Many Small Vs A Few Large? The Hydroelectric Feasibility of Small-Scale Hydropower Plants in Southern Chile

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***Abstract*—**In recent years, the performance of large dams has been challenged in different regions of the world especially due to their environmental impacts. Extensive conversion of land, major alteration of hydrological systems, and disruption of freshwater ecosystems are some of the identified effects of large dams on natural resources. After much controversy, in 2014 the government of Chile rejected the mega hydroelectric project 'HidroAysen' due to potential environmental impacts of the dams in the south of the country. However, the energy demand of Chile is continually increasing year by year, leading the government to search for alternative sources in order to meet present and future demands. The unique geography of Chile suggests that around two hundred basins have hydropower potential. Because the implementation of several small-scale hydroelectric schemes (SHS) rather than large-scale dams has not been explored as a possible alternative in Chile, this paper will present a an approach by which large versus small hydropower performance is compared in order to inform present and future water resource management.

***Keywords*—**Chile; Energy Supply; Environmental Impact; Hydroelectric Potential; Large Dams; Small-Scale Hydroelectric Schemes; Water Resource Management.

***Abbreviations*—**Cubic Meters Per Second (m3/sec); European Small Hydropower Association (ESHA); International Center on Small Hydro Power (ICSHP); Small-scale Hydroelectric Schemes (SHS); Mega Watts (MW).

I. INTRODUCTION

OVER the last thirty years, Chile has been experiencing strong economic development, with an annual GDP of six percent [World Bank, 25]. This process has meant a steady increase in electricity consumption, reaching an annual growth of seven percent between 2012 and 2013 [Bennett, 14]. However, the unstable import of natural gas from Argentina and Bolivia has generated a severe energy crisis due to the excessive dependence of Chile on this external source [Ministry of Energy, 27]. Considering this, the government and the private sector have been searching for alternative energy sources with the capacity to meet growing demand.

Within this context, hydroelectric development has been part of the Chilean energy agenda because of the considerable hydropower potential of the rivers of the country, which has been calculated to be more than 60,000 MW without exploitation [Raineri & Contreras, 18; Ministry of Energy, 27; International Center on Small Hydro Power, 32]. Large-scale hydropower development has been considered the best alternative for the management of water resources in Chile [Ministry of Energy, 27] due to its cost efficient relationship between investment and power generated. However, in recent years attitudes towards mega dams have been changing in Chile as in response to the promotion of environmental awareness by green NGOs and international concerns about the impact of large-scale development on natural resources [Larraín & Schaeffer, 22; Ponce et al., 26]. According to the World Commission on Dams [3], the price paid by affected communities and the environment has been too high in relation to the benefits provided by mega dams. In their last report, the Commission highlighted the need to assess all available options for meeting water and energy needs before proceeding with a large dam project, which means a crucial change in the water resource policy arena.

In 2008, despite growing opposition to large dams, the major energy companies of Chile, Endesa and Colbun SA, proposed the project 'HidroAysen' to the government with the aim of of constructing five mega dams in the Aysen region with an investment of US$ 3,200,000 and a total flooded area of 6,000 hectares [Environmental Assessment System of Chile, 36]. The Environmental Impact Assessment (EIA) presented by the proponents was partially approved by the government in late 2008. However, the Chilean population rejected the government's decision arguing that 'HidroAysen' would destroy valuable biodiversity and irreplaceable ecosystem services in the Aysen Region through the construction of the water reservoir and related facilities [Goodwin et al., 9; Habit et al., 11; Vince, 24]. Headed by the national NGO 'Patagonia without Dams,' environmentalists and the broader community generated significant controversy at the national and international levels, which finally led the government to reconsider the previously approved EIA of 'HidroAysen'. Finally, after a long conflict, in July 2014 the project was officially rejected by a special Inter-ministerial Committee because of the likely environmental impact of the dams [Ministry of Environment, 37].

Despite this outcome,, the increasing energy demands in Chile require the government to find new energy sources to support the country's economic growth. Under this scenario, the National Energy Strategy [Ministry of Energy, 27] has defined five non-conventional renewable energies to be implemented in different regions of the country; solar and geothermal in the north, wind and biomass in the central area, and small-hydro in the south of Chile. It is this latter option that represents a clear opportunity for the development of Small-scale Hydroelectric Schemes (SHS). This paper describes the feasibility of such an alternative option in hydropower generation.

II. LARGE DAMS: THE BEST OPTION?

International concern about the environmental/social performance of large-scale dams has been increasing since the beginning of the present century. In the year 2000, in its last report, World Commission on Dams indicated that the benefits to society provided by dams cannot be compared with the costs to environmental and disadvantaged groups [Khennas & Barnett, 2]. Biodiversity loss, extensive conversion of land, climate modification, and irreparable alteration of hydrological flows are some of the impacts that large-scale dams have on natural resources [Millennium Ecosystem Assessment, 7]. Critical thresholds on biodiversity loss, climate change, and nitrogen cycling have been largely transgressed over recent years [Rockstrom et al., 16] which has been used as the basis of challenges to the development of large-scale dams. Furthermore, dams represent a significant flood risk in regions of the world at risk of natural hazards such as seismic activity [Pittock, 21].

More than half of the large rivers globally are affected by dams, with consequent fragmentation and flow regulation of important hydrological systems [Nilsson et al., 8]. A combination of climate change with large-dams development is creating irreversible impacts on biodiversity and ecosystems services in several regions of the world [Pittock, 21]. Furthermore, disputes regarding transboundary water are an important outcome of mega dam construction, not only in relation to hydrological systems but also the geopolitical situation of numerous countries in Africa and Asia [Wolf, 1].

In Chile, the 'HidroAysen' project was partially approved by the government in 2008 as a possible option to address increasing energy demand, which is expected to double by 2030 [Bernesson et al., 5]. With an approximate investment of US$3.2M, the project was supposed to provide a total installed capacity of 2,750 MW by constructing five dams in the Baker and Pascua Rivers [BBC News, 28; Environmental Assessment System of Chile, 36] (Figure 1).

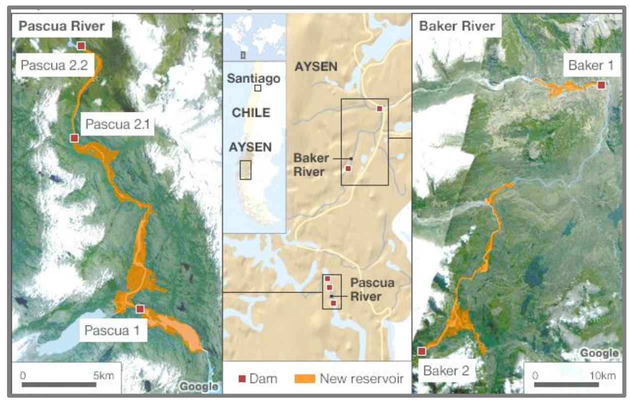

Figure 1: Location of the 'HidroAysen' Project in Southern Chile

The large flooded area of the project (5,900 ha) as well as the length of its transmission line (2,000 km) encouraged civil society, scientific groups, and several environmental NGOs to appeal the primary approval of the government. Amidst ongoing controversy, the project was officially rejected in June 2014 [Ministry of Environment, 37]. Within this context, the government has now started a campaign to boost alternative energy sources with low environmental impact. According to the National Energy Strategy (2012–2030) mini-hydraulic, wind, biomass, solar, and geothermal energy are the best options for present and future development [Ministry of Energy, 27]. Considering the geographical characteristics of Chile, each of these renewable energy sources have potential to be implemented in different regions: solar and geothermal in the north, biomass and wind in the central valley, and mini-hydraulic in the southern territory.

III. SMALL-SCALE HYDROELECTRIC SCHEMES AS A POSSIBLE APPROACH

Recently, run-of-river hydropower plants have been implemented in several countries as new alternatives to the exploitation of water resources. Because they do not require water storage or large tracts of land, their environmental impact is almost negligible on land and aquatic ecosystems [Paish, 4; Bernesson et al., 5; Balat, 10; Aggidis et al., 20]. According to the European Small-Scale Hydropower

Association (ESHA), this type of technology does not interfere with the hydrological flows of a basin system due to the low discharge required for their operation, allowing the conservation of fishery resources [Kosnik, 19; European Small Hydropower Association, 29]. Regarding social impacts, run-of-river schemes do not involve land conversion or resettlement issues, and as a consequence they have the overall support of local communities [Khennas & Barnett, 2; Rojanamon et al., 17]. On the other hand, as SHS does not disrupt hydrological systems, they do not affect agriculture and irrigation practices [Ministry of Energy, 27] (Figure 2).

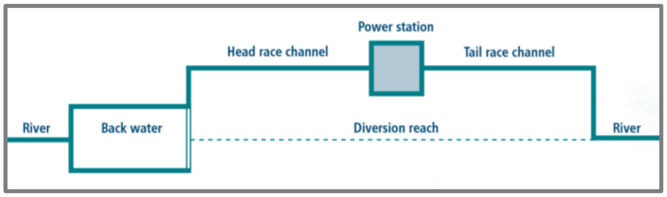

Figure 2: Layout of Small-Scale Hydroelectric Power Plant

According to the International Center on Small Hydro Power (ICSHP) there are 148 countries world-wide using small hydropower schemes [International Center on Small Hydro Power, 32]. Until the year 2011, there were over 75 GW of total installed capacity provided by SHS, with an expected further potential of 170 GW. Considering the unexploited potential of SHS, as well as its environmental and social advantages, the United Nations Industrial Development Organization (UNIDO) is currently promoting an international system of dialogue and networking to engage small hydropower stakeholders in the development of this technology as a suitable option for present and future energy diversification [United Nations Industrial Development Organization, 23]. The European Small Hydropower Association (ESHA) reveals that several countries in northern Europe are implementing small hydropower schemes as part of the national power grid, under an environmentally friendly approach with remarkable results [European Small Hydropower Association, 29]. With an installed capacity of over 13.5 GW an annual generation of 48,783 GWh in 2010, SHS produces about 7,8% of Europe's Renewable Energy electricity, and plays an important role in generating stable and cost-efficient electricity. In addition, 4,200 SHS companies contribute to the European economy through the direct and indirect creation of over 29,000 jobs across the continent.

In Canada, the industry of SHS has been rapidly increasing over time due to the availability of hydrological resources in the country. In 1986, the total energy provided by SHS was 560 MW across 99 sites in the country. In 2006, the energy provided by SHS had reached 3,500 MW with 359 sites for its operation [Natural Resources Canada (NRCan), 38]. In Turkey, since 1995 the total installed capacity produced by small hydropower has tripled due to increased private investment in the sector, and is expected to continue growing over the next few years [Balat, 10]. In China, SHS provides 97% of the energy provided by renewables, supplying electricity to one-quarter of the total population. The development of SHS in this country has been extremely fast, with 6,93 GW of installed capacity in 1980 to 34,66 GW in 2004. By 2050, forecast results predicts a total installed capacity of 120 GW [Zhou et al., 12]. Japanese government and agencies are currently promoting small-scale hydropower as a form of renewable energy from such standpoints as CO2 reduction, diversification of energy sources, reduction of maintenance costs of facilities and revitalization of local communities. There are 1,369 operational small hydropower plants in and 2,476 untapped small hydro sites [Agency for Natural Resources and Energy (ANRE), 39]. Overall, international trends show that the contribution of SHS to the total energy supply has been and will be increasing with time.

At the economic level, SHS will probably involve a higher investment than large-scale dams. An SHS costs around US$2M per MW of installed capacity versus the value of the 'HidroAysen' project [Natural Resources Canada (NRCan), 38] which is US$1.2M per MW of installed capacity [Environmental Assessment System of Chile, 36]. However, the value of the unique ecosystem services of the Aysen Region is not included in the neoclassic economic equation.

Even though there is no official valuation of these services, it is obvious that both the government and civil society had to prioritize the conservation of the biodiversity of southern Chile. From an ecological economics perspective, human welfare cannot be measured only through economic growth and development but also should consider the current ecological limits of the planet, allow for fair distribution, and promote an efficient allocation of resources [Daly & Farley, 6; Costanza et al., 30].

IV. STEP-WISE RESEARCH PROCESS

Considering the environmental, social, and ecologically economic advantages of SHS as well as the recent governmental rejection of the megadam proposals in southern Chile, the idea of implementing several run-of-river schemes as a possible alternative to the 'HidroAysen' project is presented here. This requires analysing the hydraulic potential of rivers in southern Chile and determining the hydroelectric feasibility of this approach comprises four main steps (see also Figure 3).

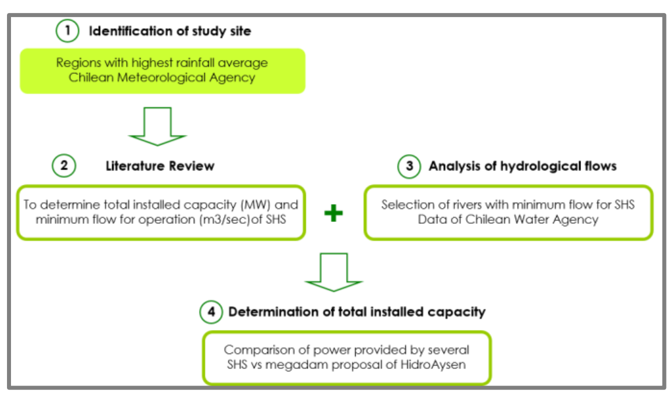

Figure 3: Step-wise Process in Identifying the Hydroelectric Feasibility of SHS in Southern Chile

1. Identification of the study site: In order to ensure a stable energy supply, the selection of the study site corresponds to the regions with higher average annual rainfall, which allows a constant flow for the operation of SHS. To achieve this, the data available on the website of Meteorological Agency of Chile [34] was used, which identifies rainfall patterns of the main cities and regions of the country.

2. Identification of the hydro-electrical requirements of SHS: There are different classifications of SHS. Based on recent literature on SHS development, the total installed capacity (MW) and the minimum flow for operation (m3/sec) of this type of schemes are determined within the study site.

3. Analysis of the hydrological flows: Having defined the study site as well as the necessary flow for SHS the flow of rivers and canals of the study area were analysed using data available on the website of the Water Agency of Chile [40]. This provides real-time information about the hydrologic characteristics of several rivers across the country. All monitoring stations with available flow data were initially considered. In the case of major rivers with a flow over 600 m3/sec, had more than one monitoring station along the river. Because of the large flows of these rivers, all the monitoring stations were considered as possible sites for the development of SHS since they require an insignificant amount of the total flow of these rivers.

4. Determination of the potential installed capacity for SHS: After collecting the flow data of the rivers and canals of the study area, only the hydrologic systems with a higher flow rate than the identified benchmark in the Stage 2 of this methodology were selected for detailed analysis. This benchmark corresponds to the minimum flow required for the proper functioning of SHS. The total number of potential sites with enough flow for the operation of SHS, will be multiplied by the MW of individual installed capacity of each SHS (also identified in stage 2 of this methodology) in order to obtain the total installed capacity of the rivers and canals of the study site. The potential installed capacity of SHS development was then compared with the installed capacity of the proposed of mega dams in southern Chile.

V. RESULTS

1. Determination of the study site: In order to ensure constant operation of SHS, it is necessary to consider regions of Chile with the highest rainfall patterns. According to the Meteorological Agency of Chile [34] the sites with higher annual rainfall (over 1,000 mm) are the regions of Bio Bio, Araucania, Los Rios, Los Lagos and Aysen. In the case of Los Rios and Los Lagos, the data was aggregated as they used to belong to the same region until recently [Military Geographic Institute of Chile, 35] (Figure 4). It is worth noting that the location of the mega dam proposal (HidroAysen) is in the Aysen region, within the present study site.

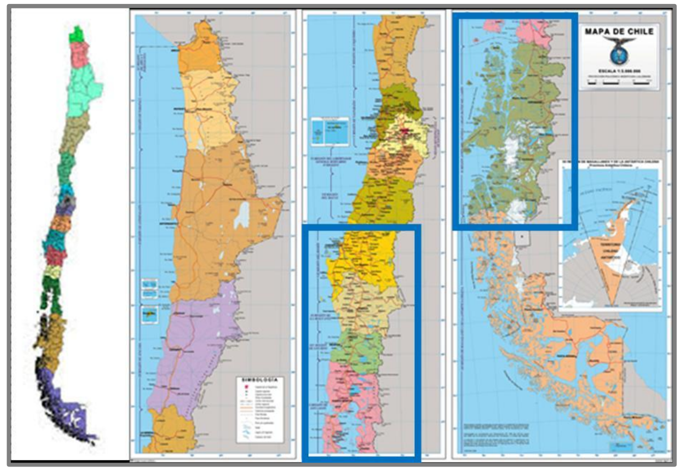

Figure 4: Identification of the Study Site

2. Identification of hydroelectrical requirements of SHS: There are different classifications of the SHS schemes, but taking into account the significant hydropower potential of Chile as well as the latest available technologies, an adequately installed capacity for SHS corresponds to 50 MW, and the minimum flow for its operation is equal to 13 m3/sec [Huang & Yan, 13; Prakash & Bhat, 15; United States Environmental Protection Agency, 31; The Hydro Equipment Association, 33; Natural Resources Canada (NRCan), 38].

3. Analysis of the hydraulic characteristics of the rivers of the study site with reference to the rivers that have enough flow (m3/sec) for the operation of SHS. According to the data available in the Hydrological Report 2014 of the Chilean Water Agency of Chile, there are 61 monitoring stations with a flow rate higher than 13 m3/sec [Water Agency of Chile, 40]. Each of these monitoring stations represents a different river, except for larger rivers that have more than one monitoring station. Each of these monitoring stations represents a potential site for the development of SHS.

Flow data of the rivers and canals of the regions of Bio-Bio, Araucania, Los Rios, Los Lagos and Aysen according to available information in the website of the Water Agency of Chile [40] are presented below (Figures 5-8). In order to allow a better understanding of the graphics, a horizontal line was plotted with the value identified as the minimum flow required for the operation of SHS (13 m3/sec).

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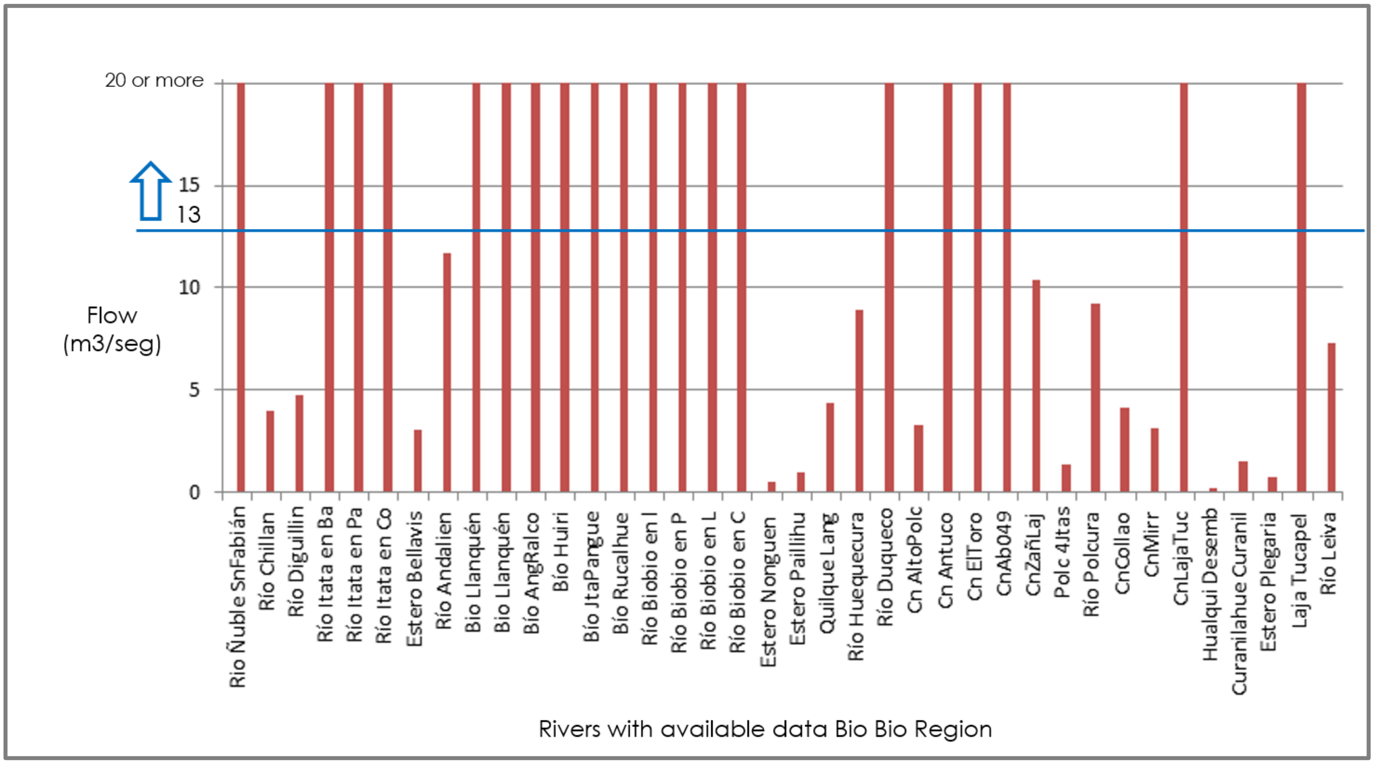

Figure 5: Flow (m3/sec) of the Rivers of the Bio-Bio Region

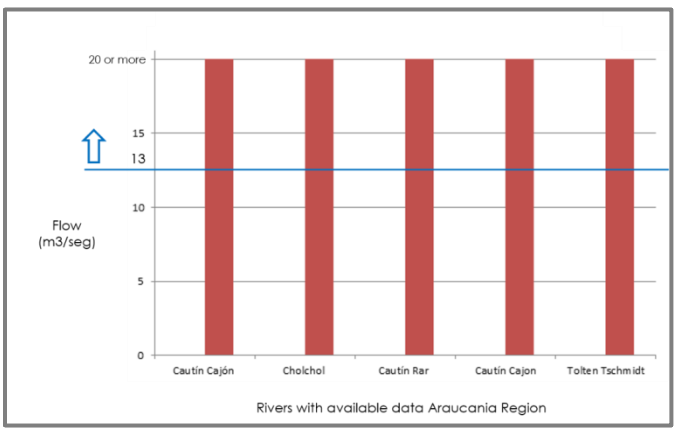

Figure 6: Flow (m3/sec) of the Rivers of the Araucania Region

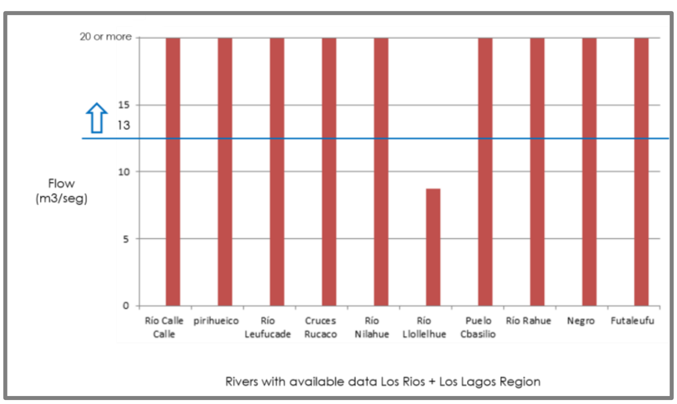

Figure 7: Flow (m3/sec) of the Rivers of the Los Rios and Los Lagos Region

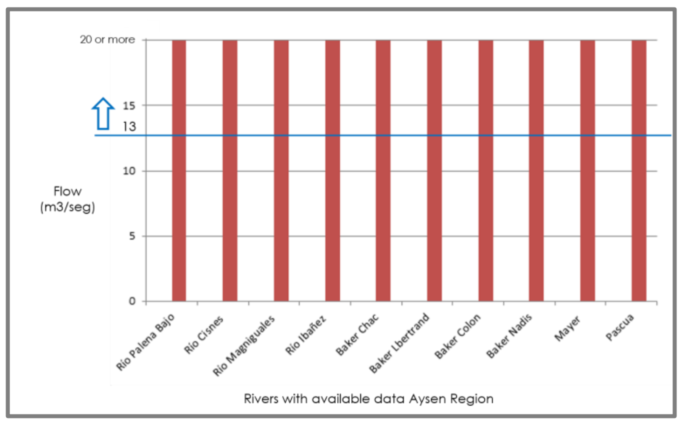

Figure 8: Flow (m3/sec) of the Rivers of the Aysen Region

Only those rivers and channels with a higher flow than 13 m3/s were selected for the purposes of this research. Table 1 presents the 61 potential sites for the development of small scale hydroelectric power plants, identifying the names of the rivers or canals and their respective flow, pursuant to the available gauging station data [Water Agency of Chile, 40; Salgado & Beavis, 41].

Table 1: Potential Sites for SHS Development

No.	Name of the river or canal	Flow (m3/seg)	No.	Name of the river or canal	Flow (m3/seg)
Bio-Bio Region			32	Cautin Almagro	871.820
1	Ñuble San Fabián	73.172	33	Tolten Schmidt	1,231.550
2	Chillan	17.420	**Los Rios + Los Lagos Region**		
3	Diguillin	22.352	34	Calle Calle	236.277
4	Itata Balsa Nueva	418.708	35	Pirihueico	144.446
5	Itata Paso Ondo	630.544	36	Leufucade	85.488
6	Itata Colemu	906.844	37	Cruces rucaco	386.599
7	Bureo en Mulchen	58.27	38	Nilalhue	53.605
8	Bio-Bio Llanquén	80.140	39	Llollehue	55.036
9	Bio-Bio Ralco 1	28.596	40	Puelo basilio	995.076
10	Bio-Bio Huiri	126.478	41	Rahue	144.893
11	Bio-Bio Pangue	242.500	42	Negro	349.154
12	Bio-Bio Hulquecura	438.428	43	Futalefu	321.26
13	Bio-Bio Rucalhue	429.403	**Aysen Region**		
14	Bio-Bio Culebra	488.749	44	Palena	614.290
15	Bio-Bio Puente Piulo	295.894	45	Cisnes Junta Rio Moro	32.501
16	Bio-Bio Longitudinal	721.451	46	Cisnes Puerto Cisnes	35.68
17	Bio-Bio Coihue	912.751	47	Magniguales	150.690
18	Renaico en Pan	68.27	48	Bakes Chacabuco	612.560
19	Vergara	46.15	49	Ibanez	43.874
20	Nicodahue	21.58	50	Baker L Bertrand	544.578
21	Huequecura	38.606	51	Baker Colon	733.314
22	Duqueco	103.418	52	Baker Nadis	720.140
23	Lonquimay	56.65	53	Mayer	238.888
24	Antuco	50.792	54	Nefantes	93.123
25	Abanico	23.340	55	Pascua Des Lago	742.116
26	Laja Tucapel	19.735	56	Pascua Jta Quetru	847.299
27	Curanilahue	15.465	57	Blanco	300.258
28	Leiva	32.208	58	Aysen	485.306
Araucania Region			59	Simpson	47.2
29	Cautin Cajon	371.035	60	Nirehuao	44.75
30	Cholchol	730.660	61	Emperador	27.22
31	Cautin Rariruca	128.862			

4. Comparison of the total installed capacity of small and large-scale schemes: The megadam proposal for 'HidroAysen' was intended to provide a total installed capacity of 2,750 MW. According to the findings of this report, there are 61 potential sites for the development of SHS. Because each SHS plant can provide an installed capacity of 50 MW, 61 SHS plants can provide a total installed capacity of 3,050 MW, which represents a higher hydroelectric performance than the 'HidroAysen' project.

VI. Conclusion and Future Work

At the international level, the development of small scale hydropower is becoming increasingly important, basically because of its almost negligible environmental impact. The size and operating system of small hydropower allows the hydroelectric exploitation of different rivers without the necessity of large water reservoirs or extensive land occupation.

For a long time, large-scale hydropower has been considered the best alternative for the exploitation of water resources in Chile. Although large dams have generated many economic and energy benefits for the country's development, this type of hydropower has caused irreparable damage to the valuable biodiversity of central and southern Chile as well as significant social conflicts. Due to growing environmental awareness in the country, both civil society and the government have recently rejected the 'HidroAysen' project, because of its high impact on the natural resources of the proposed construction site.

In order to address this situation, these authors have introduced a possible alternative for the management of water resources in Chile. According to the findings of this research, several small-scale hydropower schemes (SHS) in Southern Chile can provide even more electricity than the rejected 'HidroAysen' project, with a negligible impact on the environmental sphere. As previously noted, the implementation of a number of SHS will probably require a higher investment than the construction of a few large-scale dams under a neoclassic economic approach; yet ecological economics could certainly provide a different perspective through the valuation of the ecosystem services jeopardized by the construction of megadams.

Considering the current crisis of our ecological support system, it is crucial that society focuses on sustainability rather than just economic growth, incorporating the conservation of natural capital and allowing social and intergenerational fairness. In this scenario, SHS deployment could represent a feasible environmental, economic and social alternative for the management of water resources in Chile. Further research is necessary to determine the value of the ecosystem services in southern Chile, and subsequently incorporate this approach in the present and future decision-making arena.

References

[1] A. Wolf (1998), "Conflict and Cooperation along International Waterways", *Water Policy*, Vol. 1, Pp. 251–265.

[2] S. Khennas & A. Barnett (2000), "Best Practices for Sustainable Development of Micro Hydro Power in Developing Countries", *Energy Sector Management Assistance Program, World Bank*, Washington, DC.

[3] World Commission on Dams (2000), "Dams and Development: A New Framework for Decision-making", *World Commission on Dams*, Capetown.

[4] O. Paish (2002), "Small Hydro Power: Technology and Current Status", *Renewable and Sustainable Energy Reviews*, Vol. 6, Pp. 537–556.

[5] S. Bernesson, D. Nilsson & P. Hansson (2004), "A Limited LCA Comparing Large-and Small-scale Production of Rape Methyl Ester (RME) under Swedish Conditions", *Biomass and Bioenergy*, Vol. 26, Pp. 545–559.

[6] H. Daly & J. Farley (2004), "Ecological Economics: Principles and Applications", *Island Press*, Washington DC.

[7] Millennium Ecosystem Assessment (2005), "Ecosystems and Human Well-Being: Wetlands and Water Synthesis", *World Resources Institute*, Washington, DC.

[8] C. Nilsson, C. Reidy, M. Dynesius & C. Revenga (2005), "Fragmentation and Flow Regulation of the World's Large River Systems", *Science*, Vol. 308, Pp. 405–408.

[9] P. Goodwin, K. Jorde, C. Meier & O. Parra (2006), "Minimizing Environmental Impacts of Hydropower Development: Transferring Lessons from Past Projects to a Proposed Strategy for Chile", *Journal of Hydroinformatics*, Vol. 8, Pp. 253–270.

[10] H. Balat (2007), "A Renewable Perspective for Sustainable Energy Development in Turkey: The Case of Small Hydropower Plants", *Renewable and Sustainable Energy Reviews*, Vol. 11, Pp. 2152–2165.

[11] E. Habit, M. Belk &O. Parra (2007), "Response of the Riverine Fish Community to the Construction and Operation of a Diversion Hydropower Plant in Central Chile", *Aquatic Conservation: Marine and Freshwater Ecosystems*, Vol. 17, Pp. 37–49.

[12] S. Zhou, T. Tang, N. Wu, X. Fu & Q. Cai (2008), "Impacts of a Small Dam on Riverine Zooplankton", *International Review of Hydrobiology*, Vol. 93, Pp. 297–311.

[13] H. Huang & Z. Yan (2009), "Present Situation and Future Prospect of Hydropower in China", *Renewable and Sustainable Energy Reviews*, Vol. 13, Pp. 1652–1656.

[14] C. Bennett (2009), "Chile to Warm up its Renewable Market", *Renewable Energy Focus*, Vol. 9, Pp. 70–83.

[15] R. Prakash & I. Bhat (2009), "Energy, Economics and Environmental Impacts of Renewable Energy Systems", *Renewable and Sustainable Energy Reviews*, Vol. 13, Pp. 2716–2721.

[16] J. Rockstrom, W. Steffen, K. Noone, A. Persson, S. Chapin, E. Lambin & M. Falkenmark (2009), "Planetary Boundaries: Exploring the Safe Operating Space for Humanity", *Ecology & Society*, Vol. 46, Pp. 472–475.

[17] P. Rojanamon, T. Chaisomphob & T. Bureekul (2009), "Application of Geographical Information System to Site Selection of Small Run-of-river Hydropower Project by Considering Engineering/Economic/Environmental Criteria and Social Impact", *Renewable and Sustainable Energy Reviews*, Vol. 13, Pp. 2336–2348.

[18] R. Raineri & G. Contreras (2010), "Efficient Capacity Investment and Joint Production Agreements in an Oligopolistic Electricity Market: The HidroAysén Joint Venture Project", *Energy Policy*, Vol. 38, Pp. 6551–6559.

[19] L. Kosnik (2010), "The Potential for Small Scale Hydropower Development in the US", *Energy Policy*, Vol. 38, Pp. 5512–5519.

[20] G. Aggidis, E. Luchinskaya, R. Rothschild & D. Howard (2010), "The Costs of Small-Scale Hydro Power Production: Impact on the Development of Existing Potential", *Renewable Energy*, Vol. 35, Pp. 2632–2638.

[21] J. Pittock (2010), "Viewpoint-Better Management of Hydropower in an Era of Climate Change´, *Water Alternatives*, Vol. 3, Pp. 444–452.

[22] S. Larraín & C. Schaeffer (2010), "Conflicts over Water in Chile: Between Human Rights and Market Rules", *Heinrich Boll Foundation-South Cone Office*, Canadian Council, Santiago.

[23] United Nations Industrial Development Organization (2010), "Projects for the Promotion of Small Hydropower for Productive Use", *United Nations Industrial Development Organization*, Vienna.

[24] G. Vince (2010), "Dams for Patagonia", *Science*, Vol. 329, Pp. 382–385.

[25] World Bank (2011), "Chile, Assessment for the Water Resource Management", *World Bank*, Environment and Sustainable Development Office, Latin America and the Caribbean, Santiago.

[26] R. Ponce, F. Vasquez, A. Stehr, P. Debels & C. Orihuela (2011), "Estimating the Economic Value of Landscape Losses due to Flooding by Hydropower Plants in the Chilean Patagonia", *Water Resource Management*, Vol. 25, Pp. 2449–2466.

[27] Ministry of Energy (2012), "Government of Chile/Ministry of Energy/National Energy Strategy 2012-2013", URL: http://www.minenergia.cl/estrategia-nacional-de-energia-2012.html.

[28] BBC News (2012), "BBC News/World/Latin-America/Proposed Dams in the Aysen Region of Chile", URL: http://www.bbc.co.uk/news/world-latin-america-13445300>

[29] European Small Hydropower Association (2012), "Environmental Integration of Small Hydropower Plants", *European Small Hydropower Association*, Brussels.

[30] R. Costanza, G. Alperovitz, H. Daly, J. Farley, C. Franco, T. Jackson, I. Kubiszewski, J. Schor & P. Victor (2013), "Building a Sustainable and Desirable Economy-in-society-in-Nature", *ANU E-Press*, Canberra.

[31] United States Environmental Protection Agency (2013), "Renewable Energy Fact Sheet: Low-Head Hydropower from Wastewater", *United States Environmental Protection Agency*, Washington DC.

[32] International Center on Small Hydro Power (2013), "World Small Hydropower Development Report", *International Center on Small Hydro Power*, Hangzhou.

[33] The Hydro Equipment Association (2014), "The Hydro Equipment Association/Hydropower/Small Hydro", URL: http://www.thehea.org/hydropower/special-focus/small-hydro.

[34] Meteorological Agency of Chile (2014), "Meteorological Agency of Chile/Rainfall Report 2014", URL: http://www.meteochile.gob.cl/inf_precipitacion.php.

[35] Military Geographic Institute of Chile (2014), "Military Geographic Institute of Chile/Map of Chile", URL: http://www.igm.cl/descargas_gratuitas.php.

[36] Environmental Assessment System of Chile (2008), "Environmental Assessment System/HidroAysen Project", URL: http://www.eseia.cl/expediente/ficha/fichaPrincipal.php?modo=ficha&id_expediente=3103211.

[37] Ministry of Environment (2014), "Ministry of Environment/Press room/Rejection of HidroAysen", URL: http://www.mma.gob.cl/1304/w3-article-56497.html

[38] Natural Resources Canada (NRCan) (2014), "Small Hydro Project Analysis", *RETScreen Clean Energy Project Analysis Software*, Government of Canada, Toronto.

[39] Agency for Natural Resources and Energy (ANRE) (2014), "Technically Exploitable Hydropower Capability by Power Output", *Agency for Natural Resources and Energy*, Tokyo.

[40] Water Agency of Chile (2014), "Water Agency of Chile/Real Time Monitoring Stations System", URL: http://dgasatel.mop.cl/filtro_paramxestac.asp.

[41] N. Salgado & S. Beavis (2015), "Many Small vs A Few Big? Solutions for the Controversial Proposal of Mega Dams in the Chilean Patagonia", *Asian Conference on Engineering and Natural Sciences*, Tokyo.

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