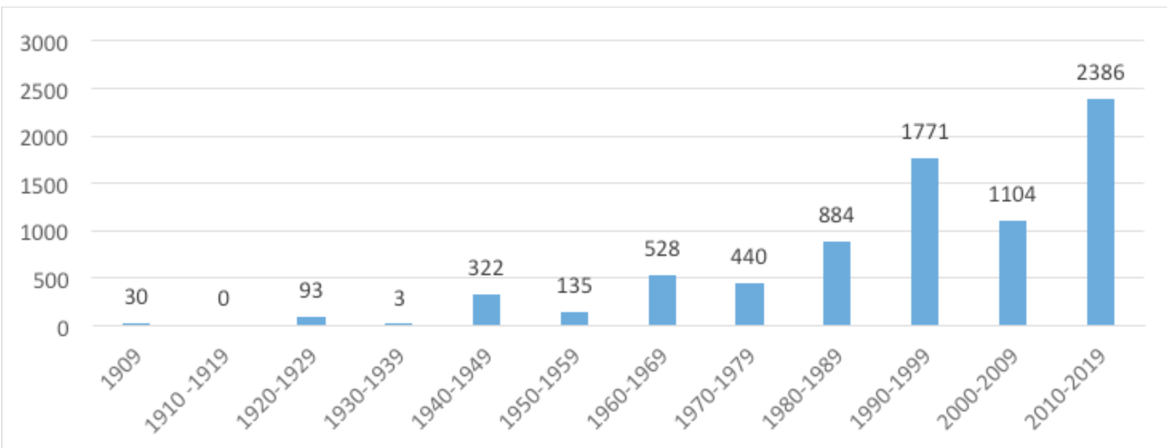
Due to Chile's particular geography, a narrow strip of land between the Andes mountain range and Pacific Ocean, it´s hydropower potential has been developed intensively, with the first power plant "Central Florida" installed in Santiago, Metropolitan Region in 1909. Since then, 153 hydropower plants have been commissioned and are injecting energy into Chile's National Electric System, or SEN (Sistema Eléctrico Nacional, in Spanish). The SEN is the main alternating current power grid, spanning all of Chile from Arica and Parinacota Region in the north to Los Lagos Region, almost 3,000 km to the south.

The increase in hydropower projects commenced slowly after the year 1909, but grew exponentially after the 1990`s (see Graph 1 and Graph 2).

Graph 1: Nº of hydropower projects commissioned in Chile from 1909 to 2019[1]



Graph 2: Gross power [MW] of commissioned Hydroplants in Chile from 1909 to 2019



In 1994 Chile passed the first legislation that created the existing Environmental Ministry, which required power plants (over 3 MW) to evaluate eventual impacts and to get an environmental licence before implementation. That regulation incorporated environmental and social requirements into project design in its different phases (Environmental Impact Evaluation System, or SEIA). Of the 153 projects that are operating, today only 37% have an environmental license (the others are prior to environmental law, or smaller than in size that required to be evaluated in the SEIA). Another 45 hydropower projects have been approved by the Chile´s Environmental Agency, and have not yet been commissioned, or are under construction and not yet operating.

However, no broad strategic planning has overlooked this exponential growth, and each individual project doesn't consider the overall effect of this lack of this

[1] Includes power plants that are in testing fases before comisining.

planning on a global scale. It must be said that some efforts of cumulative impact assessment are included (in newer projects that have gone through the SEIA), but not on a global scale.

3. Objectives

Evaluate the current impact in selected environmental indicators of hydropower projects currently functioning in Chile from a global point of view, considered 'base case' without strategic planning.

Develop an optimization model that considers the same environmental indicators, and prioritized the best hydropower projects from an environmental standpoint. That is, the objective is to simulate the 'optimum scenario' (with strategic planning), and indicate in which order each hydropower project should have been constructed.

4. Methodology

4.1. Definition of environmental criteria relevant to this study

This study looks in detail of the current situation 'base case without strategic planning' regarding a few environmental criteria relevant on a global perspective. The criteria was selected considering The International Hydropower Association (IHA) Sustainability Protocol, and are the following:

- **Number of new affected rivers:** The total amount of rivers that are intervened by works of art; dams, return channels, and intakes were identified. In cases were the hydropower projects used existing infrastructure, the number could be zero (for example, projects that capture and return to an existing manmade water channel).
- **Kilometers of intervened rivers:** This considers the total length of river(s) that is (are) intervened, either by reservoir surface, or by the segment that is between the intake and return channel. Since biodiversity and water quality is very different depending on where the hydro project is situated, the total distance intervened regards all habitat and abiotic factors as equally important.
- **Number of new affected basins:** The location of the hydropower project has special relevance. Most rivers in Chile flow from east to west, and empty into the Pacific Ocean, but there are some smaller basins that flow into lakes or smaller arteries that are relevant from a more political point of view. Since communities and indigenous people are not a direct criterion of this study, the ideal scenario is that fewer basins should be affected, for

fewer communities to receive eventual negative environmental and social impacts (principally related to the construction phase, resettlement, living standards, and water rights).

- **Reservoir surface:** It is a relevant indicator, to assess the efficiency of each individual project versus Gross Power (MW). Also it has a relevant effect on flooded terrestrial habitat, eventual relocation of communities and land use.
- **Kilometers of new transmission lines required:** This criteria is relevant in the study, since transmission lines usually require new roads and land use for the construction phase and for maintenance activities. There are also visual impacts, eventual impacts on cultural heritage, etc. The study considers that the main transmission line (SEN) that is located from north to south, is the main “electrical highway”.

It is important to state that there can be other relevant environmental and social criteria that are not considered in the present study, like; indigenous people, relocation of communities, fish habitat, etc. However, these are aspects that are more difficult to model with the available information and, therefore, should be properly evaluated with other environmental and social management tools.

4.2. Proposed model “Optimized grid”

Considering the same criteria, we propose an optimized grid, prioritizing which projects should be implemented if there had been strategic planning. An algorithm was built using the Python software, and each criterion was normalized. This considers that every project is ranked on each individual environmental criterion, and depending on its environmental “Score” (from 1 to 100 for each different criterion), a final point system was set. The project with the highest score was selected, and then the software was run again with the remaining projects, recalculating all scores. This iterative scheme permits a realistic approach to model based strategic planning.

The study also considers precedence restrictions, that prioritizes new projects to be constructed close to existing ones fewer kilometers of transmission lines, and fewer basins to be affected.

In last place, protected areas were revised, to lower scores of projects that were located upstream; and that could eventually affect protected areas.

It is relevant to state that strategic planning must be designed with specific objectives and multiple factors have to be taken into perspective. The “Optimized grid" (with strategic planning) for this study has only defined a few aspects, that can be perfected depending on the goals of the users.

5. Results

A total of 198 hydropower projects were revised, of which 77% are currently commissioned (153 projects functioning); 49% of these are projects that do not have environmental license (97 projects are prior to environmental law, or that are not required to be evaluated in the SEIA). The other 28% of functioning projects have environmental licenses. There are a total of 45 projects that have environmental licenses, and have not yet been implemented.

The Python software was run (see Annex 1 for modeling results), proposing the optimized grid, considering the best projects (see Annex 2 for project scores and order of construction). The results show the first project to be constructed, in order to maximize the energy generation with a minimum environmental impact, is Alto Maipo, with a score of 93,7, followed by Quilleco, Alto Cachapoal, Convento Viejo and Rucue, with scores between 81 and 92. The project with a minimum score recommended to be constructed was Rio Huasco, with a score of 65.

Aggregate results also show all of the environmental criteria evaluated for the 'Optimized grid' has less impacts than the Base Case (see Table 1), that is, Chile current condition.

- Results in much fewer projects to be employed; maintaining almost the same gross power.
- In general bigger projects (reservoirs) have higher scores, and with the proposed model generating lower reservoir surface.
- Less kilometers of rivers affected, and fewer basins affected.
- More efficiency in costs, since the total costs are lower.

Table 1: Final results compared between 'base case' and 'optimized case'

INDICATORS	Base Case	Optimized	% Variation
Nº of projects operating	153	48	-68%
Gross power [MW]	6.709	6.788	1%
Power average	44	141	-
Reservoir surface (ha)	20,289	12,390	-39 %
Km affected river (Run of River)	871	514	-41%

Km of transmission line (km)	2.152	869	-60%
Total Cost (MM USD)	17.162	14.940	-13%
N° of affected basin	38	14	-63%
N° of affected rivers	99	44	-56%
km LdT/MW	0,32	0,13	-60%
MM USD / MW	2,56	2,20	-14%

6. Conclusions and Discussion

Chile has developed great part of it´s hydropower potential without adequate strategic planning. The absence of planning has had higher environmental impacts, versus and optimized grid.

The finding of this study indicate that implementing strategic planning in hydro power projects, though a designed model that focuses on key environmental factors, can significantly reduce environmental impacts, maintaining the installed power capacity. This can also reduce implementation costs and permit higher efficacy in the proposed grid.

In general, the results of this study suggest that bigger hydropower projects are more sustainable and have less environmental impacts, than the sum of many smaller mini hydro projects. For example, the Alto Maipo Project (530 MW) ranked as the best sustainable project.

This is a general statement, since the results of the study do suggest there are many mini-hydro that have very high scores (for example Convento Viejo, that is the 4th best project). On the opposite, there are some large projects not recommended by the algorithm, for example, because their large reservoirs (like the Rapel dam that is not needed to maintain the installed power).

In conclusion, with adequate planning Chile would have been able to develop more efficient power plants, which would affect a smaller amount of rivers and basins, lower environmental and social costs, with a lower amount of transmission lines and a lower cost for the country.

Countries that are in preliminary stages of their hydroelectric development could save significant sums of money and avoid numerous environmental impacts with proper planning.