Unveiling the potential for combined heat and power in Chilean industry - A policy perspective

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\textbf{A B S T R A C T}

Combined Heat and Power (CHP) has again become a key element in international energy and environmental policy, since it is one of the most promising methods of ensuring grid stability, making an energy system more flexible and environmentally friendly. This is particularly true in the case of Chile, which has an energy system that progressively introduced volatile renewable energy sources such as wind and solar energy. This scenario has led to the development of a new regulatory strategy and CHP flagship projects throughout the country. Despite this interest, there has been no analysis of CHP development or the impact of the latest regulatory changes on its evolution. This study presents an updated cadastre of the CHP facilities as of 2018, together with an analysis of its evolution in terms of an energy policy. From this cadastre, interviews with experts, and a review of the regulations and incentives, the study identifies the main policy barriers for CHP development in Chile. Furthermore, this study presents a series of challenges and recommendations for the country.

1. Introduction

Initially, the CHP development, an industrially available technology existent already for over a century, was linked to industries with production processes that require steam as input. Since then, the most recent incentives for CHP development have been closely linked to various energy policy objectives, such as increasing the competitiveness and efficiency of the system, increasing safety and reducing the use of energy (Hendriks and Blok, 1996; Lemar, 2001; Pade et al., 2013). Despite not being a clean electricity source per se, combined heat and power (CHP) has demonstrated to be an important means to more efficiently using fossil fuels, saving valuable natural resources and reducing emissions because it produces both heat and electricity at the same time (US Department of Energy and US Environmental Protection Agency, 2012).

CHP is thus an integral part of policies that are aimed at reducing greenhouse gas emissions and facilitating the transition to sustainable systems in countries with very different context (International Energy Agency, 2014). In the case of the US, for example, the installed capacity of CHP has increased in recent years, and similarly in the EU, specific plans have been implemented for its expansion in the coming decades (European Commission, 2012). In Chile, non-conventional renewable energy sources (NCRES) have increased their presence in the country’s energy matrix thanks to their wide potential, the inclusion of a quota system and the high competitiveness of wind and photovoltaic technologies (International Energy Agency, 2018). As the use of NCRES accelerates, CHP plants have been identified as representing an opportunity to provide flexibility to the system. For this reason, CHP development in Chile is part of the 2050 Energy Agenda, a route that promotes, among its 38 guidelines, encouraging a high penetration of NCRES in the electricity matrix, using locally available resources, and taking advantage of energy development potential in production processes (Ministerio de Energía de Chile, 2015a).

Nevertheless, the regulatory situation of the CHP technology in Chile, the diffusion of the technology worldwide and the impact of regulation on its development has not been properly explored. The most
recent study on CHP and its potential for development in the country was released by the University of Chile in 2010 (Universidad de Chile, 2010). However, there is no evaluation of the CHP development in the country or the effects of policies implemented since 2004. To take advantage of the CHP potential, different actions are required, among which the overcoming of knowledge, economic and regulatory barriers stands out (Anaya and Pollitt, 2015; Lopes et al., 2007).

Due to the lack of studies on the subject, as well as the difficulty of finding data on the status of the CHP facility parks in Chile, this study aims at filling that gap and presents a methodology to generate a cadastre of the CHP plants installed in the country. The cadastre provides an initial overview of the CHP potential in the country by sector of activity, technology and geographical area. On the basis of this cadastre, a review of the previous studies and a series of semi-structured interviews with experts in the Chilean energy system and from companies with CHP facilities, the barriers and perceptions of CHP are identified. This allows to examine the current situation of the technology in the country. Based on the results of the cadastre and the identified barriers that were raised during the interviews, the current regulatory framework is evaluated to assess to what extent current policies have encouraged any effect.

To this end, the article is structured as follows. Section 2 presents the main benefits and barriers for CHP technologies, while section 3 continues with an explanation of the methodology implemented in this article. Section 4 provides an overview of results including the analysis and review of Chilean regulations on CHP, the presentation of the cadastre for Chile, the results of the interviews and an analysis of the cadastre results in a regulatory context. Finally, section 5 concludes and provides recommendations for energy policy.

2. The potential of CHP for meeting energy efficiency and sustainable objectives

2.1. Benefits of CHP

The main advantage of CHP is the efficient gain from saving natural resources and reducing emissions into the atmosphere, because it produces both heat and electricity at the same time. The overall CHP systems’ efficiency is situated in a range of 65–80 percent depending on technology type, which is higher compared with conventional central generation-transmission system; iv) a redistribution and reduction of operating costs and fuels associated with centralized generation.

The renewed interest in CHP technologies is based on these findings and the need to increase the flexibility of the system due to the rising use of NCRES. Technically, a service that provides electrical flexibility can be defined as a sustained power setting at a given time and duration in a specific location in the electrical grid (Eid et al., 2016). Available CHP facilities that supply energy to energy-intensive industries may behave as dispatching loads by reducing electricity withdrawal from the grid or releasing the energy generated (Kia et al., 2017). Nevertheless, in many cases, installed CHP facilities are used only to meet the requirements of the production processes itself (self-consumption), missing the opportunity to provide flexibility to the electrical grid and the potential positive effects of CHP. These effects are amplified when the technology is integrated in larger systems, such as in the development of microgrids (Zidan et al., 2015) and in combination with other sources of energy (Mathiesen and Lund, 2009).

The expansion of CHP facilities is thus considered one of the main strategies to participate in Demand Side Management (DSM) mechanisms, such as Demand Response (DR) providing electrical flexibility. To take full advantage of this potential, it is still necessary to generate incentive systems and market participation strategies, whose complexity has prevented many countries, such as Finland (Rinne and Syri, 2015), Spain (Romero-Rubio and de Andrés Díaz, 2015), Chile or Germany (Valdes et al., 2019), from developing a systemic approach to the issue. This situation means that the full potential has not been realized in sectors with a great capacity to provide flexibility to the system, such as industries with large electricity and heat consumption in their production processes.

2.2. Barriers to CHP

Despite its benefits, CHP has not been widely developed as the international experience shows that the high energy efficiency of CHP systems and potential cost reductions do not always guarantee investment (International Energy Agency, 2014b). In most of the places where the CHP capacity uptake has been supported, for example in the USA and EU, deregulated electricity markets and different strategies have simplified the introduction. As in the case of the NCRES, the mechanisms used to promote CHP include certificate schemes, investment support, fiscal support, feed-in tariffs and the beneficial allocation of CO₂ emission permits (International Energy Agency, 2018). These schemes, designed to different distributed generation technologies complement most of the programmes to support the use of NCRES, with diverse results (Shoreh et al., 2016). However, the ability to implement incentive schemes that reward the positive effects of CHP remains as one of the main energy policy challenges (Anaya and Pollitt, 2015; Kalam et al., 2012).

Other technical challenges that CHP may generate are intimately linked to the active management of distribution networks. Anaya and Pollitt (2015) identify among the main challenges the voltage fluctuation, thermal capacity congestion, fault-level contributions, frequency variation, regulation and harmonics. These issues may especially arise in systems where the distribution network design does not particularly consider issues of stability related to the decentralization of energy generation. This, in addition to generating costs of grid expansion and management, presents problems in transmission and distribution networks that are designed to remain passive under most circumstances. However, distribution companies need incentives to connect CHP plants and offer active management services generating new commercial arrangements (Lopes et al., 2007).

Among the most important economic factors that can act as a barrier to CHP expansion, is the existence of competing technologies. In Brazil, a country with a large potential for CHP, Škiko and Tómasquim (2003) found that the strong position of hydroelectric energy in the energy mix is the cause of the low generation costs that have caused a lack of interest in CHP development, promoting its adoption only in those industries that recycle heat for electricity generation. Moreover, the US Department of Energy and the US Environmental Protection Agency listed the
negative perception of CHP from distribution companies, who see the installation of new CHP capabilities as a potential cause for revenue depletion as an important inhibiting factor (US Department of Energy and US Environmental Protection Agency, 2012). Thus, to defend themselves, these distribution companies can discourage the use of CHP, for instance, by lowering sales prices, offering long-term supply contracts or even making their installation difficult by creating administrative barriers (Chittum and Kate, 2013). On the other hand, the lack of investment in CHP limits the size and direction of the industry’s sales and service infrastructure. Thus, CHP has been rendered an unimportant technology for most energy developers and equipment suppliers. In fact, previous studies have shown that utility companies are rigid and slow to accept change (Downie, 2017; Shah et al., 2013) although they try to include new commercial activities related to energy transition in their portfolios (Frei et al., 2018). Finally another factor connected to the internal logic of companies is that the investment in CHP is not considered part of the main business strategy for most industries. Therefore, it may be subject to greater investment obstacles and have a lower priority within investment plans (US Department of Energy and US Environmental Protection Agency, 2012).

These market factors are also linked to issues related to the uncertainty associated with projects that require significant capital investment and a long-term return on investment. This is especially the case in political and economic environments where there may be significant and unexpected changes in the prices of fuels and electricity, regional/ national economic conditions, or the regulation of public services and electricity markets (Madlener and Wickart, 2004). The administrative and environmental dimension plays a very important role in CHP projects, as facilities must comply with a series of local zoning, environmental, health and safety requirements on site. These include regulations concerning air and water quality, fire prevention, fuel storage, hazardous waste disposal, worker safety, and building construction standards. Víctor et al. (2015) identified a number of barriers for the case of New York City, including difficulties with the grid interconnection process, difficulties in obtaining local permits and meeting code compliance, among others. More recently, Mittal et al. (2018) analyzed the barriers to biogas CHP projects in rural areas, identifying six main categories of inhibitors: Financial/economic, market, social and cultural, regulatory, technical, infrastructural and informational barriers. Bhandari et al. (2019) further identified three main barriers in the case of CHP in EE.UU: a) the business model of the electrical utility b) negative subjective impressions and c) challenges in allocating the risks and benefits. These findings suggest that the barriers to the development of CHP infrastructure are also very context dependent.

3. Methodology

The methodology developed for the elaboration of this study aims at investigating the Chilean policy context for CHP, identifying the main characteristics of its historical evolution and the current situation. The following sections present the main characteristics of the methodology adopted as well as the sources consulted.

3.1. Review of regulatory framework

To understand the regulatory framework governing CHP projects, a review of the current regulations in Chile has been carried out. The development of the legislation of the Chilean regulatory framework was reviewed, including regulations and standards as well as documents describing the general energy policy guidelines. Moreover, available scientific documents on the subject were collected from a bibliographic search in Google Scholar and Scielo Chile (database of Chilean scientific journals indexed scielo). For this purpose, the following keywords were selected: “Demand Side Management”, “CHP”, “Combined Heat and Power”, “Demand response”, “Cogeneration” and “Ancillary Services”. The search was carried out in both Spanish and English and to limit the number of documents, the word “Chile” was added in all cases.

Among the documents analyzed, 23 reports generated by public agencies, consulting firms and international organizations stand out, as well as the 18 regulations that deal with the issue of generation in the region mentioned in the previous section. The international literature on barriers and drivers to CHP was also analyzed. Specifically, 62 published articles were identified that dealt with this topic from a technical or energy policy point of view. Special consideration was given to two topics: barriers to CHP in countries with Mediterranean climates, such as Southern Europe and South American countries and case studies in countries that have successfully developed CHP potential, mainly located in northern Europe. This analysis identified the lack of an updated database on the CHP park in the country, dating back to the last study found in 2010 (Universidad de Chile, 2010).

3.2. Cadastre generation

The generation of the cadastre is developed in three phases.

- First, a series of requirements were carried out to the Ministry of Energy, through its system of public consultations open to the public. Information on all CHP plants contained in the 2010 cadastre was requested. This allowed to update the information of the plants to the year 2017.

- In a second step, the database of the National Electrical Coordinator was consulted to identify any new CHP plants that have entered into operation in the period 2009–2017. To complement this information, the Environmental Assessment Service (SEA) database was consulted as it provides information on plants that had requested an environmental impact report. However, not enough information was obtained to establish whether the plants are still in operation or not. Therefore, the databases of the Ministry of Energy, the National Electricity Coordinator (CEN), and websites and statistical yearbooks of the companies that own cogeneration equipment were revised.

- The final stage begins with the reception of the database of cogeneration equipment installed in Chile from the Cogeneration Program of the GIZ to the year 2018. The list is revised and information is crossed with the data already available following the same sources consulted in the previous stage.

The cadastre, accessible under https://doi.org/10.17632/z2cvmf9p96.1, contains the electrical and thermal installed capacity, electric power injected into the grid, energy carriers used to cogenerate, geographic location, start year of operation and the type of technology used (gas or steam turbine and internal combustion engine).

3.3. Interviews

In order to gain a better understanding of perceptions in the energy sector regarding CHP, a series of interviews with experts and key actors was conducted during the months of November 2018 to April 2019. The interviews focused on the use of CHP as a resource to provide flexibility to the system. They have a format of semi-structured interviews, and were developed by a consulting team hired for this purpose. During the interviews, 10 experts in the Chilean electricity market were contacted from academia, consulting firms, the CNE and the Ministry of Energy as well as companies in the generation sector. The semi-structured interviews allow to collect qualitative data and explore the perceptions and nuances of the interviewees. The interviews are composed of open-ended questions that guide the structure of the interview after an introduction on the specific topic that was dealt with. This allows the interviewees to answer the questions regarding this technology. The development of these interviews coincides in time with the debate on the restructuring and renewal of the country’s electricity market. In particular, the country is in the process of discussing the development of complementary services legislation whose main objective is to increase
the flexibility of the system through the use of DSM in order to promote the expansion of wind and photovoltaic technologies in the country.

4. Results and discussion

4.1. CHP in Chilean regulations

The development of a special regulatory strategy for CHP in Chile is relatively new (Fig. 1). It was not until 2003 that CHP systems were defined as systems that are intended to provide power to electrical installations independently of the public electrical grid or in combination with it (Superintendencia de Electricidad y Combustibles SEC, 2003). In terms of pricing, prior to 2004 there was no special treatment in Chile for small electricity generation facilities located in the consumer domain that could inject surpluses into the electrical grid. The first advance in this subject was proposed by Law 19.940, which addresses small-sized energy generation companies whose energy source is unconventional (with surpluses that do not exceed 20,000 kWe), excluding them from partial or total charges for the use of transmission systems (Ministerio de Economía, Fomento y Reconstrucción de Chile, 2004).

Later, in 2005, Supreme Decree 244 was promulgated, which determines the regulations for Small Generation Means (PMG, in Spanish), Small Distributed Generation Means (PMGD, in Spanish) and Non-Conventional Renewable Generation Means (MGNC, in Spanish) (Fig. 2). PMG are generation means whose power surpluses available to the system are less than or equal to 9,000 kWe and that are connected to facilities of the National, Zonal or Dedicated Transmission System. PMGD are generation means whose power surpluses are less than or equal to 9,000 kWe and are connected to facilities of a distribution concessionaire. Finally, MGNC are non-conventional renewable generation means whose power surpluses supplied to the system are less than 20,000 kWe. The fundamental element of Supreme Decree 244 is that it creates an exclusive regulatory strategy so that those customers, companies and/or individuals that own electric power generation equipment associated with their productive operations can sell their surplus power to the system (Ministerio de Economía, Fomento y Reconstrucción: Subsecretaría de Economía fomento y Reconstrucción de Chile, 2005). Although this regulatory development is important, it is in fact a development designed for all distributed generation technologies and not so much a special framework for CHP.

In 2008, Law 20.257 introduced the term Efficient CHP Facility, defined as a facility in which electric power and heat are generated in a single process of high energy efficiency and whose maximum power supplied to the system is less than 20,000 kWe. An efficient CHP Facility can also take advantage of the existing regulations for PMG, PMGD and MGNC to sell its surpluses to the system (Ministerio de Economía, Fomento y Reconstrucción; Subsecretaría de Economía; Fomento y Reconstrucción de Chile, 2008). Then, the Net Billing Law, enacted in...
2012, allowed all end users of electricity that have Non-Conventional Renewable Generation Means to sell their surplus power to the electrical system. The CHP promotion programme initiated by the IEA in 2007 certainly plays an important role in this development (International Energy Agency, 2007). However, to benefit from this legislation, the customer or end user must have an installed capacity that does not exceed 300 kWe (Ministerio de Energía de Chile, 2017). This measure aims to avoid technical problems arising from the development of distributed generation media in the management of the distribution network (Lopes et al., 2007). Fig. 2 shows each regulatory alternative in which a facility can be classified as a CHP type, depending on the surplus electric power available to the electrical grid.

In 2015, the Regulation for Efficient Cogeneration (Ministerio de Energía de Chile, 2015b) was promulgated, which establishes the specific requirements that Efficient Cogeneration Facilities must meet. Additionally, some advantages are included for these facilities, such as the exception of charges for the transmission system use. Finally, CHP facilities whose surplus injection to the transmission or distribution system is less than 20,000 kWe shall be considered as efficient CHP facilities if they use waste heat from any facility, machine or industrial process whose main activity is not the production of electric power.

The latest relevant energy policies for CHP are the carbon tax Energy Route 2018–2022. The carbon tax started in year 2017 and is equivalent to 5 US dollars/ton of CO₂ emissions. However, the emissions tax will not apply to Biomass CHP plants (Ministerio de Hacienda del Gobierno de Chile, 2014). The Energy Route Guideline includes among its top 10 commitments to “Achieve four times the current capacity of small-scale renewable DG (less than 300 kWe) by 2022”, which would favour the promotion of small-scale CHP equipment. In addition, this document promises the dissemination and promotion of self-generation and consumption projects and the promotion of DG in the industrial and commercial sectors, particularly for small and medium organizations.

Chile’s CHP Regulation Status in 2019 stands in contrast to other countries with a higher weight of CHP in its energy mix. It is characterized by being a general regulatory framework, which does not include specific legislation for CHP until 2015. This is due to the technological neutrality that prevails in the vision of the regulatory system and prevents favouring one means of generation over another. This contrasts with specific CHP promotion frameworks developed in other countries where the CHP also benefits from the advantages and subsidies of NCRES. Legislation in Japan, for example, includes in 2008 tax extensions, subsidies for the purchase of CHP equipment for companies and public bodies and R&D programs (International Energy Agency, 2008a, b,c). Or for example Germany, where in 2008 CHP biogas plants could participate in feed in tariff programs, inclusion of CHP and efficient CHP in renewable energy promotion programs, and tax exemptions (International Energy Agency, 2008a,b,c).

4.2. Existing CHP capacity in Chile

The first estimate of the CHP potential and cadastre of industries with CHP installed capacity in Chile was conducted in 1995. This study, reports an estimated technical CHP potential of 1,000 MWe, of which only 260 MWe were considered feasible. In 2010, the Study for the Development of CHP in Chile was published. This report generated the fundamental basis to elaborate an effective action plan to encourage a massive implementation of CHP in the energy matrix between 2010 and 2020, proposing to overcome the existing barriers and to assess the benefits of CHP in Chile. In addition, this study generated an update of the previously estimated CHP potential – in 2004 - focusing mainly on the sectors Industry and Mining, since these use the greatest amount of energy, a necessary condition for the application of CHP.

From the cadastre, it is possible to identify three fundamental milestones in the development and historical evolution of CHP in Chile. The first one, was the installation of the first plant, which began operating in 1930 in the Metropolitan Region of Santiago. The second milestone corresponds to the beginning of the 1990s, when the installed capacity in CHP began to show a noticeable increase. The third milestone is between 2004 and 2008, where a new and drastic increase in the CHP installed capacity was apparent.

Regarding the second milestone, it is noticeable that at the beginning of the 1990s, there was a quantitative jump with respect to forestry exports (Gutierrez Saavedra, 2007). Coincidentally, this sector is the main element that has implemented CHP in its production processes. Therefore, it is clear that this industry, a large consumer of electricity and heat, implemented new CHP systems in conjunction with the expansion of plants and facilities. This productive sector also has biomass as a resource, an energy carrier widely used in CHP technologies in Chile. Thus, of the 283 MWe installed that began operating between 1990 and 1998, 180 MWe (64%) belonged to the forestry, pulp and paper sectors, all using biomass as fuel. Likewise, approximately 40% of the CHP facilities registered in 2018 operate in the forestry, pulp and paper sectors.

The third milestone was between 2004 and 2008, influenced mainly by two causes. The first is the natural gas crisis caused by the decrease in gas imports from Argentina, which triggered the transition of the Chilean energy matrix towards the use of high-value and highly polluting fossil fuels (diesel). This created an abrupt growth in energy costs (particularly between 2005 and 2008), by which the demand sector was motivated to install its own generation facilities (including CHP systems). The second cause is the implementation of new public policies aimed at promoting the use of NCRES and energy efficiency, a milestone that also introduced the term Efficient Cogeneration - Law 20.257 in 2008.

The historical development and entry into operation of the CHP systems in Chile is shown in Fig. 3. Based on the current cadastre of the CHP plants operating in Chile, it is concluded that so far, there are 55 plants operating in 2018, adding an electrical and thermal capacity of 1,418 MWe and an estimated 7,750 MWh. Regarding the geographical distribution of the CHP plants, over 90% of the facilities are located from the Metropolitan Region and Valparaíso to the south of the country, while approximately 33% are in the Biobío Region. These are also the ones with the largest capacity to generate electricity and heat.

In relation to the injection of power into the electrical grid, it is observed that in 2018, 2,540 GWh were injected from CHP, which is equivalent to less than 4% of the total electricity produced in the country. The plants that did not inject into the electrical grid are 30, which add up to 210 MWe of installed power. Of these, 26 have less than 20 MWe installed power, which makes them eligible to enter the Efficient CHP category, as established by Law 20.257 and Decree 6, whereas the remaining 4 plants could be part of this category if the surpluses injected into the electrical grid do not exceed 20 MWe and if their energy efficiency is in accordance with the provisions of Decree 6. It is worth noting that there may be CHP plants with capacities less than 3 MWe that do not appear in the databases from which the current cadastre was developed.

Finally, the CHP potential for Chile with reference year 20171 has been estimated, according to the thermal requirements of final use presented by the 2017 National Energy Balance (Comisión Nacional de Energía de Chile, 2020) in the industrial, mining, public and commercial segments (Fig. 4). Results show that the Mining and Industry sectors have 1,717 MWe not yet exploited, the Commercial sector could implement an additional 727 MWe of CHP, and the Public sector could add 462 MWe of CHP. Adding 2,544 MWe of total potential to the country. To obtain this estimate, the following uncertainty has been resolved: what installed electrical capacity (MWe) of CHP is required to satisfy the thermal demand of 2017 in each sector? Modifying the

1 At the moment of making these calculations the last consolidated National Energy Balance was 2017. Therefore, the numbers presented in this paragraph and in Fig. 4 relate to this year.
methodology presented by the IEA (International Energy Agency, 2008a,b,c) the potential of the current heating and electrical demand (industrial, commercial and public sectors) was determined. For example, to estimate the potential for CHP in the industrial sector in Chile, the following steps are involved\(^2\): 1) Identify the industrial energy demand for 2017; 2) Subtract the part used for electricity; 3) Subtract the existing heat demand already met by CHP and; 4) Estimate the share of remaining heat demand that can be met by CHP in 2017.

Based on the current cadastre of CHP plants operating in Chile (year 2018), Table 1 shows that the most widely used energy carrier of all installed capacities reviewed is biomass with 76% as the primary energy source, while the rest uses mainly biogas, diesel, natural gas (NG), liquefied petroleum gas (LPG), coal and pet coke. It also shows how most of the installed CHP MWe is located in the industrial sector, mainly the forest industry, pulp and paper production (18 of the 21 biomass plants

\(^2\) It is worth mentioning that this is the gross potential, therefore, a more detailed analysis, including further factors such as economic feasibility, should reduce the values found.
in the country are in these sub-sectors). The 1,418 MWe countrywide installed capacity only represents 6.2% of the total generation capacity installed in the country which places Chile above several EU countries (Fig. 5).

As biomass and biogas are renewable fuels, currently the CHP park installed in the country produces a priori on average a lower amount of CO2 emissions per MWh than the electrical system. The CO2 emission factor was 0.4187 tons of CO2 equivalent per MWh generated by the electricity system. This is due to the high dependence on fossil fuels in Chile that resulted in 2018 in 38% coal and 14% natural gas of the total generation of electricity (Comisión Nacional de Energía de Chile, 2020). This evidence confirms that the development of CHP in the country contributes to reducing CO2 emissions by displacing the consumption of electricity from the electric grid in certain industries.

4.3. Barriers and challenges of CHP in Chile

Following Ruggiero et al. (2015) to understand what barriers need to be removed to promote the CHP energy sector we present the results of 10 semi-structured interviews with industry and non-industry representatives. Because Chile presents a very particular context due to its electrical system configuration, its geography and sociocultural elements, the analysis has been complemented by the development of interviews. These interviews make it possible to know the subjective aspects and perceptions of the key actors in the country with respect to CHP. The professional profiles of the interviewees are: 2 senior managers working in energy companies, 3 advisers to the government, 1 consultant on energy projects, 1 project leaders on CHP projects, 1 representative of energy associations and 2 researchers in the field of energy. They were selected on the basis of their experience and their knowledge of the Chilean electricity and CHP sector. The interviews lasted for about 30–60 min and were conducted in Spanish between April 2018 and April 2019. They were developed by professional firms external to the team conducting this research.

During the interviews the most relevant barriers for the CHP development in Chile were identified. As in Ruggiero et al. (2015) and Howard et al. (2014), the main barriers associated with CHP exist not only in the regulatory field. Based on the literature review presented in section 2 these barriers have been divided into four different fields. The first one is associated with changes in governmental public policies and issues related to legislative, regulatory, normative and institutional matters. The second is linked to the lack of CHP knowledge, ranging from concepts to technical or technological elements and economic matters associated with the electricity market, fuel and CHP equipment. The third group is related to economic costs. Finally, the last group is conformed by environmental barriers. The final column shows the number of interviews where each issue was raised by the interviewed. This column signals the lack of information on CHP potential and technological ignorance as the most common barrier raised during the interviews.

In relation to the barriers proposed in Table 2, by help of the review of the current regulations and the recent evolution of the CHP park, it is possible to affirm that the country has been implementing a series of advances to overcome these barriers. Nevertheless, interviewed 7 noted that “there is a significant delay because there are no resources in the authority (CNE, Ministry of Energy), there is a lack of personnel.” A barrier also risen in other studies (Mittal et al., 2018). The creation and joint work of some institutions, such as the GIZ, the Sustainable Energy Agency, and MINENERGIA may be established as a solution to this issue. Their cooperation project offers technical and economic support for investments in new CHP systems. It is necessary to consider that public policy actions are limited which may influence the perspective that there is a lack of knowledge on the subject by policy officials. Various interviewers mentioned that any new implemented regulation: “has to be technology-neutral, seeking to deliver the right signals to the market so that agents can make decisions based on these signals. This is why no particular role can be assigned to CHP.” Nevertheless, this particularity of the Chilean energy market is not perceived as a barrier even when it does not allow the government to implement specific support mechanisms for CHP (International Energy Agency, 2018).

One way to analyse the effect of the technological neutrality is under the light of o the results of the cadastre. For example, in relation to the current status of efficient CHP, in August 2018, five efficient CHP projects are operating in the country, three of them under the regulatory strategy for PMGD and two associated with the regulation for Net billing, which represent only 1.1% of the installed capacity. Figs. 6 and 7 show the distribution of CHP facilities according to their size and participation in the schemes defined by the law. The former figure presents the installed capacities and the latter the amount of CHP plants. Regarding the large CHP facilities over 20 MWe, the results show that there are important challenges to make them participate in the strategies outlined in the law. These facilities, are not considered PMG or PMGD and participate in the generation market like any other generator. This means that they have no incentives with respect to other energy sources participating in the spot market. The medium facilities, mostly MGNC, participate much like PMG or PMGD, whereas the small facilities, due to their situation, mostly participate as PMGD.

Regarding social, market and information barriers, the routes that promote the CHP as a particular option of reliable and economic energy have not been found. All participants in the interview affirm that in the Chilean energy industry “there is a lack of information and regulation”. So far, there are no companies specialised in the CHP sector with the capacity to implement CHP projects in the country, which reduces the opportunity to develop new projects in the industrial and public sector. On the other hand, as in other countries where the market has not been fully exploited, there is a significant shortage of qualified individuals to perform tasks of planning, installation and maintenance of CHP systems (Mittal et al., 2018). Regarding this issue, the MINENERGIA and AChEE, together with other entities, have been addressing the issue of energy

| Sector/Source | Biogas | Biomass | Coal | Diesel | LPG | NG | Petcoke |
|---------------|--------|---------|------|--------|-----|----|--------|
| Commercial    | 0.03   | 0.274   | 0.645| 0.163  | 80.6215| 59.9 |
| Industrial    | 15.38  | 1083.3  | 39.2 | 63.9   | 0.195| 73.987|
| Public        | 0.163  | 80.6215 | 59.9 |

Fig. 4. Potential for CHP in Chile in 2017.
Over the last few years, they have focused their efforts on offering courses, national and international seminars and workshops, through which material on national and international advances and experience in the subject are communicated. As such, this is reflected in the energy policies that will be implemented at the national level.

On the other hand, the Energy Efficiency Division of MINENERGIA identified that the costs for CHP systems range between US$2 to US$5 million per MW installed, depending on the type of technology used, Fig. 5.

### Table 2

| Barrier                        | Description                                                                 | Answers |
|-------------------------------|-----------------------------------------------------------------------------|---------|
| **Social and Market Barriers**|                                                                             |         |
| Emerging technology           | Although CHP technologies are mature and known in different parts of the world, Chile is still an incipient market. | 3       |
| Lack of qualified personal    | Since it is a relatively new market, and the existing demand for services associated with CHP is low, there is a shortage of qualified planners, installers and maintainers. | 5       |
| Technological ignorance       | There is a lack of knowledge of the CHP technology in Chile and of the medium- and long-term economic benefits. | 7       |
| Information on the CHP potential | Companies are not aware of their CHP potential and do not know who to contact to evaluate it. | 9       |
| Development of CHP in the country | There is a lack of information and public records on the existing CHP projects in Chile. | 4       |
| **Regulatory Barriers**       |                                                                             |         |
| Lack of a specific regulatory strategy | Although there are specific participation strategies for CHP, there are also a large number of laws and regulations that apply to CHP, although these aspects have not been explicitly designed for CHP. | 7       |
| **Financial Barriers**        |                                                                             |         |
| High investment costs         | In 2016, the average costs ranged from US $2 to US$5 million per MW installed, although it depends on the type of technology used. | 3       |
| Low return on investment      | Payback periods are between four and seven years. | 5       |
| Distancing from the core business | In general, the CHP issue moves away from the core business of companies. As financing is limited, taking advantage of the investment or borrowing for issues that are related to their core business takes priority. | 5       |
| High uncertainty              | There is a high uncertainty level associated with the prices that fuels and electricity will have in the future, which makes it even more difficult to obtain agreements and financing. | 2       |
| **Environmental Barriers**    |                                                                             |         |
| Reduction of emissions        | The lack of information to offset emissions and the lack of recognized emission compensation mechanisms for CHP. | 0       |
| Carbon tax                    | Likewise, there is no incentive to mitigate emissions through CHP, as the entire tax is covered by the demand charges. | 0       |

Fig. 5. CHP Share of Total Electricity Generation Capacity (%) in 2015 vs Chile in 2018. Source: Eurostat and own calculations.

Fig. 6. Installed CHP electrical capacity divided by plant size and participation program.

Fig. 7. Number of CHP plants based on their size and participation program.
while the payback periods are between four to seven years (Roberto Valencia, 2016). Interviewees perceived these figures as too high by many industries and that companies would not consider investment with such payback periods. A barrier also raised in other contexts with high degree of uncertainty in the future (Mädler and Wickart, 2004; Víctor et al., 2015). In this sense, among the financial barriers to implement CHP and energy efficiency programmes in large capital companies and generators, interviews signalled that there is a lack of incentives, since it is preferred to invest in businesses with greater profitability than CHP (Downie, 2017). It should be noted that currently in Chile, there are 130 companies that report large energy consumption, equal to or greater than 50 Tcal per year valued in approximately $2,500 million annually (Allende, 2016). However, the available energy potential has not yet been fully exploited.

One of the interviewed experts affirmed that “It is necessary to review the effectiveness of programs, which is achieved by measuring objective parameters.” This barrier, already detected in previous studies (Universidad de Chile, 2010), remains strong, even though progress has been made in the regulatory strategies pertaining to CHP (as reflected in Law 20.571 and Decree N° 6, described above). Overall, the existing schemes offer similar incentives for PMG, PMGD or MGNC. A challenge for the regulatory system is to find mechanisms to reduce investment costs, one of the biggest barriers found in the interviews and literature review. This would require that the financing plans do not focus so much on the future as on the current reductions in transportation or distribution rates. Current schemes do not eliminate barriers associated to the initial installation costs, and although they reduce the payback period, it does not dissipate the uncertainty associated with market prices or future quantities sold in the market, which may depend significantly on the demand of the productive process, to which is added the uncertainty associated with the prices of raw materials. While the current model favours investment, for it to increase the number of investments, it is necessary to explore mechanisms such as modifying the taxation associated with the purchase of CHP equipment, creating a green bond market, or establishing mechanisms to include mandatory percentages of efficient generation among generation companies or to include those percentages among the established NCRE obligations.

Likewise, in the development of the cadastre, it has been noted that there are CHP plants that prioritize the generation of electricity, instead of development of the thermal resource, since the first offers higher revenues. Meanwhile, other companies that have CHP equipment only operate for a fraction of the year, due to the lack of heating demand during the rest of the seasons, missing out on the energy potential available. This is an important barrier for CHP diffusion also identified in other contexts (Ruggiero et al., 2015). Another influential factor is the importance of knowing the energy demand of the company before choosing the technology to be used. There is a need to reduce the barrier that exists in free-price customers (In Spanish “Clientes Libres”) electricity price, since when the spot market price of free-price customers is low, it negatively affects the development of CHP projects with plans to inject energy into the electrical grid.

The analysis of the previous regulations shows the great amount of legislation related to the installation of CHP, as well as the complexity of the mechanisms for its incorporation into the market. This regulatory complexity discourages small facilities, since in many cases, potential users do not have the necessary knowledge to process and execute all the requirements provided by law (Consultants 1 and 2). On the other hand, larger facilities, which would have the necessary skills and knowledge, face a series of regulations that, although affecting their CHP facilities, have not been specifically developed for them. A common barrier in the development of CHP projects (Howard et al., 2014). Finally, due to the complexity of the regulation, CHP facilities can in some cases participate in various mechanisms, see Fig. 2, which can generate additional regulatory uncertainty and greater complexity in decision-making. In this sense, when asked about the possible development of new market mechanisms for Ancillary systems, there is a consensus among interviewed that “Schemes that give adequate price signals [...] should provide incentives to reduce the various costs of balancing and adjusting the system”. However, the ability to implement incentive schemes that reward the positive effects of CHP is one of the main energy policy challenges (Anaya and Pollitt, 2015; Kalam et al., 2012). Thus, an in-depth study of the tariffs for self-producers and for backup contracts is required, where prices of the electric power injected into the grid recognise the benefits of distributed generation. In this sense, tools are necessary to provide more flexibility to PMGD and PMG generators as reducing the requirement to communicate one month in advance their generation estimates.

In business terms, one of the main risks for an investor that is interested in developing a CHP project has to do with the uncertainty associated with the changes in rules or regulations. This can be observed in the amendments to the General Law of Electric Services or in the changes to the Technical Standard of Safety and Quality Services (Comisión Nacional de Energía de Chile, 2018). However, some of the barriers associated with the connection and possible electric power injection of the CHP have been overcome by modifications in the regulation and preparation of guidelines for the admission of CHP projects into the Environmental Impact Assessment System (SEIA- Sistema de Evaluación de Impacto Ambiental). Nevertheless, Ministry officials recognise that: “It is appreciated that private companies or universities have the availability to carry out pilot projects in different fields, but with the current scenario, it is very complex for them to carry out and they give up” (“ChileSustentable – Análisis de Barreras para el Desarrollo de ERNC,” 2011; Universidad de Chile, 2010).

In addition, it is notable that there is still a lack of incentive for those customers with high electricity demand to incorporate CHP to obtain savings in electric bills during peak hours. This is especially complicated since most of the customers are free-price customers who have signed long-term supply contracts with generation companies that, to discourage their customer’s investment in CHP and the subsequent loss of the power supplied to them, can offer revisions of contracts. In this sense, tools are necessary to provide the power of negotiation to the PMGD and PMG with distribution and generation companies to negotiate contracts under equitable conditions.

Regarding the environmental regulation, the carbon tax in its current configuration can influence energy tariffs and limit its ability to discourage CO₂ emissions as thermal generators can transfer to the final consumers the higher expenses they incurred. On the other hand, the environmental barriers were not even raised by any participant on the interviews. Nevertheless, if the purpose was to reduce CO₂ emissions, it would be more efficient, from a social evaluation point of view, to also establish efficiency standards for new thermoelectric plants and to define adaptation periods to the new standards for the oldest generation units.

5. Conclusion and policy implications

In Chile, the evolution of the CHP facilities shows how the energy system is marked by the gas supply cut-off from Argentina and the increase in electricity prices in the mid-2000s. In the absence of supply, there was a need to build new generation plants with the purpose of addressing the supply shortage. The installation of new capacity in those companies that invested in CHP for their own consumption has the potential to provide flexibility to the electrical grid. Although these investments have demonstrated the existence of a collaboration niche between companies and the government to increase the resilience of the system, this potential has not been fully exploited yet. However, the fact that progress has been made in the promotion, use and implementation of biogas plants, which, for example, take advantage of waste from the dairy sector, and the CHP installation in three hospitals towards the southern sector of the country that are high consumers of heat, represent new milestones in CHP development.

On the other hand, the previous analysis shows that, although the
country has strived to provide a regulatory strategy capable of supporting the CHP development, there are still important challenges for reducing or eliminating the access barriers of CHP to the electric system. One of the most important barriers is the development of mechanisms that allow generation and distribution companies to discourage the installation of new CHP plants on the demand side. For this, modifications of the distribution sector, modifications in contracts between free-price customers and generation companies as well as incentive policies and even the establishment of efficient CHP quotas could be considered. These changes should ultimately lead to the development of new business plans for both consumer companies and generation or distribution companies. This would lead to a radical change in the current conception that generation and distribution companies have of CHP. One way to promote this change could be the development of pilot experiences focused on the development of new business models that go along with the current facilities in the public sector.

A second recommendation consists of conducting systematic studies, grouping the different projects that show interest in connecting to the electrical system and potential demand for heat. This could be complemented by new low-interest financing options for the development of projects or tax exemptions so that they can easily choose the capital to develop their investment and payback periods by means of power and energy sales. However, to accomplish this, it is necessary to reduce the risk associated with regulatory changes, offering guarantees that the private sector will not assume risks such as additional costs due to changes in regulations and/or new requirements. This is a key issue due to the technical neutrality of the Chilean energy market that does not allow to use other kind of support mechanism to the development of CHP projects. Finally, it is necessary to expedite the environmental process in regard to CHP plants that use renewable resources and have the approval of the communities that surround the location of the installation.

In this sense, it is imperative to continue with the promotion and co-finance CHP projects that fulfill a social role, such as those that are available in public buildings like schools, hospitals and administrative buildings that have high energy requirements. For instance, in the extreme south of the country, a sector with a high heating demand may be included as opportunities to establish district heating systems. To materialize the above described, it is necessary to have not only an initial investment but also a supplement that extends over time and provides technical and economic support for the maintenance and correct operation of the equipment, as well as education for the communities and professionals that use these systems, at least during the initial years after being installed. The same applies to the case of the small-scale agricultural industry, where the high availability of organic waste is a potential energy source for the development of new CHP projects (biomass, biogas), as has been demonstrated in the dairy sector. A fundamental characteristic of these types of projects that makes them more attractive when developing a promotion policy is the use of environmentally friendly energy. This can be applied in remote areas, far from environmental saturation and with a strong social component, since communities can participate. This scenario contrasts with the current situation of the so-called "sacrificial zones", towns that coexist with the presence of high pollutant amounts resulting from the settlement of numerous production industries in conjunction with thermoelectric plants, all in one place. Thus, CHP stands as an excellent tool to overcome that problem and a development model since it proposes the use of clean and distributed resources, with the potential to provide flexibility to the electrical grid, bringing together environmental, social and technical benefits.

It is important to discuss the effect that the combined use of this technology with DSM can have over a sector that currently implements only CHP. As described above, using DSM in CHP plants has been beneficial for both companies and the electricity market. Of course, there must be a regulatory strategy capable of allowing, encouraging and balancing these efforts within the existing traditional electricity market. In Chile, considering the current regulations for Efficient CHP, a clear example could result from the analysis of the existing operating CHP plants in the country, according to the cadastre presented in this paper. As shown, there are 30 CHP plants with a capacity of 210 MWe that are not injecting power into the electrical grid, but if these practiced DSM, some could sell their surpluses to the grid. It is feasible that the correctly used DSM in these plants, according to international experience, can help achieve beneficial results and that injection into the electrical grid is possible, which would make the system more flexible.

Finally, it is necessary to mention the need to have a state policy for Energy Efficiency and CHP that is cross-sectional and lasts beyond the rotation of governments. Although energy policy initiatives such as Energy 2050 go in that direction, this should be specifically reflected in the legislation, and there should be a continuous effort to reduce the processing times of the regulatory strategy. In the case of Efficient CHP, the creation of the regulatory strategy took almost 10 years since the enactment of the law that introduced the term Efficient CHP, the creation of the regulation that established the requirements that Efficient CHP Facilities must meet, and finally the technical training for Efficient CHP Facilities connected to distribution networks. A state approach and a permanent policy could help to move forward continuously in shorter terms and make viable the CHP projects that are not feasible today.

Roles

Conceptualization: JV; Data curation: YM, AP, JV; Formal analysis: JV, AP, YM, LR, WD; Funding acquisition: YM, LR, WD; Investigation: AP, JV, YM, LR; Methodology: YM, AP, JV; Project administration YM, JV, LR, WD; Supervision JV, LR, WD; Validation JV, LR; Visualization AP, JV.; Roles/Writing - original draft: JV, AP, YM, LR, WD; Writing - review & editing: AP, YM, JV, LR.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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