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Review of Chile's decarbonization efforts

In the Intended National Determined Contributions (INDC) published by Chile in 2015, Chile committed to reduce its CO_2 emissions per GDP unit to 30% below the 2007 levels by 2030 [1]. In 2017, Chile ratified its commitments made under the Paris Agreement to the Conference of the Parties (COP). Chile has been a leader in establishing forward thinking carbon policy in Latin America. In 2014, Chile imposed a carbon tax of 5 USD per ton of CO_2 emitted on generation facilities with a capacity of 50 MWth or more. The implementation of the carbon tax began in 2017.

The Chilean government and the Ministry of Energy have relied on other carbon policy instruments to advance in the decarbonization of the electricity system, amongst them establishing a working group to develop voluntary and binding agreements to retire coal generation facilities. On January 29th 2018, an agreement was signed between the Chilean government and the companies which own coal-fired power plants. The agreement signing process was facilitated by the Ministry of Energy and the Chilean Generator Industry Association. The agreement stated the following:

1. No new coal-fired projects were going to be developed unless they had carbon capture and storage technologies, or an equivalent.

2. The Ministry of Energy would establish a working group with main stakeholders (private and public sector, NGOs, academia) to jointly evaluate the social, economic, environmental, health, employment and technical tradeoffs associated with the definition of a decarbonization plan for the electricity system.

Recently, the Chilean government announced more aggressive decarbonization goals by presenting its intention to reach carbon neutrality by 2050 [2]. Existing coal generation facilities will have to be either converted or retired in order to fully decarbonize the electricity system. On June 2019, generation companies signed agreements with the government to retire 8 units (1047 MW) within the next 5 years. As part of the decarbonization commitments, the Ministry of Energy and the generation companies must review the decarbonization plan every 5 years. Chile has other carbon policy initiatives in development, an energy efficiency and a climate change law are being developed and discussed to further advance decarbonization efforts.

This article is focused on reviewing the studies and process conducted by the decarbonization working group, contextualizing the role of coal generation in Chile, reviewing the agreements signed between generation companies & the government, presenting the conversion & retirement alternatives, and describing the social & environmental challenges with reconversion or retirement of coal facilities. Finally, the article highlights some of the lessons learned from the process and future work which could be addressed.

Summary of decarbonization working group process

The working group led by the Ministry of Energy included policy makers, industry experts, NGOs, industry associations, academia and firm executives. The working group established a process which lasted for six months. The primary objective of the process was to conduct a multidisciplinary analysis which would allow the working group to jointly develop a conversion and retirement schedule for existing coal generation facilities. The multidisciplinary analysis reviewed environmental, social, economic, reliability & system adequacy elements associated with the retirement or conversion of a coal facility. The working group explored the technological alternatives and best practices for retirement and conversion. The analysis conducted and process is shown in Figure 1.

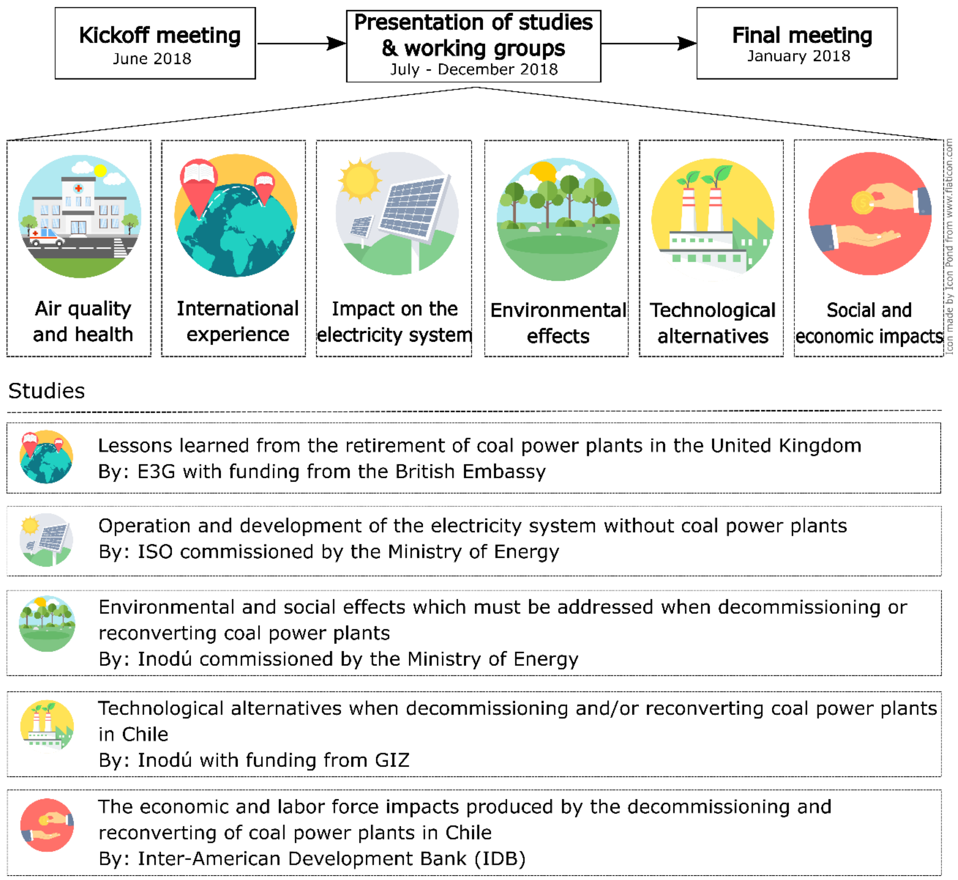

Figure 1: Decarbonization working group process (adapted from presentation prepared by Ministry of Energy).

Coal generation & its role

Coal represents 22% of the gross installed capacity in Chile. In total, 10 thermoelectric generation facilities exist in the country, which together account for 28 coal-fired based generation units [3]. As shown in Figure 2, the units are concentrated in 6 regions. For many of the regions coal-fired plants are an important source of jobs for the community and a driver of local economic activity. Historically the installation of these coal generation facilities was motivated by primarily three main drivers:

- **The expansion of the electricity system prior to 1990** catalyzed the installation of 7 units (907 MW) which accounts for 16% of the existing coal capacity. The units were primarily installed by the coast in the northern and central part of the country. Two units were commissioned before 1970 and one unit was commissioned during the 1970's.

- **A need to supply large consumers during the 1990's** drove the installation of 7 units (1100 MW) which accounts for 20% of the existing coal capacity. These units were primarily installed in the in the northern part of the country.

- **The Argentinian gas crisis in 2006** propelled the installation of 14 coal units (3550 MW). The units installed post the Argentinian gas crisis account for 64% of the existing installed coal capacity. Approximately 35% of this capacity is installed in the central region of the country. Before the Argentinian gas crisis, Chile relied primarily on CCGT and hydroelectric resources. During the Argentinian gas crisis, natural gas supply was completely shut off which led to spikes in electricity prices.

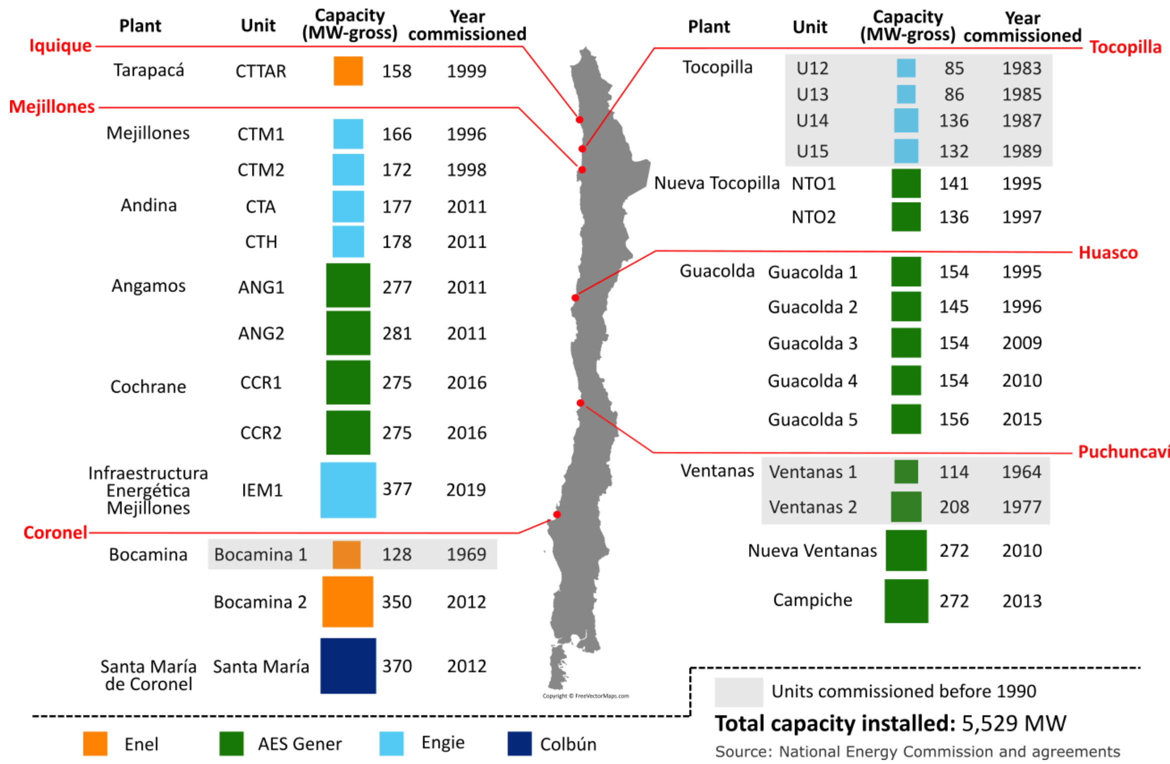

Figure 2: Coal-fired plants installed (Source: inodú)

International benchmark

Other countries in Latin America such as Costa Rica have set more aggressive decarbonization goals. In 2018, Costa Rica launched a decarbonization plan which, among other goals, set the objective of having an electricity generation mix which relies on 100% on renewable energy by 2030 [6]. Nevertheless, the country does not have significant coal generation capacity. In 2018, Costa Rica generated 98.6% of its energy from renewable energy resources, 73.4% of the energy came from hydroelectricity [4]. Costa Rica's, hydroelectric resources have allowed the country to set more aggressive goals.

As opposed to Costa Rica, in Chile approximately 37% of the electricity generated comes from coal facilities and most of the existing coal facilities were installed post 2009. The reduction of greenhouse gas emissions in Chile will involve the conversion or retirement of coal-fired power plants. There are countries in Latin America which rely on installed coal capacity such as Colombia and Mexico which have not presented an explicit plan to reduce their reliance on coal-fired generation. While other measures have been taken, such as carbon taxes in Colombia and Mexico[1], or the Mexican renewable energy targets[2], neither of these two countries have announced a concrete plan to reduce their reliance on coal-fired generation.

[1] https://unfccc.int/sites/default/files/resource/47096251_Colombia-BUR2-1-2BUR%20COLOMBIA%20SPANISH.pdf
[2] https://unfccc.int/sites/default/files/resource/MEX_6aNC_Revisada_0.pdf

Worldwide, Chile is part of a group of countries which relies heavily on newer coal capacity to supply their demand compared to other countries. As shown in Figure 3, Chile along with Germany and the Netherlands have newer coal generation capacity and have committed to stop relying on coal generation by a specified date in the future. Just like Chile, Germany recently made commitments to phase out coal. On January 2019 the German Coal Commission, supported by the federal government, presented a roadmap to phase-out of coal generation by 2038. The Netherlands announced a more aggressive decommissioning schedule compared to Chile and Germany. The Netherlands has committed to retire their coal capacity by 2030. Countries like Australia and South Africa which have a coal intensive energy mix have not made announcements to decommission coal facilities.

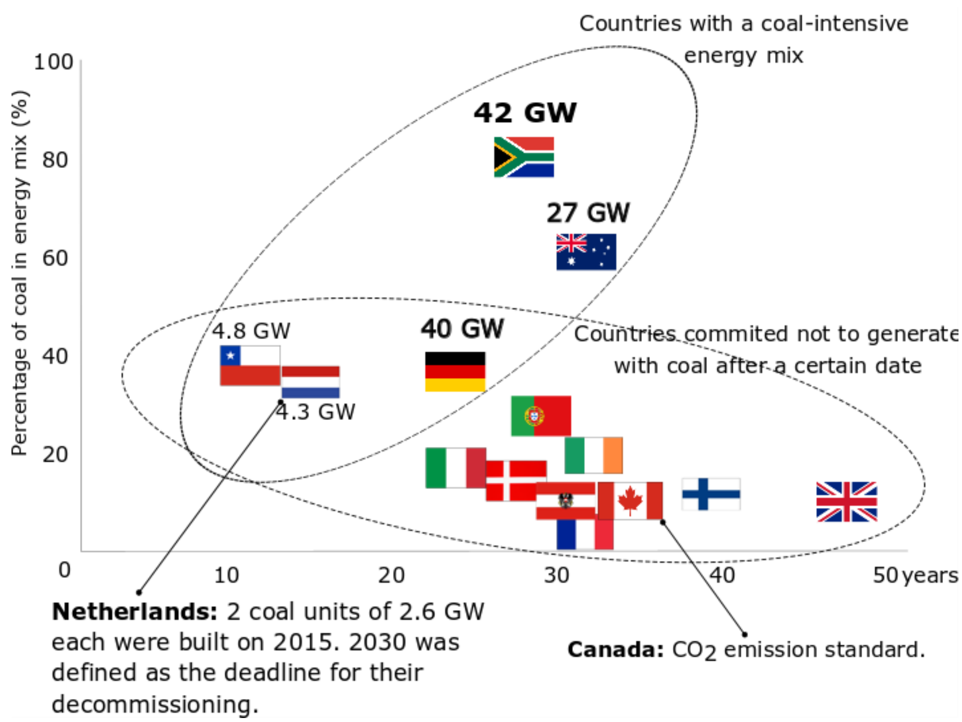

Figure 3: Coal participation vs. plant's age (Source: inodú [5])

The evolving role of coal generation in the power system

Chile has been integrating variable renewable energy at an accelerated rate, for example, during the month of July 2019, 12.5% of the energy generated in the Chilean Electricity System came from either wind or solar. With the integration of renewable energy in Chile the role of coal generation will have to evolve from its original role which was to provide baseload energy. The new role of coal was observed in 2018 in the northern part of the system as shown in Figure 4. Given the transmission restrictions that were present in 2018 between the northern and central region, coal generation lowered its generation capacity during the day to accommodate solar generation.

Overall, the Chilean electric system is still mainly hydrothermal. Coal generation dominates the northern region of the country while hydroelectric facilities generation is more abundant in the south as shown in Figure 4. In 2018 in the central and southern region units operated to primarily provide baseload. The role of coal generation is not only limited to providing energy into the system, it is also providing ancillary services mainly in the form of reserves in the northern part of the system.

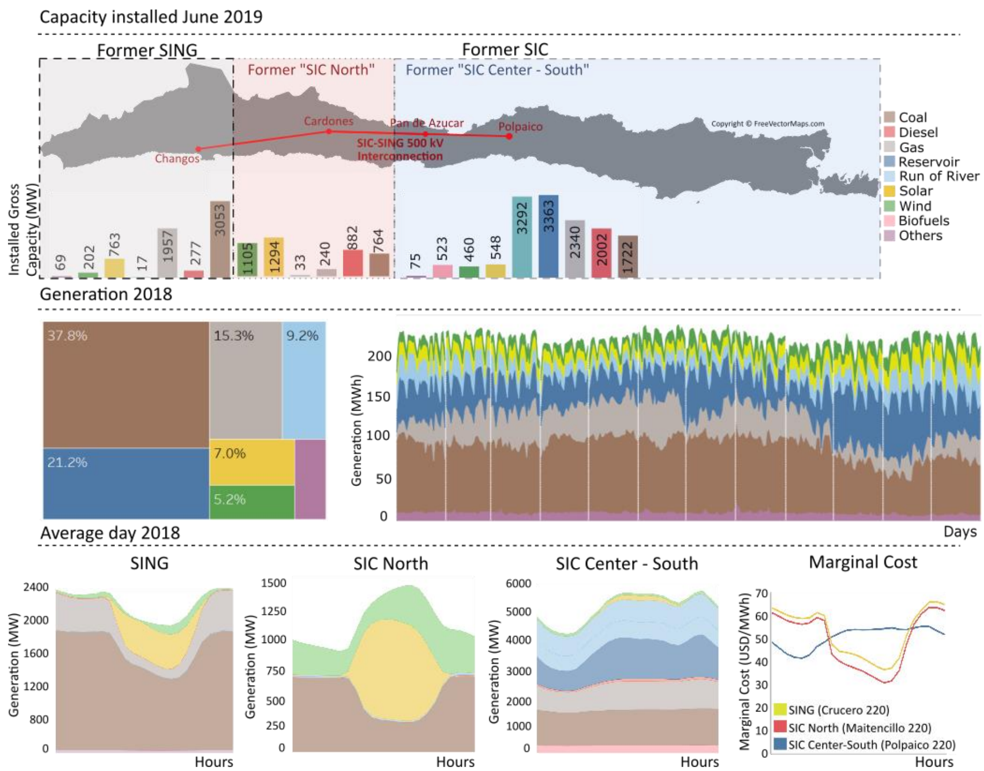

Figure 4: Capacity installed and generation National Electric System (Source: inodú)

As more renewable energy is integrated into the power system, the need for baseload decreases and the need for intermediate generation increases as shown in Figure 5. Intermediate generation must have the flexibility to rapidly adapt to the intermittent and variable output of wind and solar. The competitiveness of coal in this new market structure will depend on other environmental, economic and technical factors shown in Figure 5. As renewable integration advances, new reliability and adequacy needs will have to be addressed [6].

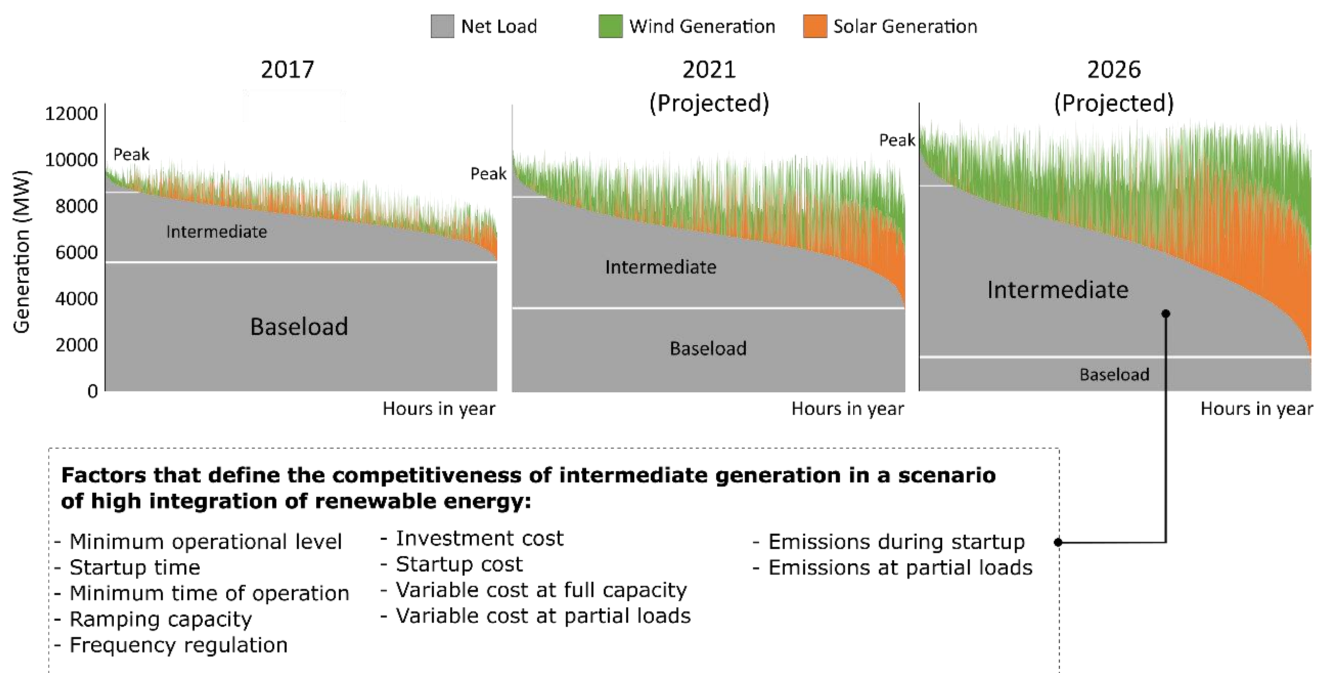

Figure 5: Factors that influence the competitiveness of coal (Source: inodú)

Stakeholders affected by coal generation

Retiring or converting a coal facility is not only a technical, economic and environmental endeavor. There many stakeholders whose needs and interests are directly or indirectly intertwined with the operation of a coal generation facility in Chile. Such relationships were assessed in a study prepared by inodú for the Environmental and Climate Change Division within the Ministry of Energy for the decarbonization working group. A stakeholder who is affected by the operation of a coal facility could be identified by the following criteria:

- Are directly or indirectly affected by the power plant's inputs and outputs.
- Receive a direct or indirect benefit from the power plant's operation.
- Have a significant and legitimate interest in the operations (or the stop of operations) of coal generation facilities.

Figure 6 shows a value exchange map for the main stakeholders affected by coal generation in Chile considering the most relevant social, environmental and economic impacts of decommissioning and reconverting a unit. The map includes the most relevant direct and indirect value exchanges, which include not only energy and economic value, but also good and services, public policy definition, jobs, public welfare, information, among others.

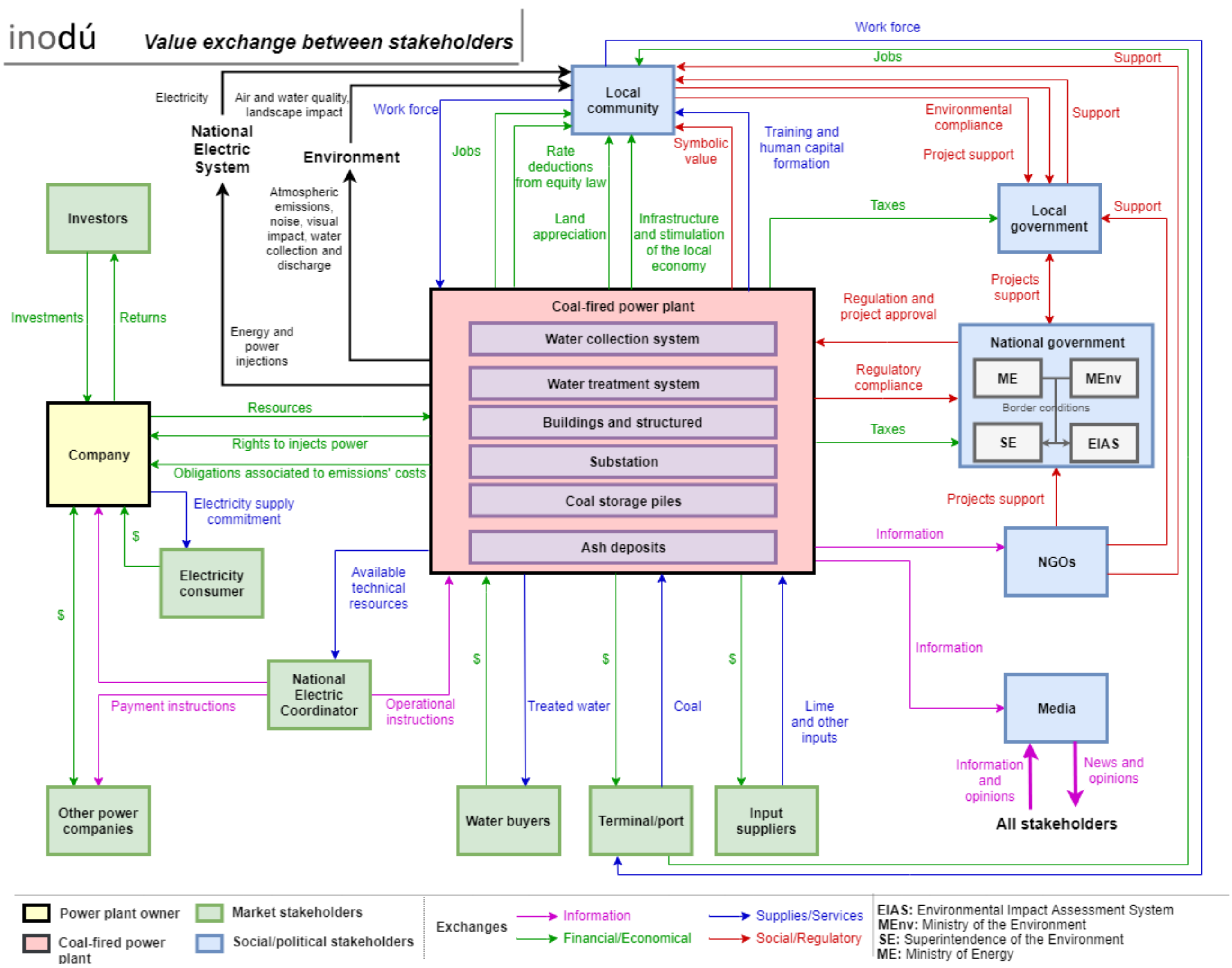

Figure 6: Stakeholder map of a coal-fired power plant (Source: inodú)

The retirement of a coal power plant creates environmental benefits such as the reduction of local emissions, global emissions, environmental impacts from withdrawal of water from water bodies, discharges to water bodies, amongst others. However, the retirement of a coal power plant has direct consequences on the local community and local government, especially affecting jobs, tax payments and social welfare. As shown in Figure 6, the interactions and dependencies which exist between stakeholders can be complex. For example, NGO's and the media can have a significant effect on the views of the local community and local government depends on the approval of the local community. However, the taxes paid by the coal generation facility can be an important component in financing local government activities, especially in smaller communities such as Huasco, Mejillones, and Tocopilla in Chile. Furthermore, in some of these smaller communities the coal generation facilities can provide jobs to a significant portion of the local labor force and affect the livelihood of locals who sell services and goods to the power plant such as water, coal terminals, other supplies or associated services.

The impact in each region where coal facilities are located will be different and the resources needed will vary significantly based on the reality of each community. In a study conducted by the Inter-American Development Bank (IDB) for the decarbonization working group, the IDB estimated close to 4,317 direct employees and 9,345 indirect employees could be affected if coal generation facilities are shut down in Chile. As shown in Table 1, municipalities like Mejillones, Tocopilla and Huasco the direct employment associated to coal generation exceeds 3.8%. The potential job losses from a closure of a coal generation facility stresses the need to consider retraining and reemployment policies for the coal facilities workers.

Table 1: Direct & indirect employment estimates associated to municipalities (Adapted from IDB study).

Municipality	*Direct employment associated to coal generation*	*% of direct employment of total in municipality*	*Indirect employment associated to coal generation*	*Total Population in municipality*
Iquique	76	0.1	165	191,468
Mejillones	1,533	3.8	3,319	13,467
Tocopilla	589	4.4	1,275	25,186
Huasco	533	6.8	1,154	10,149
Puchuncaví	808	1.6	1,750	18,546
Coronel	777	0.3	1,682	116,262

Other important stakeholders associated to coal generation facilities are users of the National Electricity System such as the National Electric Coordinator which acts as the Independent System Operator (ISO) in Chile, other generation facilities and electricity consumers. In a study conducted by the ISO for the decarbonization working group, the ISO determined that transmission and generation assets will be needed in the future in order to maintain the security of the system. Therefore, a gradual retirement of the power plants is crucial in order to give time for this new capacity to be added. The study concluded that over time coal generation will have to be replaced by other flexible generation technologies which can provide reserves such as concentration solar power (CSP) with storage, pumped-storage and generation with natural gas will be needed to meet the system's reserve requirements. Additionally, the ISO concluded that up to 4000 MW in transmission infrastructure expansion could be needed.

Signed agreements

After concluding the six-month joint multi-disciplinary analysis led by the Ministry of Energy which included community members, policy makers, industry experts, and firm executives, agreements were signed on June 4th, 2019 between the generation companies and the government. As shown in Figure 7, all companies which own coal generation assets committed to:

- Not starting any new coal-fired power plant projects which do not have a carbon capture and storage system, or an equivalent technology.
- Reevaluating the plan every 5 years after 2025. The technical, social, economic and environmental impacts will have to be re-evaluated to adjust the decarbonization plan and agree on future retirements.
- Stopping operations of all coal facilities by 2040
- Keeping their existing units as strategic reserves for a maximum of 5 years after they are retired.

The power plants' retirement schedule was conceived considering the following criteria:

- Older units will be decommissioned first.
- Units will be decommissioned gradually.

Figure 8 shows the retirement schedule derived from the agreements between the generation facility owners and the government. In total, as part of the agreements made, 1047 MW will be taken off the grid, affecting both the northern and southern zones of the country.

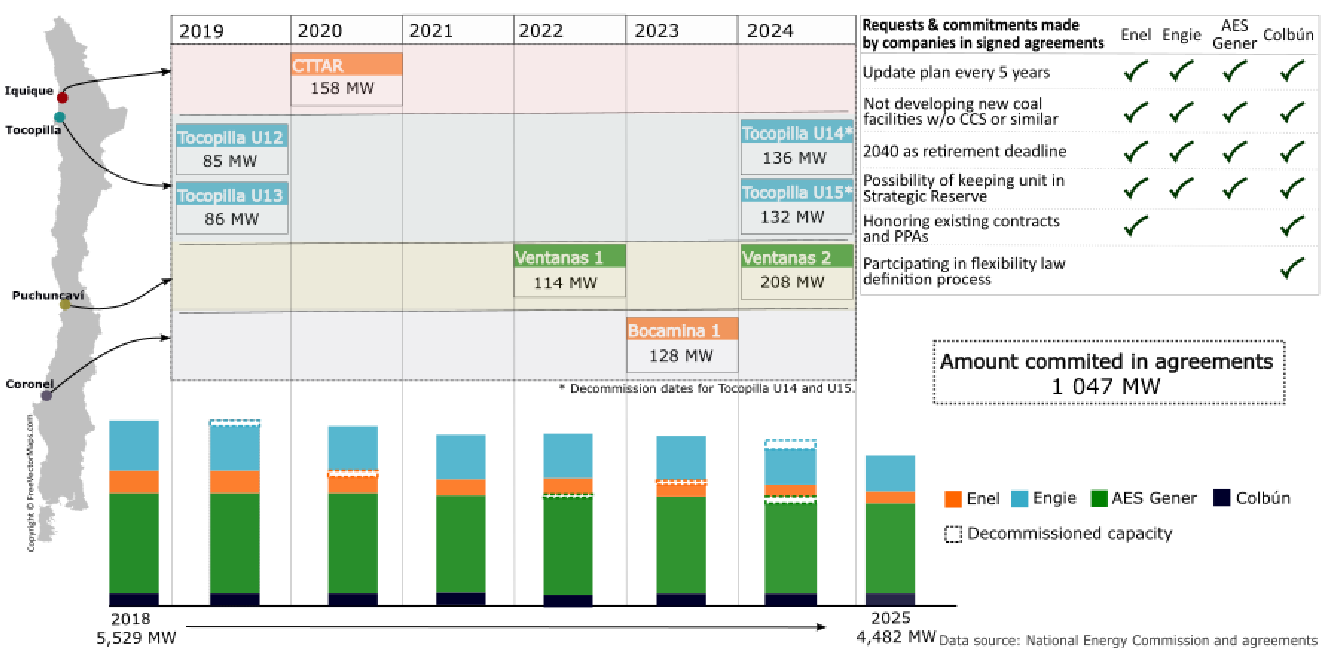

Figure 8: Coal retirement schedule 2019 – 2024 (Source: inodú)

Technological alternatives

Many factors influence the possible conversion and reutilization of coal generation infrastructure. The viability of the options depends on the owner's assessment of the existing infrastructure, which is influenced by regulatory conditions, power market needs, and the competitiveness of the different options to supply energy consumers. Table 2 synthetizes the factors that influence the conversion of thermoelectric units in a high-renewable integration scenario.

Table 2: Factors that influence the conversion or decommissioning of thermoelectric units in a high renewable integration scenario (Source: inodú [7]).

External factors	• Market regulation • Consumer's and electric system's needs • Market competitiveness • Technology development • Environmental regulation
Internal factors	• Corporative strategy • Profitability • Implementation complexity • Operations and operational costs

Every generation unit is different, this should be considered when evaluating potential conversion alternatives. Even units with similar capacities and installed in the same location may have differences in terms of performance and operational characteristics. Therefore, any conversion must be evaluated independently, considering every particularity which could increase the cost and have effects in the performance of the unit. Consequently, the expected generation performance, GHG emissions and flexibility of a converted unit may vary between units, even when using the same technologies.

Fourteen alternatives were presented to the decarbonization working group to convert and reutilize coal generation in Chile. Mature and non-mature alternatives were considered and were classified as alternatives that convert the unit or reuse a part of the remaining infrastructure. The impact on carbon emissions, flexibility (as a higher flexibility promotes the incorporation of VRE generation), costs and effects on jobs were evaluated for each alternative and summarized in Figure 9 .

Alternatives classified as mature will be easier to implement in the short term. However, non-mature technology alternatives could improve in the future. Hence, the costs and implementation risks could be reduced over time. In the long term, some of the emerging alternatives could contribute in the reduction of GHG emissions and increase the flexibility of the power system in a more effective way than alternatives which are currently considered mature. Nevertheless, the decisions must be taken considering both short- and long-term options, considering costs, effectiveness and the system's needs.

Unit Conversion

Total Conversion

Mature	CO_2 emissions	Flexibility	Investment cost	Jobs
To natural gas	− −	+	Medium	Slight Reduction
To forest biomass	− − −	−	Medium	Neutral

Partial Conversion

Mature	CO_2 emissions	Flexibility	Investment cost	Jobs
Coal and natural gas co-combustion	−	+ +	Low	Neutral
Use of natural gas during minimum stable level and startup	−	+ +	Very low	Neutral
Coal and forest biomass co-combustion	−	−	Medium	Neutral
Non-mature				
Use of carbon storage and capture systems	− − −	− −	Very high	Increases
Electricity and hydrogen cogeneration	− − −	Unknown	Very high	Increases

Use of Unit Infrastructure

Installation of other generation units

Mature	CO_2 emissions	Flexibility	Investment cost	Jobs
Waste-to-energy facility	−	− − −	Very high	Reduction
Gas engines	−	+ + +	High	Reduction

Installation of energy storage

Non-Mature	CO_2 emissions	Flexibility	Investment cost	Jobs
Short-term storage technologies (batteries)	− − −	+ +	Very high	Reduction
Compressed air energy storage (CAES)	− − −	+ + +	High	Reduction
Molten salt storage system	− − −	+ + +	Unknown	Reduction

Other uses

Mature	CO_2 emissions	Flexibility	Investment cost	Jobs
Closing and decommissioning	− − −	Does not apply	Low	Reduction
Water desalination	Neutral	Neutral	Does not apply	Reduction
Mothballing	− − −	Does not apply	Very low	Reduction

+ Increases − Decreases

Figure 9: Selected technology alternatives (Source: inodú [7])

Social and environmental challenges with conversion or retirement of coal facilities

Converting or closing a coal-fired power plant has several social and environmental challenges, these were analyzed by inodú in a study prepared for the Environmental and Climate Change Division within the Ministry of Energy and presented to the decarbonization working group [5]. To minimize the environmental, social and economic challenges created by the retirement or conversion of coal-fired generation units the following best practices were presented:

- **Provide certainty of new environmental requirements such as emissions restrictions or carbon pricing/taxing.** Environmental regulation influences the expectations for the operations of coal units and their role in the market. This is especially necessary for units which started their operations after 1990, as many of these coal-fired power plants were originally built to satisfy the demand of large clients.

- **Communicate the closure with anticipation.** A schedule must be set and disclosed especially to the affected communities.

- **Establish an early definition of goals and purpose for the site.** The use of the remaining site must take into consideration the community's needs as well as the technical and economical feasible options. In Chile, many of the units are located in a facility where another newer unit will continue to operate once the older units are converted or retired. The options for the use of the site will also be influenced by the environmental state of the facility and associated remediation costs.

- **Conduct environmental research early for the site** to determine if there is contamination that must be remediated.

- **Address the economic challenges created by the plant's decommissioning.** The economic challenges could be addressed by retraining and reemploying the plant's workers, establishing new sources of revenue for the region and avoiding the deterioration of public services (such as health and education). Economic development plans could complement the decommissioning. However, it is also important to manage the community's expectations the jobs created by the feasible alternatives.

The roles and responsibilities that will have to be assumed by either by the current stakeholders or new parties that might be interested to address the challenges faced will have to be defined. The following should be addressed:

- **Defining the closing firm's responsibility** in terms of the site's remediation and the future development of the community.

- **Use multi stakeholder groups to identify potential uses for the site** and/or provide input to the entities responsible to find and evaluate alternative uses for the unit and site.

- **Establish opportunities which encourage third parties to present possible development alternatives for the site and** couple with financial incentives.

- **Define the role of the municipality and key local stakeholders.** The municipality and local stakeholders play a key role in developing a vision for the region and advocating for new projects which align with the region's development vision.

Lessons learned and future work

The process led by the Ministry of Energy and the agreements signed were an important step forward in advancing decarbonization efforts in Chile. The process is bound to continue given the commitments made by the government and industry. The following are good practices which can be extracted from the process that might be useful to other countries embarking in similar processes or discussions:

1. Decarbonization is a multidisciplinary endeavor which has social, environmental, technical and economic implications. Establishing joint fact-finding processes between affected stakeholders and experts can help develop better decarbonization plans.

2. Setting a long term decarbonization goal helps provide long term guidance, for Chile 2040 was agreed upon as the date to fully remove all coal generation from its electricity system.

3. Committing to define a decarbonization roadmap every five years provides flexibility; creates a real option to address changes in markets & technology; establishes an opportunity to increase effectiveness of plans as better information becomes available in the future; and prevents full reliance on long term tecno-economic modelling which has high levels of uncertainty. Overall, jointly reviewing the decarbonization plan creates the option to make more aggressive and effective commitments in the future at potentially lower overall cost and with less uncertainty for the country.

4. Decarbonization cannot be addressed effectively and efficiently relying just on one policy, to effectively decarbonize the system a broad set of policy adjustments and market trends must be leveraged. In Chile it will be important to continue to advance and monitor the following:

    a. **The availability and price of shale gas from Argentina -** This year contracts to supply gas to Chile have been signed at between 3.4 USD/MMBtu and 6.3 USD/MMBtu. The availability of inexpensive shale gas from Argentina could lead to the market displacement of coal generation units. There is uncertainty in the medium and long term around the actual availability of Argentinean natural gas.

    b. **The flexibility of the thermoelectric generation portfolio -** The higher the flexibility of thermoelectric facilities, the lower the curtailment of renewables and the lower the total emissions. In Chile there are some regulatory challenges and operational issues which are affecting the flexibility of thermoelectric facilities and the electricity system. For example, air emission standards in Chile for combined cycle units operating at partial load can limit the flexibility of existing CCGT units. In some instances, the minimum loads and minimum down times of coal generation facilities have constrained the capacity to integrate more renewable energy without curtailment.

    c. **The evolution and competitiveness of alternatives to convert or replace coal facilities -** For example, the cost of storage is rapidly decreasing based on market adoption worldwide, lower costs of storage technologies in the future will make decarbonization more economically attractive to market participants.

d. **The Levelized Cost of Energy (LCOE) for renewables -** Today, in many locations in Chile the LCOE of solar is lower than the variable cost of producing electricity with a coal generation facility. Monitoring the cost of renewable energy technologies and rates of integration of renewable energy will be key to continue to develop a more effective decarbonization strategy and adjust transmission development plans.

e. **The evolution of PPAs with non-regulated clients -** Recently in Chile two large mining consumers announced that they were signing PPAs for 100% renewable energy. If this trend continues amongst non-regulated clients it will create market pressures to stop relying on coal generation and a deficit of renewable energy will rapidly emerge in the Chilean electricity system. More than 5 TWh/year of contracts are set to expire between 2021 and 2026 for non-regulated clients.

f. **Reliability metrics and adequacy goals -** As renewable integration advances, new reliability and adequacy needs will have to be addressed. Regulatory and operational changes are required to prepare the system to have the flexibility needed to continue the effective and efficient integration of renewable energy. Such changes can incentivize investments to timely deploy flexible assets to continue the integration of renewable energy and maximize value delivery to end consumers.

g. **The effectiveness of the current carbon tax to address decarbonization goals -** Effective carbon policy also involves defining the necessary carbon price and tax mechanisms. In 2017 and 2018 through the Partnership for Market Readiness (PMR) various alternatives to evolve the existing carbon tax were explored. Further enhancing the current carbon tax will help achieve concrete decarbonization goals and help satisfy the needs of stakeholders by providing more certainty and urgency to the decarbonization efforts.

There is work and questions that could be addressed in the next five years which could support the implementation of the existing agreements and help with the definition of the next set of agreements which will have to be signed after 2024. The following are some of the questions that should be considered:

1. How will some of the best practices that were identified to convert or retire coal facilities be implemented for the facilities that are set to be retired and converted in the next five years?

2. What work could be done to support communities like Huasco, Mejillones, and Tocopilla which job market and local economies could be significantly affected by the retirement or conversion of coal facilities?

3. What market conditions or policies would create an environment which would make it easier for industry and government to jointly agree to more aggressive decarbonization goals? For example, what would be required to set the goal to completely decarbonize the Chilean Electricity System before 2040?

4. How could the expiration of PPAs with non-regulated and regulated clients be used to further drive decarbonization?

5. What pilot projects or activities could be conducted between now and 2024 to reduce the perceived risk of implementing the coal facility conversion and retirement alternatives identified?

6. What will be the decarbonization goals for other industries?

Although there is still work to do, the agreements recently signed are a positive step forward in which companies committed to completely stop the operations of coal facilities by 2040 and concrete commitments were made to initially retire a fifth of the existing installed capacity in the next five years.

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