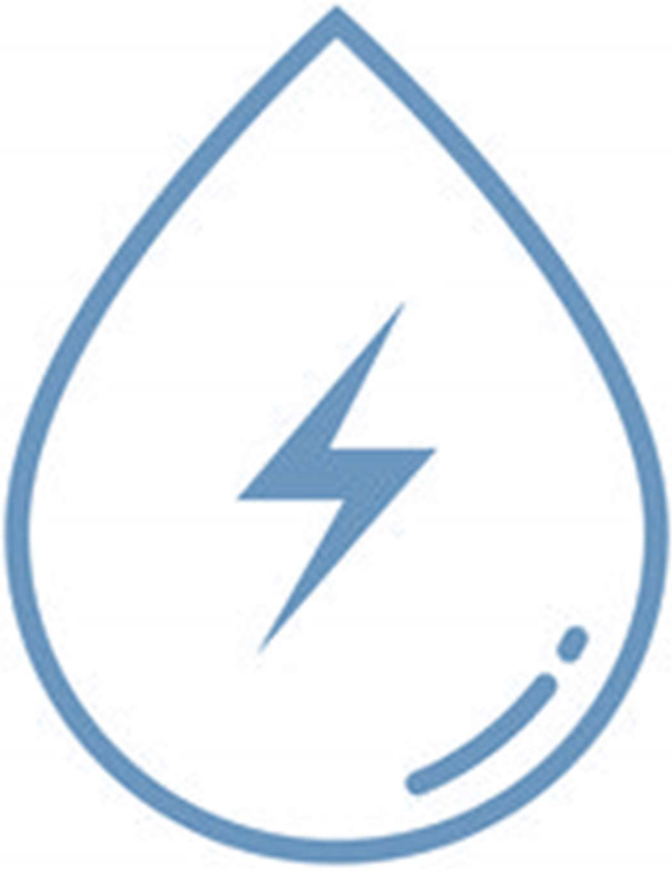
Hydropower

A Renewable Energy, but is it Sustainable? | Brief description



A Critical examination of hydroelectricity sustainability by

WINDS OF CHANGE

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Hydroelectricity generation is renewable, but is it sustainable?

Context

Fossil fuels dependence must disappear, and the amount of carbon in the atmosphere reduced. Therefore, a more efficient use from energy, and a higher share of energy from renewable sources are mandatory.

Thesis

Hydroelectrical power generation plays a key role in the energy matrix of Chile and New Zealand, foreseeing to become more relevant. Despite its clean and eco-friendly image, it has significant environmental impacts. Raising the question of its sustainability.

Goal

Provide information for an informed discussion regarding the bidirectional interaction between hydroelectric power generation and environment impacts within the changing context of El niño/La niña and broader climate change.

Structure & Deliverable

The study focuses on Chile and New Zealand, describing the El niño/La niña effect over both countries, providing basic information regarding the role of hydroelectric power generation and how it impacts the environment. Additionally, projects taking place at both countries are quickly reviewed as study case to evaluate their impacts.

The main findings will be delivered in a report, that will be summarized into a brochure and also presented in a graphical manner for easier dissemination.

Contents

Climate Change and ENSO

Large-scale wind circulations over the major parts of the Earth's surface drive the climate system, where changes to one part of the climate system can affect others (Climate Signals Beta, 2019). As global temperatures increase, the global circulation is likely to shift and produce a variety of consequences. The IPCC[1] fifth assessment report states, "it is likely that circulation features have moved poleward since the 1970s, involving a widening of the tropical belt, [and] a poleward shift of storm tracks and jet streams" (Climate Signals Beta, 2019). This is already evident in the polar regions , altering the atmospheric circulation patterns linked to the warming Arctic temperatures.

The Southern hemisphere has a significantly more open ocean than the northern hemisphere (Climate Signals Beta, 2019). Thus, as the more continental northern hemisphere experiences global warming on a continental level, changes in ocean temperatures and currents will affect the distribution of water in the southern hemisphere. One such example of circulation that affects ocean temperatures and current patterns in the midlatitudes is the El Niño Southern Oscillation (ENSO), particularly relevant for Chile and NZ.

ENSO manifests as two opposite phases of a naturally occurring global climate cycle; these phases are known as El Niño and La Niña. ENSO influences rainfall, temperature, and wind patterns around the world, including those of New Zealand and Chile. During an El Niño event, ocean water from off the coast of South America to the central tropical Pacific warm above average, associated with lower atmospheric pressure. The warming takes place as trade winds (the permanent east-to-west prevailing winds that flow around the equator) weaken or even reverse, blowing warm water from the western Pacific toward the east. As a result, sea temperatures in the far western Pacific can cool below average.

Contrarily, during a La Niña event, ocean water from off the coast of South America to the central tropical Pacific cools to below-average temperatures. This cooling occurs because of stronger than normal easterly trade winds, which churns cooler, deeper seawater up to the ocean's surface (NIWA, 2016a). Sea temperatures can warm above average in the far western Pacific when this happens. This change impacts weather patterns around the world, but in a different way than El Niño does.

ENSO is involved with some of the most dramatic variations of the global climate system, on an annual timeframe and thus is an important consideration on many levels; economic activity, agriculture, environmental health, freshwater availability, and power generation are all affected by ENSO in countries around the globe (Stein, 2020). An extreme El Niño event typically results in a cooling in the west of the Pacific Ocean, i.e. in New Zealand, and warming in the east, i.e. in Chile. Climate change is increasing the frequency of these extreme events, resulting in both worsening droughts and intensified droughts in the two aforementioned nations (Stein, 2020). This has been addressed both in scientific papers and, more recently, in the media, signalling the increasing importance of these shifts in circulation patterns. As stated by the New Zealand Herald, the current risk of extreme El Niño events is around five events per 100 years (Morton, 2017). This is set to double by 2050 when considering a modelled emissions scenario reaching the 1.5°C peak (Morton, 2017).

[1] The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change. https://www.ipcc.ch/

As extreme ENSO events influence ocean temperatures, and thus precipitation, in both Chile and New Zealand, affect on the availability of such resource, impacting the direct usage for the agroindustry and life in general, but also the already stressed energy matrix, as will affect the ability of these countries to utilise hydropower as a source of energy generation. It is unclear what extreme El Niño and La Niña events may lead to in terms of rainfall patterns within the mid-latitudes, but it is likely that extremes of droughts and flooding will only be amplified with the increasing strength of ENSO (Stein, 2020). In our warming climate, it is critical to gain an understanding of how ENSO may limit or enhance water availability in Chile and New Zealand, and what this will mean for the future of hydroelectric potential.

ENSO and water availability in Chile

In Chile, the displacement of the subtropical anticyclone from the Pacific towards the west facilitates the presence of unstable atmospheric layers near the surface. This atmospheric condition increases the frequency of frontal cloud bands and intensifies them, associated with precipitation. The literature agrees that a strengthening of ENSO will lead to droughts in Chile, particularly in the North and Central regions. Droughts are already characteristic in Northern Chile (Meza, 2013) and this will become an increasing issue as the global temperatures increase. However, according to (Thatje et al., 2008), the arid regions of Chile experience tremendous increases in rainfall during extreme El Niño events. These tremendous increases in precipitation have untoward effects; namely flash floods, erosion, river inundations, mudflows, and landslides (Thatje et al., 2008).

Cai et al. (2020) summarised the effects of ENSO events in South America succinctly, positing that El Niño leads to drought in the Amazon and north-eastern regions of the continent, but flooding in the west and south-eastern South America. Unsurprisingly, this created marked socio-economic effects, and the growing extremes in water availability limit the reliability of hydropower in Chile. However, Cai et al. (2020) also indicated that rainfall reductions due to greenhouse warming, which is already present in central Chile, can overcome ENSO-related increases in rainfall, and thus the overwhelming effect of climate change in Chile is likely to be persistent dry conditions.

ENSO and water availability in New Zealand

During El Niño, New Zealand tends to experience stronger or more frequent winds from the west in summer, which can encourage dryness in eastern areas and more rain in the west. In winter, the winds tend to blow more from the south, causing colder temperatures across the country. In spring and autumn, south-westerly winds are more common. ENSO influences rainfall, temperature, and wind patterns in New Zealand, but accounts for less than 25 percent of the annual variance in these climate features (NIWA, 2016a). Despite this relatively small influence, the effect of extreme El Niño events can be significant.

New Zealand typically experiences stronger and more frequent westerly winds in the summer, leading to more rain than normal in the west and drier conditions in the east (NIWA, 2016b). This is amplified by the positioning of the Southern Alps and the main North island ranges. As El Niño events are likely to become twice as common by 2050, this leads to the suggestion that hydropower in New Zealand may not be negatively affected, as many of the current hydroelectric stations in New Zealand are supported by tributaries in the west. However, La Niña's impacts in New Zealand bring moist, rainy conditions to the north-east of the North Island, and reduced rainfall to the south and south-west of the South Island (NIWA, 2016b). This may have adverse effects on the hydroelectric potential of the South Island.

It is important to consider that both central and eastern regions of the South Island will experience drought-like conditions under both extreme El Niño and La Niña events (NIWA, 2016b). The ocean-driven climate system experienced in New Zealand will bring cool, wet conditions to typically wet regions, and drier conditions to areas that are already dry (Morton, 2017). These growing extremes are a result of a strengthening of ENSO. Which will offer diverse, region-specific challenges regarding water availability, which must be considered when planning for future reliance on hydroelectricity in New Zealand.

Energy matrix

There is an intuitive link between energy and development, however, no causal relationship has been clearly established between energy consumption and economic growth. This is likely due to the multidirectional relationship between GDP and prosperity, a dynamic that varies depending on the context. Access to energy initially boosts the GDP, but a higher GDP also leads to greater energy consumption.

Interestingly, New Zealand and Chile show very similar histories within the global scenario, where both reached a virtual 100% energy access at around $20,000 per capita GDP (see Figure 1). This highlights that despite the GDP difference over time, these countries' similitudes go beyond geographical, geological aspects, and energetic strategies (as will be elaborated later).

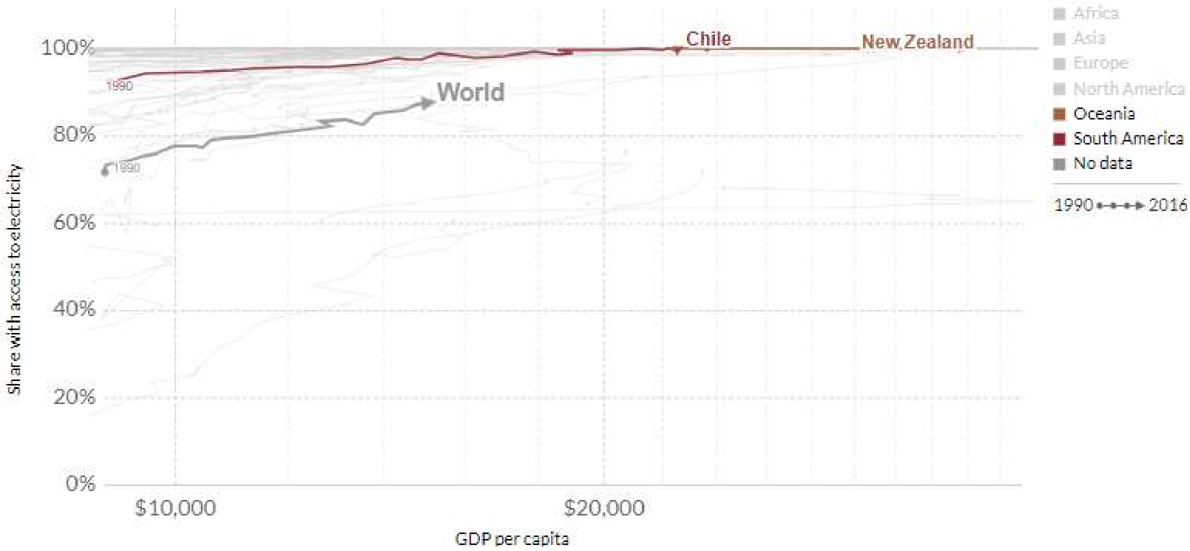


Figure 1: Access to electricity versus GDP per capita (adjusted to price differences between countries and inflation) for selected countries in between 1990 and 2016 (Hannah Ritchie, 2014)

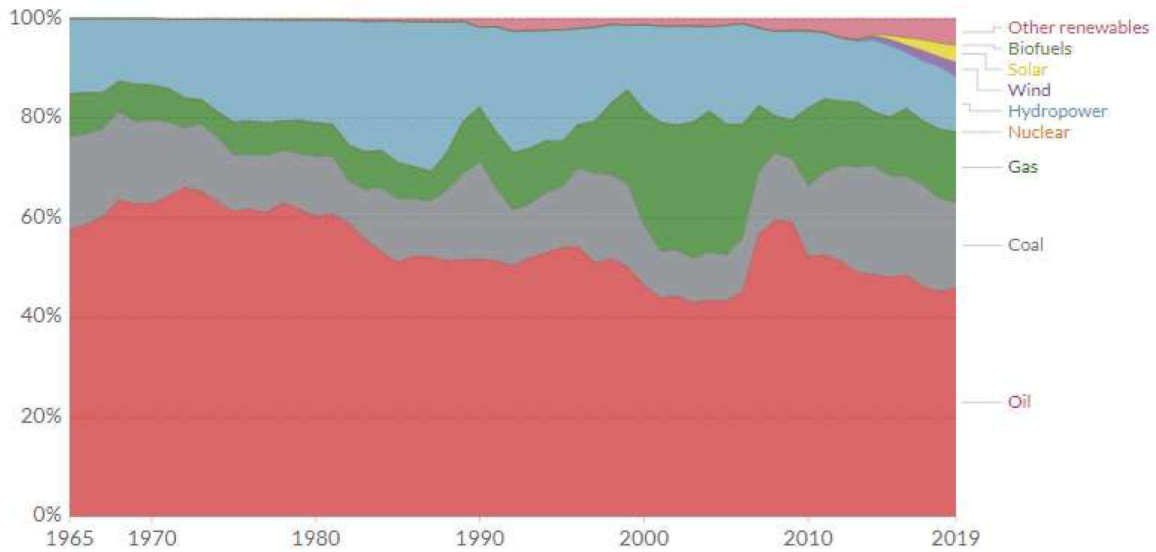
For simplicity, it will be considered here that access to energy is key for economic development and overall quality of life. Simultaneously, it is one of the human activities with greater environmental impacts due to the inherent greenhouse gas emissions of a carbon-based energy matrix. Therefore, decarbonizing and improving the energy matrix plays a pivotal role in any country's strategy towards a low emission economy and sustainable future.

Current composition and transition in Chile and New Zealand

How much energy and which energy source is more appropriate depends on a number of factors; hence every country's strategy must be assessed individually, considering their particularities and constrictions. Nevertheless, comparing the energy consumption provides a broad idea of where is the energy coming from.

Figure 2 shows the corrected primary energy sources used by Chile and New Zealand, taking into account the inefficiencies inherent to the use of fossil fuels, and how the different energy sources inputs compare within the matrix (Internatinal Hydropower Assosiation, 2020)

(A)



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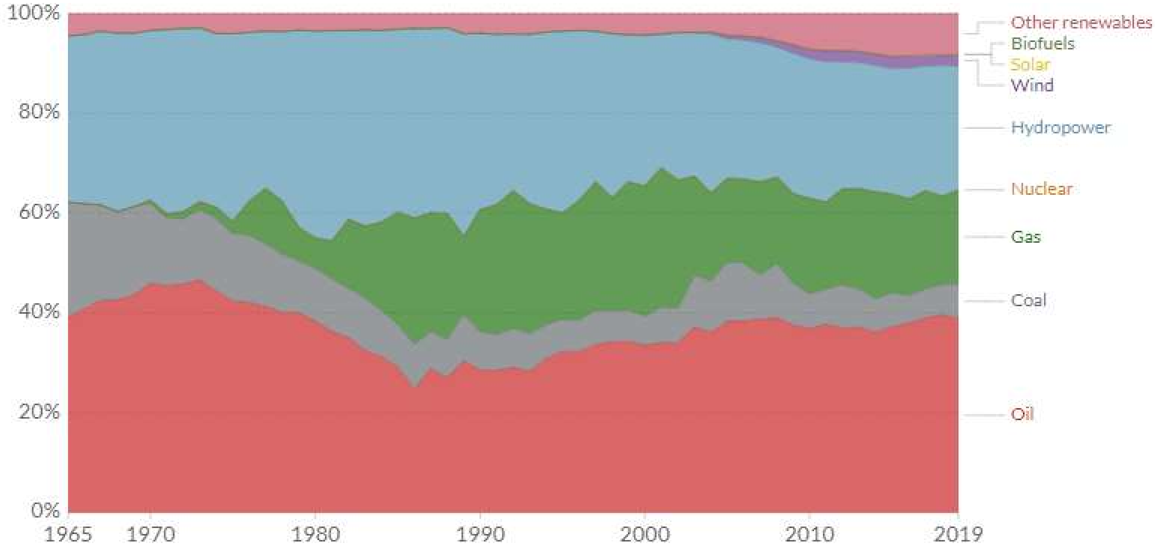


Figure 2: Corrected energy demand of energy by energy for Chile(A) and New Zealand (B) source between 1965 and 2019. * Others renewable includes geothermal, biomass and waste energy (Hannah Ritchie, 2014)

Both examples have a strong component of hydroelectricity, sourcing about 30% of the New Zealand energy, and likely to grow with the pumped hydro storage (Morgan) and other projects to reach the goals of 100% renewable energy (New Zealand) and 70% (Chile) by 2030.

Flexibility and energy storage

Electricity is one of the most user-friendly user ways of energy, with a consumption affected by seasonal variations. This variable demand must be matched by the power generation, growing concern when thinking on an energy matrix based on inherently fluctuating renewable energies (ter-Gazarian, 1994).

Power storing is any device or method that allows the power system to hold the energy generated in the system until is needed, uncoupling the power generation and demand (ter-Gazarian, 1994), inherently linked to the flexibility of the system. Therefore, storage is recommended when:

-Aiming to improve the system efficiency

-Energy conservation is desired to reduce the consumption of a primary fuel use

-A sole energy source is available

-Energy supply security is relevant

The inherent fluctuation of renewable energies is commonly taken as a disadvantage as is not possible to directly store them. Nevertheless, an energy storage technology capable to transform these renewable energies into a different and storable energy form would bring a) A time and rate decoupling between the energy generation and consumption, b) A secondary energy storage capacity that accepts energy generated by the power system and converts it into a storable energy form, returning as much of that energy as possible after the desired time of storing (ter-Gazarian, 1994).

In this context, a diverse energy matrix not just distributes power generation along the day, but it would also allow the use of “new” primary energy sources such as biomass, waste, coal, or water to produce synthetic fuels. These synthetic fuels can replace fossil fuels during peak demand periods, or fill in renewable energy generation gaps. Given the energy-storing role these fuels fulfil, a disengage between the power generation and consumption is achieved, but a power transformation system and store are required. (ter-Gazarian, 1994) (Duo, Dykstra, & Pavlostathis, 2018)

Generally speaking, the energy flow from a primary source is not constant but depends on the season, time of day, and weather conditions. Energy demand is not constant either; it depends on the same circumstances but mostly in reverse. So, there is a need for a mediator between the source of energy and its consumer, otherwise, every event should occur simultaneously (ter-Gazarian, 1994).

In nature, the sun’s energy has been stored as organic fuels (wood, coal, oil), water evaporation, and the wind among others, acting as secondary energy storage. Several technologies such as electric batteries, flying wheels, pumping water, compressing air, power-to-gas, etc. have been developing to emulate this phenomenon. As seen in Figure 3 (Schaaf, Gruning, Roman, Rothenfluh, & Orth, 2014), hydrogen and synthetic-natural-gas bring a larger storage capacity for longer periods. Additionally, a city gas grid is already available for storing and distributing massive amounts of energy as methane, reducing the required investment (Power-To-Gas, 2018)

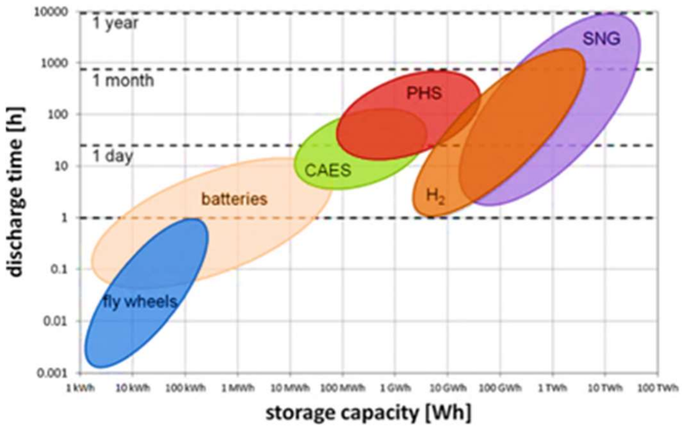


Figure 3: Estimated storage capacity and Discharge time for different energy storing technologies. CAES, compressed air energy storage. PHS, pumped hydro storage. SNG, substitute natural gas (Schaaf, Gruning, Roman, Rothenfluh, & Orth, 2014)

Hydropower technology

Hydroelectric power generation uses kinetic energy of moving water to turn turbines that will use the mechanical energy to produce electricity. As seen in Figure 4, a dam with a large drop is commonly built to increase the head, the vertical distance that the water will fall before reaching the turbines. An increased vertical distance would store more potential energy in the body of water, until the electrical energy is required, at that moment the intake is open and the potential energy becomes kinetic energy later transferred to the turbines. (U.S. Energy Information Administration, 2020)

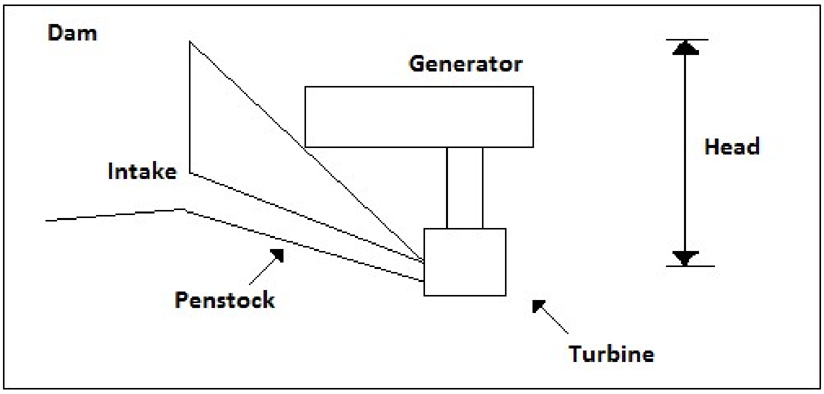


Figure 4: Schematic representation of a typical dam for hydroelectric power generation (Hydroelectric Power - Introduction, n.d.)

Hydroelectricity power generation is advertised as a renewable and very clean energy source, as it does not consume water, but only uses it, and in fact has a number of advantages listed below:

- power is usually continuously available on demand,
- given a reasonable head, it is a concentrated energy source,
- the energy available is predictable,
- no fuel and limited maintenance are required, so running costs are low (compared with diesel power) and in many cases imports are displaced to the benefit of the local economy,
- it is a long-lasting and robust technology; systems can last for 50 years or more without major new investments.
- Allows energy storage

Against these, the main shortcomings are:

- it is a site-specific technology and sites that are well suited to the harnessing of water power and are also close to a location where the power can be economically exploited are not very common, or already occupied
- there is always a maximum useful power output available from a given hydropower site, which limits the level of expansion of activities which make use of the power,
- river flows often vary considerably with the seasons, especially where there are monsoon-type climates and this can limit the firm power output to quite a small fraction of the possible peak output (Hydropower basics, n.d.).

Types

Although hydropower is a general term that includes the direct use of mechanical energy provided by the moving water, in the context of national energy matrix, hydroelectricity power generation is the most relevant player due to the size of the projects, that can range from microprojects of about 100kW to more than 10,000kW

Hydroelectrical power plants can be classified based on the mechanism used to produce and capture the kinetic energy transported by the water. These different strategies have some technological differences, and will impact the site where are located differently is explained later.

a) Impoundment

These are typically large hydropower system, and use a dam to store river water in a reservoir. Water released from the reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity. The water may be released either to meet changing electricity needs or to maintain a constant reservoir level.

b) Diversion

It channels a portion of a river through a canal or penstock. It may not require the use of a dam, but also impacts the surroundings area by altering the river flow as explained below.

c) Pumped Storage

Works like a battery, storing the electricity generated by other power sources like solar, wind, and nuclear for later use. It stores energy by pumping water uphill to a reservoir at higher elevation from a second reservoir at a lower elevation. When the demand for electricity is low, a pumped storage facility stores energy by pumping water from a lower reservoir to an upper reservoir. During periods of high electrical demand, the water is released back to the lower reservoir and turns a turbine, generating electricity. (Water Power Technologies Office, n.d.), (Civil Engineering Discoveries, n.d.)

Hydropower plants Impacts over environment

Hydroelectricity is considered a clean and renewable electricity, as no fossil fuels is needed during the operation, the water is not consumed, which allows the water cycle to keep going so we can rely on hydropower. Nevertheless, hydroelectric generation is not limitless, and depends on water availability at specific locations among other factors.

Despite not having greenhouse gas emissions directly from producing electricity, there are many consequences beside the inherent impact of constructing the plants, as pointed out below:

Wildlife habitats and migratory paths damage

Hydroelectricity and pumped hydro storage imply the construction of large bodies of water, which involves blocking, diverting, or changing the natural course of river systems and water table of the surrounding landscape. This is going to alter fish migration routes -or cutting them-, some hydropower facilities use fish ladders to avoid this, and the consequent rivers' ecosystem effect and hence human food stocks, although according to energysage.com, these devices tend to be undersized.

Even diversion plants that do not require a dam, modify the river course, altering the sediment flow and oxygenation levels. Lower water flow downstream, as well as nutrient flow change can lead to loss of habitat and healthy water for animals.

Effect on surrounding land

Hydropower facilities affect their surrounding landscape, altering the system beyond their border. The mere water flow restriction can cause a loss of habitat. Water reservoirs -for hydropower or pumped storage- often cause upstream flooding that destroys wildlife habitats, scenic areas, and prime farming land, sacred lands, and even forcing the relocation of human settlements. Partly explaining why some projects produce strong citizens engagement against them (Environmental Justice Atlas, n.d.)

Indirect Greenhouse gas emissions from reservoirs

Using water to spin turbines does not directly use fossil fuels nor emit greenhouse gases, nevertheless, the reservoirs with a very low flow tend to produce anaerobic systems with high sedimentation rates. This situation leads to trapping organic material in the reservoirs, breaking down dead plants (among other organic matter), and releases gases like carbon dioxide and methane (Energy Sage, 2019). Simultaneously, the reservoir needs a clean area, that many times imply cutting down trees, and reduces water availability downstream the dam, with a detrimental effect on the carbon emissions absorption of the area.

Climate change impact over hydropower

Impacts

Climate change impacts hydroelectricity in a variety of spatial and time scales, as the plants are highly dependent on the local hydrological impacts of climate change and geographical particularities. Some general impacts distilled from the literature are commented below, although the highly case-dependency highlights the necessity of a national and local hydropower strategy.

Since the importance of hydropower generation and its potential sensitivity to climate change, the potential impacts of climate change over the hydropower generation are assessed and classified as either direct and indirect below.

Direct

It is known that global warming will increase global temperature, altering the precipitation patterns. This is directly transferred into hydropower generation due to the earlier spring snowmelt.

This impact does not affect in the same way every hydroelectric plant. As higher temperatures lead to more snowmelt and, often, more intense periods of seasonal precipitation, a higher impact is expected over high-elevation plants with small reservoirs, as is the case of Himalayan countries with high elevation hydropower (My republica, 2020).

The literature predicts that in the period of the 2080s, every 1°C increase in temperature requires an approximately 3% increase in precipitation to maintain current levels of hydropower generation. Increased snowmelt may provide an excess of water in specific areas, producing disadvantageous conditions for hydrogeneration, and unsafe conditions for downstream areas. An over-filled

Waterhead in front of the turbine will cause low generating efficiency because the excess hydraulic state biases the optimum operating condition (Agrawala et al., 2003), whereas low elevation plants instead are more likely to be influenced by precipitation than temperature, generally affected by the water availability due to runoff fluctuations.

The scale of the project also plays a role, big hydroelectric power plants offer not just immense generation capacity, but also the possibility to store water, hence, counteract seasonal precipitation. Despite this relevant role, Dam hydroelectric plants are being questioned due to their outdated technology and high impacts, as mentioned earlier, but some regions have tremendously underdeveloped hydropower systems due to the upfront costs inherent to big dams.

In this scenario, small hydropower becomes particularly relevant due to the reduced upfront cost, and the lack of dams. Therefore, playing a relevant role in rural electrification in many regions. Nevertheless, small hydropower plants are more sensitive to climate changes, implying greater generation changes as they usually rely on diversion technology, dependent on hydrologic conditions, and hence influenced by temperature and precipitation patterns.

In South America, the two main impacts are related to glacier retreat, severely impacting La Paz and Lima, but also related to the large-scale and persistent rainfall anomalies inherent to El Niño-La Niña fluctuations that are also well known to affect Oceania.

Indirect

Indirect impacts are region-specific or may be experienced in broader areas (Sale and Kao, 2012), which makes them difficult to quantify. A good case in point is the use of water for different purposes such as irrigation and residential and industrial supply, demands that are expected to rise rises due to climate change (IPCC, 2012).

As temperature rises, evaporation is expected to increases. This translates into higher losses in reservoirs due to evaporation, reducing the water supply. This higher temperature, combined with the rainfall variation may result in an increased demand for water from the agricultural sector for irrigation, even if the total yearly precipitation remains the same.

The rainfall events' intensity variation changes the water quality, with important effects on hydropower generation maintenance costs, as the water driven through the turbines carries more sediments that wear out them, increasing maintenance costs, reducing the dam, and turbine lifespans and overall power generation efficiency.

The more extreme rainfall events also affect the surrounding lands, increasing the risks of landslides. Glacial lake outburst and floods, that make crucial to accommodate increased flow by the reservoir's regulation and management. The American rivers association highlights these effects and claims that healthy rivers are a natural defence against global warming impacts (American Rivers, 2020). On the other extreme of the spectrum, extremely warm, dry weather, increases both irrigation and total electricity demand, resulting in greater stress on the available water supply for power generation.

Additionally, local legislation will affect hydropower development as the demands for sustainable development of society and the ecological environment evolve. Policymakers -and the broader community- should also be aware of these interactions and possible conflicts, particularly as the total supply of water is limited. The Columbia River Basin, for example, is legally bound to provide inexpensive power but also to protect fish and wildlife. (J. Shu, 2018)

Mitigation

National scale analysis is needed for providing the technical suggestions, context, and consequences to decide on how to develop national hydropower effectively for the future, considering rainfall variation, glacier retreat, snow-melting, global warming, and current hydroelectrical deployment (J. Shu, 2018).

An interesting example is a study on the management adaptation potential of the water resource system at the Peribonka River (Quebec, Canada), as the results suggest that between 2010–2039 the hydropower capacity will decrease by about 1.8%, but it will increase later by 9.3% and 18.3% during the periods 2040–2069 and 2070–2099, respectively.

However, only a few countries have been involved in this detail of analysis, focusing on the mitigation of climate change impacts on two strategies. One strategy is to increase the proportion of hydropower share on the energy matrix. In this sense, hydropower plays a significant role in reducing the emissions due to its almost null greenhouse gas emission during operation, although its construction is usually very pollutant. Nevertheless, if Hydropower is considered a complementary energy source to wind, solar, and biogas, it is a reliable source that brings flexibility to the system as usually offers energy storage when dams are included.

The second strategy focuses on the optimization of the hydropower operation and management of fluctuating conditions. In the U.S. most of the hydropower dams were built 75-100 years ago with inefficient equipment to today's standards (American Rivers, 2020). So, the bottom line is to update the current plants, they should be evaluated for new projects whether a cascade hydropower station or single hydropower station with a reservoir would work better.

Final Comments

Hydropower is cleaner than other energy sources, allows to store energy, hence enabling a greater renewable share within the energy matrix, and it produces a limited amount of greenhouse gas emissions during its operation. However, hydroelectricity severely impacts the water cycle, the surrounding area where it is located and produces greenhouse gas emissions not related to the power generation.

An impoundment dam is a huge engineering project, with the associated material use and personal needed for their construction, a series of roads and other structures are also needed, so even when it has a low operational impact, its construction is inherently pollutant, including the flooding areas that affect from small species to human settlements depending on the project.

Even a small hydro project or diversion hydropower plant will divert the flow path, altering the amount of oxygen available in the water, erosion, and sedimentation among other impacts that will reshape the ecosystem balance.

A quick analysis of figure 5 makes evident how the natural course of the river (A) has been channelled through human-made canals (B), with a clear difference in the tree presence at both sides (pointed with arrows). It can also be found that salmon farms (C and D) have been installed, which are exogenous nitrogen sources to the ecosystem, risking eutrophication and other nutrient imbalances that may alter bacterial and animal life.

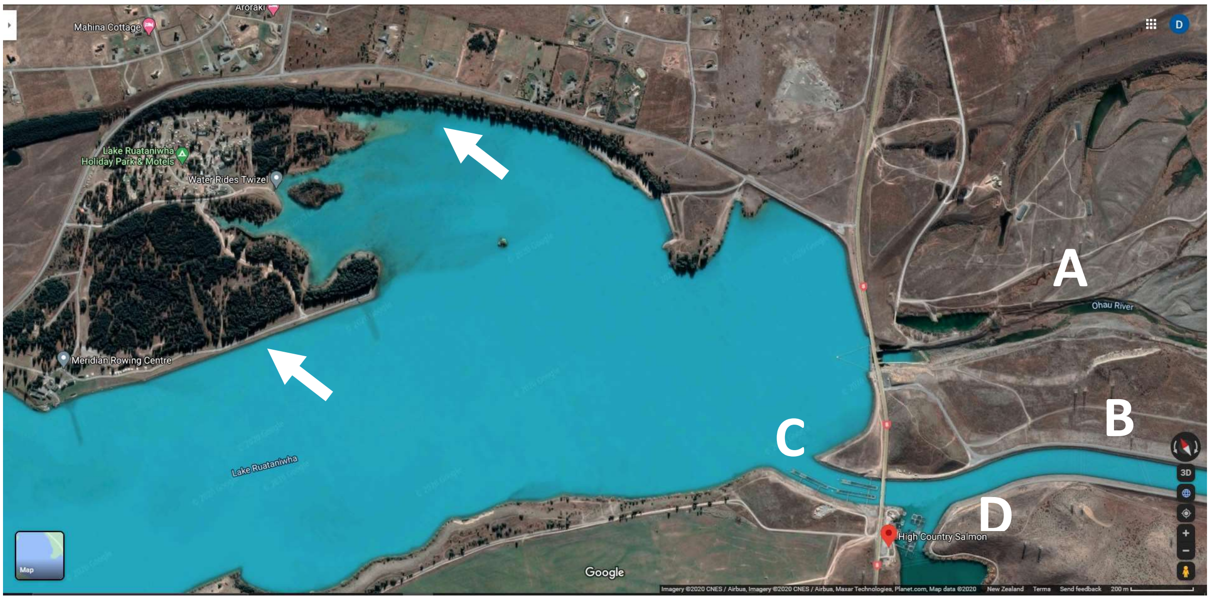


Figure 5: aerial image of lake Benmore dam and adjacent salmon farms, reference location -44.27958057294036, 170.07393484244014. Source: Google maps

Therefore, hydroelectricity seems to be in fact -to today's standards- cleaner than other relevant energy sources in the matrix, but we should be aware of the inherent impacts to assess whether hydroelectricity is sustainable or not, and decide as society if we are willing to pay the price.

For an interactive view of the report's highlights please visit the link below:

https://prezi.com/view/3mvjI5E2ILxN3Q29q0Vx/

Appendix: Hidroaysen,Chile

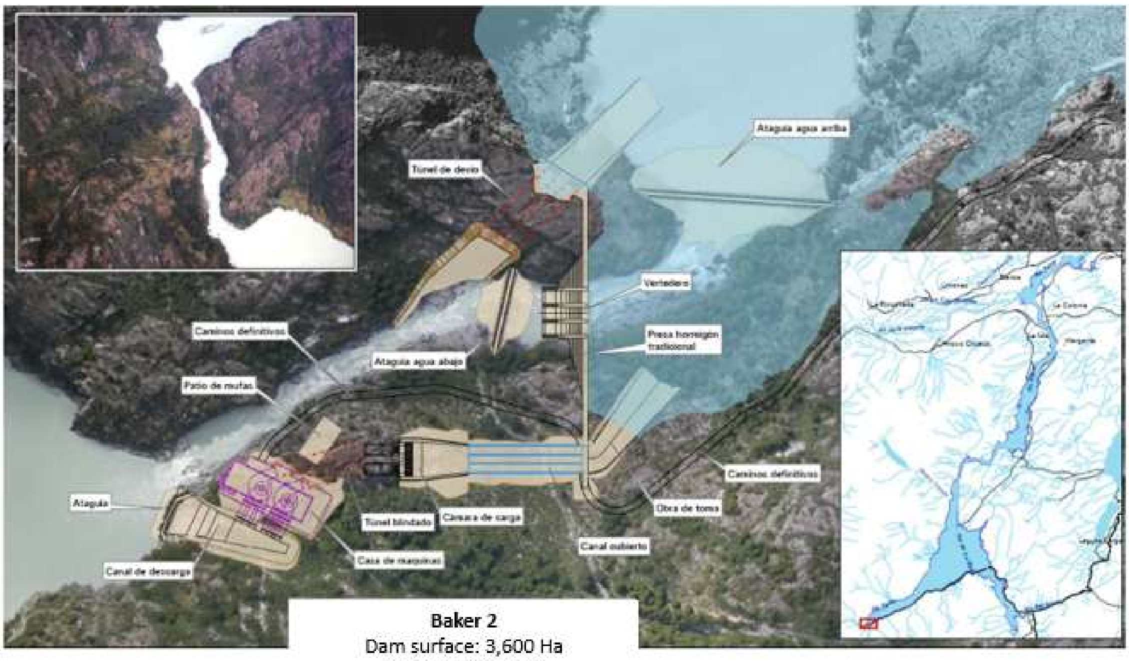
Unquestionable, Hidroaysen would have had a significant economic impact for the region, creating thousands of construction-related work positions during its construction, and becoming a relevant energy source for the Interconnected central system of Chile. Additionally, it was estimated by the London Financial Times that the area would have become a touristic hotspot before its construction, due to the international interest of seeing the pristine area before it vanishes

The intended operation was so big that needed its own 14MW powerplant to provide energy for the construction, besides a dock in Puerto Yungay, an additional ramp in Rio Bravo, improvement of almost 200km of existing road and the creation of almost 100 km of new road, besides offices, telecommunications and accommodation for the staff.

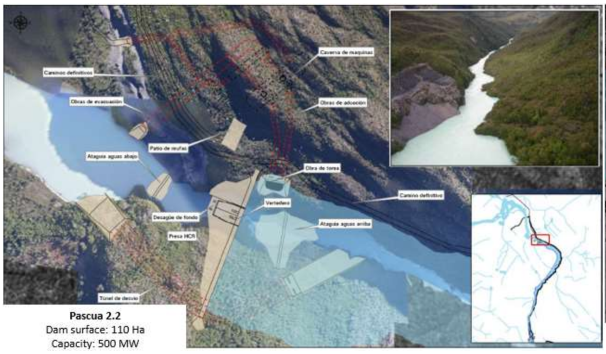
Some numbers

Total capacity	2750 MW
Number of dams	2 Baker river + 3 Pascua River
System links	180 km
Transmission line	2000 km
Transmission Towers	3800 of 80 m high
Total dam surface	5900 hectares

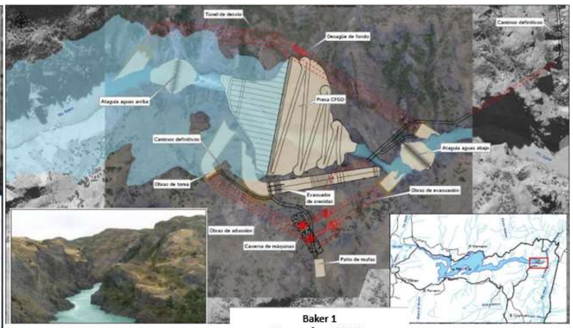
The terrain where the project was intended included areas of high volcanic and seismic activity, passing through 6 national reserves and parks, at least 8 indigenous areas, flooding part of the San Rafael Park (United Nations biodiversity reserve). This was considered a price too high, causing a strong opposition within population that led to the project cancellation.



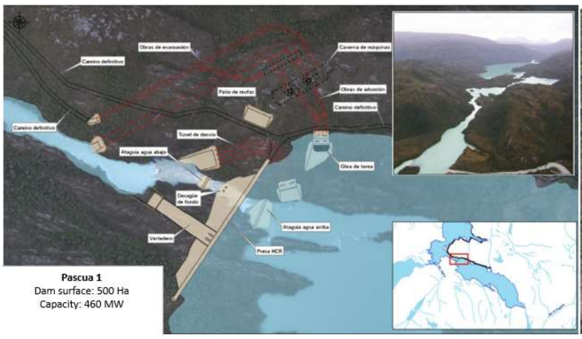
Baker 2
Dam surface: 3,600 Ha
Capacity: 360 MW



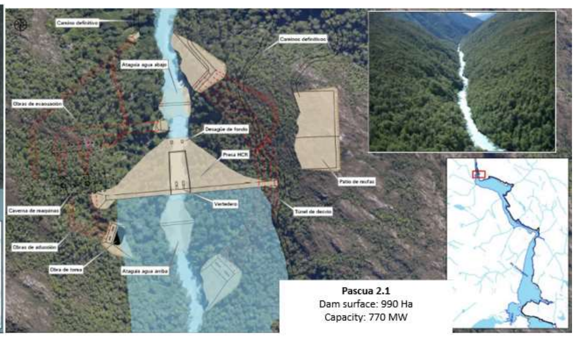
Pascua 2.2
Dam surface: 110 Ha
Capacity: 500 MW



Baker 1
Dam surface: 710 Ha
Capacity: 660 MW



Pascua 1
Dam surface: 500 Ha
Capacity: 460 MW



Pascua 2.1
Dam surface: 990 Ha
Capacity: 770 MW

Appendix: Lake Onslow,New Zealand

As New Zealand continues to work towards the revised goal of 100% renewable energy by 2030, development of new hydropower schemes are being considered; none so significant as that of the Lake Onslow Pumped Hydro Project. With the initial investigation set to cost $30 million alone, the Interim Climate Change Committee (ICCC) has predicted the cost of the project at between $2.2 billion and $4.2 billion (Jones, 2019). The proposal seeks to build a colossal storage lake above Roxburgh and Millers Flat, as an insurance policy to produce electricity in dry years and to manage demand peaks. Pumped hydro storage uses cheap electricity to pump water into an artificial reservoir, which can then be released at times when energy is required and other hydro lakes are low (Stephenson, 2020). The capacity of the proposed lake would be approximately 1000 megawatts contained in a 74 square kilometre lake and would hold 5500 gigawatt-hours of storage (Williams, 2020). This is greater than the storage of all of New Zealand's hydro lakes, which is 4409 gigawatt-hours at present.

Approximately 80% of electricity generation in New Zealand is renewable, thus further developments are imperative to reach 100% renewable as well as increasing the supply of electricity due to projected increases in demand (Stephenson, 2020). However, the economic and environmental impacts of this project pose challenges, and obtaining resources consents are likely to be difficult (Pullar-Strecker, 2020). Hydro schemes have substantial local environmental consequences due to impacts on surrounding land and ecosystems; these consequences are not consistent across renewable energy types, with wind and solar generation offering few environmental impacts comparatively. Despite the Lake Onslow scheme being labelled "expensive" and "unnecessary", if New Zealand is to achieve 100% renewable energy then overbuilding of reliable energy generation is critical (Stephenson, 2020). Retaining a small amount of fossil-fuel generation would be the most cost-effective backup for dry years, when peak demand exceeds renewable generation; however, reliable stored energy source is desirable for achieving current renewable energy goals.

Those in favour of the scheme have been quick to highlight positive environmental benefits, such as the opportunity for eco-tourism and the chance to create a predator-proof wildlife sanctuary around the reservoir (Nine to Noon, 2020). Despite the costs of the project, economic benefits have also been identified, with more than 3000 direct jobs predicted to be created for four to five years after the initiation of the scheme (Williams, 2020).

With the unpredictable nature of the changing climate and increasing demand of electricity, action must be taken towards developing renewable energy generation. There are a number of environmental and economic pitfalls of the Lake Onslow Pumped Hydro Project, which must be considered when investigating the scheme. This would clearly make a significant contribution towards renewable energy for New Zealand. What is questionable, is whether or not this is a sustainable choice for the local landscape, ecosystems and tax payers who must pay the price for such a colossal scheme.

Scope	Estimated cost	Estimated timeframe	Decision required
Phase 1: Investigation and evaluation of pumped hydro and other dry year storage solutions. Feasibility study to inform a decision on whether to proceed to the next Phase.	Up to $30 million	2021	Agreement to proceed to Phase 2
Phase 2 dependent on findings of feasibility study			
Phase 2: Engineering design and preliminary field work to understand any environmental, geotechnical and seismic aspects of dry year solution option or options agreed at the end of Phase 1.	Up to $70 million	2022	Decision whether to proceed to construction and agreement for funding mechanism
Phase 3 dependent on design work and securing of funding mechanism			
Phase 3: Construction	Unknown until dry year solution or solutions selected		

Appendix: Ralco,Chile

The Ralco Hydroelectric Plant is located in the Alto Biobío, 105 km east of the city of Los Angeles. Its operation started in 2004, after 6 years of construction, and almost a decade of social conflicts with the Pehuenche that inhabited the area.

Project's specifications:

- Declared Potence: 690 MW
- Turbine flow: 450 m^3/s
- Net fall height: 183,5 m

The Ralco project contributes with 3.100 GWh of energy per year, representing 9% of the energy required by the Central Interconnected System, which serves about than 90% of the country's population.

During construction, the project required an average of 2.000 workers, reaching a peak of 3.500, of which only 10% were local labor, Pehuenche. As a way to show that the project can also bring benefits to the relocated inhabitants, they build homes, roads and started a training program that would allow some of them to keep working on the plant during the operation.

Despite these initiatives, the project caused an important unrest between original inhabitants and the Chilean State. The company (Endesa), began the construction of the dam -the second in Alto Bio Bio- despite the Environment Law and the Indigenous Law, carrying out tasks in sacred places such as cemeteries (Quepuca) or a nguillatún field, even dynamiting areas that put a Machi Cura (sacred stone) in serious danger. The Pehuenches, duped by Endesa, agreed to swap their lands and be cornered in the Cordillera.

Among environmentalists and spokesmen for Pehuenche communities, opposition to the project emerged, criticizing the alteration of ways of life and the environmental damage that the river basin would suffer. The conflict reached the courts where finally, in 1993, the Supreme Court accepted the appeal filed by the company Pangue S.A. allowing the construction of the plant.

This kind of cases show us that hydroelectric can provide significant amounts of energy. However, they can't just be implemented based on energy balance, without measuring the impact that will generate in the local communities and their way of life. It was a chaotic way to implement the project, because it was never a complete agreement between Endesa and the local community, forcing the "law" on original inhabitants that do not even speak the language, nor agreed on live under that law. Therefore, here, it wasn't a communal decision, but a legal imposition.

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