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Solar PV Planning Toward Sustainable Development in Chile: Challenges and Recommendations

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Abstract

Over the past decade, the promotion of renewable energy projects in Chile, especially solar energy projects, has become increasingly important, as energy dependence from foreign fossil fuels has increased and concerns regarding climate change continue to grow, posing a significant challenge to the local economy. Even though recent developments toward a more sustainable energy matrix in Chile have significantly increased the investment in the solar energy sector, social and environmental fragilities, combined with the lack of well-functioning institutions and the historical marginalization of indigenous communities who have been affected by several energy projects, result in gradually increasing conflictive situations. Unless proper mechanisms are designed and implemented to rapidly and correctly address these challenges, Chile could miss the opportunities that solar energy projects can provide to the development of its communities and to the economic growth of its regions. This article studies solar photovoltaics planning in Chile, focusing on the recent developments and the main challenges ahead, and proposes policy recommendations for effectively addressing these challenges.

Keywords

solar energy, sustainability, development, Chile, policy challenges

Over the past decades, Chile has become one of the leading countries in South America in terms of institutional and political stability, economic growth, and

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Table 1. Major Changes Between 1990 and 2013 Years in Chile.

Indicator	1990	2011–2013
GDP (US$ of 2014)	31 billion	277 billion (2013)
GDP per capita (US$ of 2014)	2,388	15,573 (2013)
Poverty rate	38.6%	7.8%
Gini index	56.5	50.1 (2013)
Foreign direct investment, net inflows (US$ of 2014)	0.66 billion	20.3 billion (2013)
Energy production (Mtoe)	7.93	13.05 (2012)
Primary energy supply (Mtoe)	14.01	37.21 (2012)
Energy self-sufficiency (% of energy use)	65	30 (2012)
Electricity consumption (MWh per capita)	1.25	3.81 (2011)
Installed electricity capacity (MW)	4,418	18,465 (2013)
CO_2 emissions (kton)	34,143	72,258 (2011)
CO_2 emissions (metric ton per capita)	2.6	4.7 (2011)

Source. World Bank (2013) and International Energy Agency (2012a).
Note. GDP = gross domestic product; CO_2 = carbon dioxide.

market-oriented reforms. As a result, the country has experienced an exceptional economic performance during the past 25 years with high growth rates, low inflation, and a significant reduction in poverty (see Table 1). The economic performance, together with the institutional reforms implemented, allowed Chile to become the only country in South America to be a member of the Organization of Economic Co-operation and Development (OECD; 2009).

In spite of the high and sustained rate of economic growth, social inequality generates serious conflicts, which have affected the quality of life and threatened the social and economic sustainability in Chile. In fact, there has been only a modest reduction in the Gini coefficient during the past two decades, and the country still has the highest rate of income inequality among the OECD countries, with a level of 50.1 (see Table 1). The country exhibits a particularly noticeable class structure, characterized by more than half of its population in the lower class category and only 5% to 10% falling in the upper-class category (Ferreira et al., 2013).

Until the mid-1980s, state-owned companies dominated the energy sector in Chile, especially in the electricity market. Now, the Chilean energy sector is mostly based on the principle of a free and competitive market where the role of the government is mainly regulatory and only when necessary. As part of the restructuring of the electricity industry, in the late 1980s, Chile's largest state-owned company, Endesa, was privatized and split into 14 companies (Pollitt, 2004). A fraction of that infrastructure became the base for Colbún, a power generation company now controlled by one of the richest families in Chile. The largest portion, however, initially kept the name Endesa but later on was consolidated into Enersis, a Chilean company that controlled a significant piece of the distribution market. In 1999, a controlling interest in Enersis was bought by Endesa Spain. In addition, the divestiture of the largest state-owned distribution company, Chilectra, resulted in the creation of one generating company (AES Gener) and two distribution companies (Chilquinta in Valparaiso and Chilectra in Santiago). Through internationalization and as a result of the process of acquisitions, Endesa Chile remains the largest electricity-generating company in Chile, with 37% share of the national generating capacity including all its business affiliates and subsidiaries in the country. As of today, the market shares of the three main generating companies, Endesa, AES Gener, and Colbún, account for approximately two thirds of Chile's installed capacity (Susskind, Kausel, Aylwin, & Fierman, 2014). Even though the privatization of the two existing state-owned companies, Endesa and Chilectra, sought to improve productive efficiency and generate a strong competitive market, the new private-owned companies can still exercise market power in a highly concentrated market (Arellano, 2003). So, the traditional state-owned, vertically integrated companies were not split in a way that created a very competitive market as originally envisioned. Instead, the market remains concentrated in the hands of a few companies generating market distortions and undue levels of political influence in favor of preserving the status quo in terms of energy policy. This is especially true in terms of protecting incumbents from the entry of new actors and nontraditional renewable technologies.

The dynamism of the economy, including the significant improvement in the welfare of the population, has led to a double boost in electricity demand. This positioned Chile as the country with the highest energy consumption per capita in Latin America with 3,568 kWh, well ahead of larger countries such as Argentina (2,967 kWh), Brazil (2,438 kWh), and Colombia (1,123 kWh; World Bank, 2013). As the economy continues to grow, it is expected that the electricity demand will increase from around 65,000 MWh in 2012 to more than 100,000 MWh by 2020 (International Energy Agency, 2009; Ministerio de Energía de Chile, 2012). To sustain this growth, the country will have to add more than 8,000 MW of new generation capacity by 2020 to meet the expected expansion in demand. A significant share of this growth in consumption comes from the increased energy demand in the mining sector, the country's single largest industry, and in the residential sector of the largest urban area in the country, Metropolitan Santiago, which alone contains almost 40% of Chile's population. Most of the demand from the mining sector is concentrated in the northern part of the country, where there are no rivers with hydropower potential, forcing the development of many thermoelectric plants (99% of the electrical generation of the Northern Interconnected Power System [SING] is thermoelectric). This segment of the generation market is subjected to fuel-price volatilities and also has major global and local impacts on the environment. In fact, as Table 1 shows, the level of carbon dioxide (CO_2) emissions has increased more than twice between 1990 and 2011, driven mostly by the new thermal energy consumption. The increase in energy consumption has also led to a strong dependence on external sources to supply the primary energy needs. In fact, in 1990, the country had a level of energy self-sufficiency of more than 65%, using mostly hydroelectricity, which is a local, abundant, and clean resource, in the south (Varas, Tironi, Rudnick, & Rodríguez, 2013). The remaining sources were mainly coal and oil. Regrettably, as of today, Chile's self-sufficiency has deteriorated to between 30% and 35%, placing the country well below some other countries in South America, such as Brazil, where the self-sufficiency exceeds 90%; Colombia with more than 95%; and Argentina with around 80% (Endesa, 2013).

Because of the growing energy demand, increasing dependence on imported energy sources, environmental concerns, and rising costs of fossil fuel prices, the Chilean government has shown strategic interest in pushing for energy sources diversification. As a result, the diversification of the energy matrix has been clearly reflected in its newly approved National Energy Strategy 2012–2030 (Ministerio de Energía de Chile, 2012). In this scenario, solar photovoltaics (PV) is positioning itself as a good source of clean and competitive energy that can have a major impact on the future energy diversification of countries with high solar resources. However, historical unsolved concerns related to social and environmental fragilities, combined with the historical marginalization of the communities affected by energy developments (both renewable energy and conventional energy projects), in the past years create a potentially significant threat for further development of energy projects, including PV solar expansion planning in Chile. In this sense, it is important to define a formula to address these conflicts rapidly and properly for equitable and sustainable development.

This article examines the strategic and important role that solar energy can play as an alternative energy source to secure sustainable development in Chile and focuses on the recent developments and some of the remaining challenges for its growth planning. It also gives important recommendations for effectively addressing these challenges. The remainder of the article is organized as follows. The following section presents the global trends in solar energy applications. Then, the major hidden benefits of solar PV energy utilization in Chile are highlighted, followed by a brief description of the current status in solar PV energy applications in Chile. The next section examines the key challenges for solar PV energy planning, while the final section provides important policy recommendations and concluding remarks.

Background

In recent years, solar power generation systems have gained significant attention as a key alternative to solve energy problems in various countries. The solar PV industry grew at an unprecedented rate globally during the past decade, reaching almost 139 GW capacities in 2013 (see Figure 1). As seen in Figure 1, almost 98% of all PV capacity has been installed since the beginning of 2004. PV capacity growth in 2013 was mostly driven by the top three installers—China, Japan, and the United States.

A review of the literature on solar PV development reveals that the rapid expansion of these technologies is mainly due to technological advancements that reduce cost and improve efficiency and to different policy-supporting mechanisms (Sener & Fthenakis, 2014; Timilsina, Kurdgelashvili, & Narbel, 2012). The impact of technological advancements in this trend has been significant, as it drove solar panel prices down from US$ 4.15/W in 1996 to US$ 0.56/W in 2013 (Renewable Energy Policy Network for the 21st Century, 2014). A large number of governments have supported solar energy development through a broad range of fiscal, regulatory, market, and other policy instruments. A number of studies describe in-depth analysis of various policy instruments designed to promote solar energy (Greenpeace and European Photovoltaic Industry Association, 2011; World Bank, 2011). Among the existing instruments, feed-in tariff (FIT) and renewable portfolio standards (RPS) models have been extensively implemented. Both models have their own pros and cons in achieving

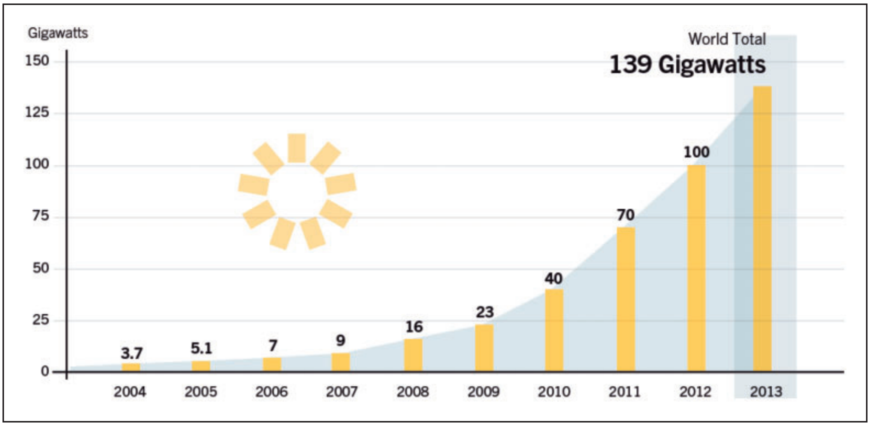

Figure 1. Solar PV total global capacity, 2004–2013.
Source. Renewable Energy Policy Network for the 21st Century (2014).
Note. PV = photovoltaic.

specific objectives in relation to the development of PV technology. There is a large amount of literature detailing the research on RPS and its options for solar energy, and it is important to highlight some of the studies' main results. Wiser, Barbose, and Holt (2010) confirms that overreliance on RPS may not help the diversity of renewable resources in the energy matrix. Timilsina et al. (2012) also studied different applications of FIT and RPS programs identifying advantages and disadvantages in solar PV applications. Their results show that although FIT programs facilitate the guarantee of a fixed return on investments, they do not help in reducing the high up-front costs of solar PV technology. On the contrary, Frondel, Ritter, Schmidt, and Vance (2010) harshly criticize FIT schemes, particularly for the case of Germany, arguing that the scheme failed to accomplish its promises on emissions reductions, employment, energy security, or technological innovation, while resulting in massive expenditures.

Throughout the South American region, different policy mechanisms have been implemented to promote renewable energy sources (RES; International Renewable Energy Agency, 2015). Among them, Brazil, Peru, and Uruguay have adopted a competitive bidding process; Argentina and Ecuador opted for the FIT mechanism; and Chile and Colombia have integrated the RPS model. The different policies chosen to support the participation of renewable energy in the region follow different backgrounds and motivations. Countries such as Argentina, Brazil, and Uruguay use policy incentives to encourage technological development focusing on specific technologies (hydro, wind, and biomass), while all the others are oriented toward integrating renewable energy by importing cheap technology and facilitating technological adaptation at the national level. The renewable energy policy adopted by the Chilean government basically follows the international trend, that is, introducing an RPS model for energy from generators as its major regulatory support mechanism, with the goal of reaching 20% from RES in their energy mix by 2025. The basic idea behind adopting the RPS model was that Chile is considered to be one of the few markets in the world where renewable technologies, including PV technology, can be competitive in the market compared with traditional technologies. This is because the country currently has one of the highest electricity prices in the region, the electricity demand is steadily growing, and the country has the greatest solar potential where radiation levels are higher than almost any other part of the world (Nasirov, Silva, & Agostini, 2015).

Benefits of Solar Energy Utilization in Chile

Even as the costs of solar power continue to decline, there is still a widespread perception from the public and many policy makers that solar energy is "too expensive." As a result of this perception, many policy makers conclude that the country should not invest in solar energy because energy prices would increase. Under these circumstances, it is clear that traditional analysis has missed a potentially large social value of solar energy. For this reason, we believe that it is worth discussing and explicitly considering several other benefits of solar energy that, even though difficult to measure, are often neglected. We mainly discuss three main benefits of solar energy that are especially relevant in the case of Chile: (a) to provide secure and sustainable energy, (b) to support economic development, and (c) to address climate change and environmental concerns.

Secure and sustainable energy. Historically, Chile has experienced several energy crises during the past two decades due to the lack of a reliable energy matrix. Until the 1990s, hydroelectricity was the main source of electricity generation and was considered to be almost the only solution to the country's growing energy needs. However, every time the country faced a draught, the security of supply was at stake, and there were even periods of blackouts and rationing (Díaz, Galetovic, & Soto, 2010, 2011).

A decade later, Chile switched rapidly to depend on Argentina's natural gas. The low-cost natural gas combined-cycle plants were attractive compared with other traditional energy sources, including hydro-powered and coal plants (Nasirov & Silva, 2014). As a consequence, the generating companies invested heavily in natural gas infrastructure, including building four pipelines from Argentina, a brand new gas distribution network, and half a dozen combined-cycle gas-fired power plants. Investment in new natural gas infrastructure summed up to around US$4 billion (Speiser, 2008). However, starting in 2004, the Argentinean government started restricting gas exports to Chile to ease its own domestic gas shortages. Shortly after, Argentina's natural gas supply became less and less reliable to the point of practically halting the gas flow. This situation forced generators to import expensive diesel oil, and the government promoted the construction of liquefied natural gas facilities to compensate these changes and secure another source of energy.

Over the past few years, the situation has become even worse in terms of meeting domestic energy needs. Energy has probably become the main obstacle for the development of the Chilean copper industry, as the cost of energy now represents about 20% of the total cost of mining (Zeballos, 2013). Chile has the world's largest copper industry, with a supply of 30% of global production. In addition, mining is a key sector of the Chilean economy representing nearly half the country's total exports and is located in the rich solar zone of the country. Mining consumes an estimated 90% of all electricity in the SING and around 38% of the total electricity demand in the country. Also, as the mining industry grows, the demand for energy is expected to grow at a rate of at least 5% per year for the next decade (Román & Vásquez, 2014). According to the projections of the National Energy Commission (Comisión Nacional de Energía [CNE]), 60% of the growth in energy demand in the country will come from the mining sector. Moreover, the high dependency on external fossil fuels and the growing demand for energy have pushed up marginal costs of energy generation in both systems (SING and Sistema Interconectado Central) of the Chilean market, a situation that has worsened as international fuel prices have increased significantly. Currently, electricity prices in Chile are among the highest in Latin America and higher than the OECD average prices for electricity, ranging from US$150/MWh to US$250/MWh.

The successive energy crises have taught a valuable lesson, and now the country is more concerned about the degree of energy diversification, understanding its important role in the security of the system (Tokman, 2009). In this scenario, adding PV sources to the energy mix can be a valuable opportunity for contributing to the country's energy diversification strategy. In particular, it can help to reduce the dependency from external fossil fuel sources, especially in the SING, where supply essentially serves mining companies and other industrial users.

Economic development and environmental concerns. Solar PV technology remains one of the most dynamic renewable energy technologies in terms of its contributions to economic development. Successful development of solar PV technologies proves that emerging economies like Chile can also use green growth strategies in the promotion of a more sustainable overall growth. A recent study conducted by international and national experts from PricewaterhouseCoopers, the Natural Resources Defense Council (NRDC), and Chile's Renewable Energy Association reveals significant economic benefits of renewable energy including PV technologies in Chile (NRDC, 2013). The study evaluated the social and macroeconomic impacts comparing two scenarios for the period of 2013 to 2028. The first one is just a base case without renewables, and the second one considers reaching a 20% penetration of renewables in 2020 that is then maintained until 2028. The impact areas considered include specifically Chile's gross domestic product (GDP), costs to the national electricity system, employment, greenhouse gas emissions, local emissions, and the use of natural resources like land. According to the analysis, the renewable energy scenario generates US$2.246 billion more in GDP than the base case for the whole period of 2013 to 2028, offering more productive supply chains in the country. In addition, 7,769 more jobs are projected under the renewable energy scenario than the base case.

Strengthening the economy in rural areas has also been a rationale for using solar PV technologies in several countries. Because rural communities are located away from power systems and because their populations are low, network extension is typically not a viable economic option for these communities. In isolated rural areas that lack access to electricity, grid extensions are often too expensive and usually have to pass the test of a social project evaluation to be financed by the government. Therefore, off-grid solar PV technologies can provide a sustainable and cost-effective alternative to other potential alternatives that would be typically deployed in such areas. Chile has more than 3,500

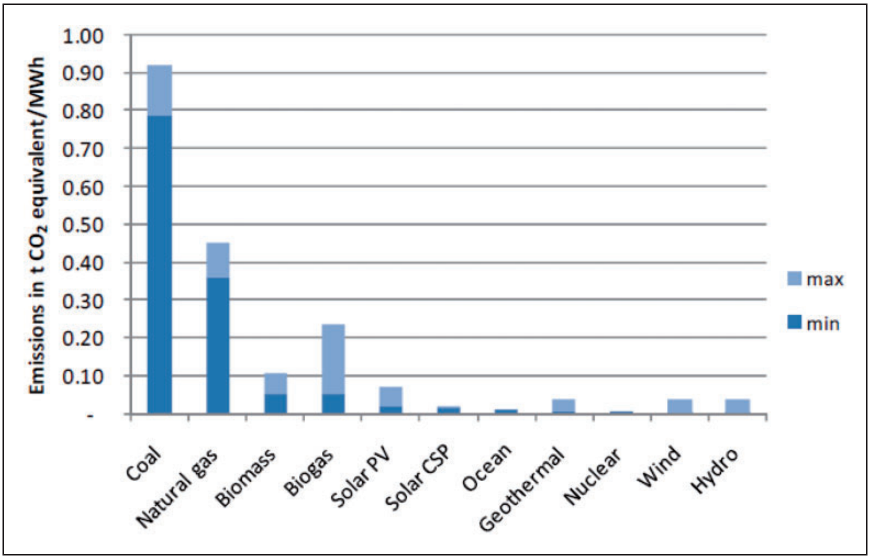

Figure 2. Life-cycle CO_2 emissions of power-generating technologies.
Source. Organization of Economic Co-operation and Development/International Energy Agency (2011).
Note. CO_2 = carbon dioxide; PV = photovoltaic; CSP = concentrated solar power.

isolated rural communities with no access to energy networks, and many of them also lack access to roads and infrastructure to maintain the flow of fossil fuels (Aquatera, 2014). Deploying solar PV energy technologies can deliver a cost-effective and environmentally friendly solution, which can increase daily productivity and improve the quality of life in these rural communities.

The other important benefit of solar power utilization lies in the environmental advantage of producing less CO_2 emissions than from fossil fuel sources. The numbers presented in Figure 2 are based on the life-cycle assessment and report the CO_2 emissions emitted by various generation technologies. As shown, solar PV technologies offer favorable environmental conditions as do hydropower, wind, geothermal, and nuclear power plants, and its environmental loads are very small in comparison with fossil fuels, including natural gas and coal. While the operation of a solar PV plant has a small environmental load, the main burden is associated with the panels' life cycle, specifically due to material manufacturing, transportation, and power plant construction.

According to the analysis mentioned earlier (NRDC, 2013), the renewable energy scenario including PV technologies could avoid the emission of 83 million tons of CO_2 between 2013 and 2028. This is equivalent to the reduction of the CO_2 emissions from 32.9 million cars in 1 year—10 times the number of cars in Chile today.

Current Status in Solar Energy Applications in Chile

Although development of modern solar energy technologies in Chile started only a few years ago, applications using solar energy in Chile have a long history. In fact, the first solar distillation plant in the world was constructed at Las Salinas, Chile, in 1872, which used solar energy to evaporate salty water (Meinel, 1976). The plant functioned for at least 11 years and produced less than 20,000 L of fresh water per day in summer (Arellano, 2011). It stopped functioning only after a fresh-water pipe was constructed to supply water to the area from the mountains. Another related record about solar energy in Chile is the first application of standalone PV systems in 1960 for remote areas where electricity from the power grid was not available (International Energy Agency, 2012b).

The development of PV solar energy in Chile is particularly attractive because the country is endowed with one of the most consistently high solar potentials in the world. The Atacama Desert, in the north of the country, offers the best conditions for generating PV solar energy with high solar radiation, low humidity, and almost 356 days of clear skies (Pastene, 2014). The annual daily horizontal solar irradiation in any region of Chile north of the Maule region—300 km south of Santiago—ranges from 3,000 to 4,200 kWh/m^2, which is significantly higher than Germany (900–1,250 kWh/m^2), France (900–1,650 kWh/m^2), and Spain (1,200–1,850 kWh/m^2; Makrides et al., 2010).

In existing legislations, the promotion and use of solar PV technologies are included within renewable energy policies, with no specific legislation dealing with PV technology alone. The legal basis concerning legislations regarding promotions of renewable policies started in Chile in 2005 when Congress approved what it was called Short Law I, which establishes key incentives for the development of small-scale energy projects for the first time since the liberalization of the market (Central Energía, 2015). The legislation allowed all small power producers (less than 9 MW) to participate in the spot market and entitled them to have a simplified commercial treatment for trading. As part of the new regulation, small-scale energy projects are guaranteed open access to the distribution networks and exempted of charges from the usage of the trunk system. For the first time in 2008, the government took an important step forward by approving an RPS scheme that introduced the obligation for companies to generate at least 10% of their electricity from nonconventional RES by 2024. In 2013, based on an estimation of new renewable capacity requirements of 6,500 GW for the next decade, the Chilean government increased the incentive by doubling its renewable energy target from the previous goal of 10% by 2024 to 20% by 2025. The change was established in a new law approved by Congress known as Law 20/25 that, in addition, introduced an auction mechanism to award 10-year power contracts to complete any part of the established quota that has not been met. The auctions will be under the supervision of the Ministry of Energy under the established principle of technological neutrality.

Table 2. Institutions Promoting Photovoltaic Technologies in Chile.

Institution	Institutional dependency	Main responsibilities
Chilean Economic Development Agency (CORFO—for its Spanish acronym)	Ministry of Economy	Facilitating financial support of companies through innovation, entrepreneurship, and technological transfers
National Commission for Scientific and Technological Research (CONICYT—for its Spanish acronym)	Ministry of Education	Promoting the creation of human capital and establishing the country's scientific and technological base
Centre for Innovation and Promotion of Sustainable Energy (CIFES—for its Spanish acronym)	Board of directors from various ministries	Implementation, tracking, evaluation, and the promotion of renewable energy programs
Environmental Evaluation Service (SEA—for its Spanish acronym)	Environmental Ministry	Administering the Environmental Impact Evaluation System

Noncompliance with the law results in a fine of approximately US$28/MWh for every MWh below the quota. During the following 3 years, if the noncompliance is repeated, the fine raises to US$42/MWh (CNE/GTZ, 2009).

Over the past years and through several different institutions, the government has introduced several other incentive mechanisms for supporting and promoting PV technologies in the country (see Table 2). The Chilean Economic Development Agency is a governmental agency dependent on the Ministry of Economy, which is responsible of facilitating financial support of companies through innovation, entrepreneurship, and technological transfers. Through the Chilean Economic Development Agency, the government has established various instruments to indirectly promote the use of PV technology, including low-interest loans, capital guarantee and risk capital funds, and innovation study grants. The Centre for Innovation and Promotion of Sustainable Energy is considered to be another key institution for facilitating the development of the PV technologies in Chile. The major mission of the Centre for Innovation and Promotion of Sustainable Energy is to coordinate public and private initiatives, to promote and advance PV projects, and to provide and make valuable information available to everyone. The National Commission for Scientific and Technological Research, an agency in the

Table 3. The Status of Renewable Energy Projects in Chile in 2015 (MW).

Technology SIC + SING	Operating	Under construction	Approved SEIA	Under evaluation
Small hydro	368	57	337	215
Solar PV	452	748	8,173	4,792
Solar CSP	0	110	760	370
Biomass	422	0	134	69
Biogas	43	0	1	8
Wind	832	165	5,513	1,960
Geothermal	0	0	120	0
Total	2,117	1,080	14,555	7,413

Source. CIFES (2015) and own construction.
Note. SIC = Sistema Interconectado Central; SING = Northern Interconnected Power System; SEIA = Environmental Impact Assessment System; PV = photovoltaic; CSP = concentrated solar power.

Ministry of Education, is responsible for promoting the creation of human capital and establishing the country's scientific and technological base. With the aim of strengthening scientific and technological foundations on solar energy, the National Commission for Scientific and Technological Research is financing the Solar Energy Research Center (SERC-Chile), a specialized scientific center that aims to build a solid base of scientific knowledge and to promote programs for the transfer of PV technology.

As of the first quarter of 2015, electricity generation from RES reached 12% of the total power capacity in the system, having already met and even surpassed the quota defined by the Renewable Law No. 20,257. PV power contributes to RES-installed capacity with 452 MW, representing 22% of the share of renewables in the country. However, investors' interests in the PV sector are increasing rapidly. As a result, Chile became the second-largest market, after Brazil, for renewable energy investment in the South American region, reaching an accumulated investment of around US$ 7.1 billion in 2014.

As shown in Table 3, a large scale of PV projects of about 8,000 MW with environmental approval, most of them sidelined, are waiting to enter the grid, and 4,792 are under evaluation. These numbers show that, potentially, there might be a promising future for the development and deployment of PV technologies in Chile.

Until today, thanks to policy incentives and encouraging market conditions, Chile has achieved tremendous attention with PV utility-scale projects. However, the development of rooftop solar projects is relatively behind utility-scale projects, as they recently kicked off. To encourage and facilitate the entrance of residential rooftop solar projects into the system, the government modified the General Law of Electricity Services (Degree 238/1982) to enable residential end users with renewable resources to inject excess energy into the grid (Central Energía, 2015). This new regulatory framework was approved under the Net Billing Law No. 20,571 in 2014. The law allows households and businesses to install a PV system up to 100 kW, so they can generate electricity for their own use and to sell the system's excess output to the national grid at a fixed tariff. However, because many details of the legislation are still missing, including the structuring of electricity rates and specifically how utilities compensate customers who generate power with rooftop PV panels, the impact of net billing on PV residential penetration is still negligible.

However, international trends about the diffusion of the residential PV sector show that under net metering, if demands for residential solar increases, traditional utilities may face serious problems (Cai, Sachin, Steven, De Martini, & Mani, 2013). As of today, the Chilean market is not experiencing this problem due to a small number of residential projects in the market, but it would be relevant in the future as power generation on the residential level might start expanding. Because under net metering program, if rooftop solar producers generate as much electricity as they consume, this will allow them to zero out monthly or even annual electricity bills. That means traditional utility companies lose their former customers, and they might even stop paying a minimum fixed rate that contributes to the financing of the utility's fixed costs. As the number of rooftop producers is growing through net metering, fixed costs will be transferred to the rate payers, thus raising their rates. In response, utility companies in many countries have launched lobbying activities against residential-level electricity producers.

Challenges for Solar PV Energy Planning in Chile

Based on the data and information collected from agency reports, company press releases, and academic publications, as well as semistructured face-to-face interviews with experts specialized in solar PV deployment, we discuss the key challenges for solar energy planning in Chile. Nine experts were interviewed with the goal of providing important insights based on their extended opinions and experiences related to our study. The targeted population for interviews were people highly familiar with the development of solar energy projects and also who were aware of the key challenges the Chilean government faces. The classification of people interviewed is presented in Table 4.

The main challenges in the sector are mostly associated with the lack of institutional capacity, deficiencies in resource management, and exclusion of indigenous communities.

Table 4. Interview Numbers by Institution.

Classification	Interview completed
Government officials:	
– Ministry of Energy of Chile	2
– Renewable Energy Center	1
Academics	2
Representatives of solar energy projects in Chile	4
Total	9

Lack of Institutional Capacity

Over the past decades, Chile has introduced several market liberalization and privatization reforms in the electricity industry that resulted in significant changes in the institutional and regulatory frameworks. In general, Chile's energy market structure is characterized by greater private-sector dominance and an institutional framework in the electricity sector that has been incrementally adjusting to developments in the sector without any major changes in its principal structure. The government regulation in the energy sector mainly consists of establishing the rules for market exchange among the various players in the generation, transmission, and distribution segments (Moya, 2007). In the interviews, it was highlighted that since its foundation in 1978, the CNE has been an institution in Chile that more likely played the role of a factual regulator in the sector, although its roles are just indicative planning and more advisory in nature. It does not, in fact, possess any regulatory or enforcement authority. The other two institutions playing a relevant role in the electricity sector are the Superintendencia de Electricidad y Combustibles (Electricity and Fuels Commission), which supervises compliance with norms, regulations, and technical standards, and the Centro de Despacho Económico de Carga (Center of Economic Dispatch), which oversees coordinating supply and demand interactions in electricity markets. While the first two institutions are public, the third is controlled by representatives of private-sector companies involved in the power system. According to respondents, this type of institutional design in Chile encourages undue levels of political influence in favor of preserving the status quo in energy policy. Besides, interviewers stressed that the current institutional structure in Chile is incompatible with a market able to incorporate the new prioritized technologies due to inadequate national planning. In practice, the lack of strategic planning to determine where new investment will occur and what types of energy generation will predominate in the matrix has led to widespread and long-lasting negative consequences related to energy shortages on several occasions. As a result of the lack in an explicit energy policy in terms of defining a strategic direction toward the type and location of supply, a series of deep conflicts over social and environmental issues have emerged in the country. Over the past decades, the Chilean government has ignored the social and environmental costs associated with large energy projects—mainly big hydro-powered and coal-fired projects—in several regions of the country, and in return, this has led to rising public controversy.

This provides evidence that in the absence of profound improvements in the state's management and the working of institutions in charge of regulating and monitoring the sector, it is not guaranteed that the government may reach its energy targets in terms of diversifying the energy matrix through prioritizing solar PV technologies. In practice, the state's weak regulatory and planning roles in the electricity sector leave government authorities—at the national, regional, and local levels—with a limited capacity to regulate the electricity sector effectively. The functioning of the main institutions in the sector generates inefficiencies, resulting in high litigation costs, certain randomness and biasness in their decisions, and difficulties in the coordination of policies where interests are shared. One of the major constraints that prevents these institutions to operate efficiently in regulating the market is their technical capacities. Technical weaknesses are due to a mix of reasons such as no independence from political power, no independent and sufficient budgeting, and low salaries to attract highly qualified personnel.

Deficiencies in Resource Management

Solar PV projects in Chile often face many challenges during the planning process due to concerns in environmental and social impact assessments (IAs) and the granting of concessions. The key regulatory mechanism used by a planning institution is called IA (Jay, Jones, Slinn, & Wood, 2007; Thygesen & Agarwal, 2014). Chile's environmental regulatory framework is based on the Environment Law (No. 19,300), which was enacted in 1994 and was then reformed in 2010 (by Law 20,417). Some of the most commonly used IAs are the Environmental Impact Assessment (EIA) and the Strategic Environmental Assessment. The main objective of these assessments is to ensure that the development of a project proceeds in an acceptable manner. In Chile, regardless of the type of resource to be exploited, every energy project has to obtain an approval from the Environmental Impact Assessment System (SEIA) to show that it does not produce damage, nor does it represent a hazard to the environment. The consideration of social impacts in Chile is carried out through the SEIA process, which is compulsory for any project—isolated or grid connected—with installations more than 3 MW and the need for a transmission grid. Even though the Chilean regulatory system requires explicit consideration of the possible environmental and social impacts of each project, there are deficiencies in the assessment framework to measure these impacts properly. Over the past decades, Chile's SEIA evaluations of large energy projects have been a constant source of conflict among communities, firms, and the government. Therefore, many energy projects from different technologies have been stuck in approval processes, and most ended up in the judicial system. For instance, among the larger energy projects, such as the Bio Bio dams in the 1990s, the Barrancones coal plant (540 MW) in 2010, and more recently, Chiloé (100 MW) and Arauco (100 MW) wind plants in 2011, and the HidroAysén mega-dam complex (2,750 MW) in Patagonia in 2013 have been rejected or challenged in court due to a weak and flawed environmental review system.

According to respondents, SEIA in Chile has been implemented to serve more as an instrument of political peddling than as a safeguard for citizens and the environment. The lack of citizen participation or discussions in SEIA decisions, for example, is often recognized as one of the main sources of political and legal challenges. In practice, project developers fail to take into account the full range of costs and benefits on local communities, resource management goals, and other policy objectives when they design EIA/Declaration of Environmental Impacts proposals. In addition, the most common shortcomings of the EIA in Chile include inadequate studies to determine population data for important and endangered fauna (both terrestrial and aquatic), incomplete analysis of the environmental impacts associated with the construction phase, absence of calculations for the economic costs to the region's growing tourism industry, and lack of adequate IA on local agricultural producers. In general, SEIA has been mostly focused on the effects on the natural environment than on social impacts. As a result, the project's impacts on the demographic mix, community and institutional structures, political and social resources, individual and family changes, and threats to cultural practices receive limited attention in SEIA assessments. In fact, no specific measurement techniques have yet been included in either Law 19,300 or SEIA for social IAs.

Obtaining concession rights for extensive territories is another critical issue in the development of the different types of renewable energy projects as noted by the study respondents. During the development process, project developers face numerous regional regulations and, at times, complex negotiations with landowners over project sites. One of the primary bottlenecks is related to the troublesome process to obtain property rights (ownership or concession) for using land owned by the state. Chile's regulatory framework regarding concessions is based on the Concession Law 1939, enacted in 1977 and then modified in 2002 by Law 19,833. The main problem is that the law does not set robust and transparent methods for a project evaluation, which result in discretionary decisions for granting concessions. Currently, submitting an application to the Ministry of National Assets, which is in charge of managing all land from the state, delays the start of a project several months or even years. Besides, the concession system lacks regulations and standards to provide an important guide in navigating difficult issues related to the status and ownership of other resources within the boundaries of the concession. On the other hand, if the land is privately owned, it could also take a long time to obtain some type of property rights because of troublesome negotiations with many owners. For instance, over the past decades, the concessions granted to mining interests have soared in Chile. This, in turn, has intensified different conflicts between mining concessions and the users of agricultural lands, all of which also impede the construction of medium-sized and large solar PV plants.

Marginalization of Indigenous Communities

In recent years, many strategically important energy projects including solar PV projects have been proposed in areas that are either legally owned or claimed by indigenous communities in Chile. From the interviews, it was noted that a common feature of these projects is a lack of adequate consultation with the directly impacted indigenous communities during their development. Other common features are the lack of compensation to the communities for damages caused and the absence of mechanisms to ensure that impacted communities can participate in some of the benefits that the projects generate (a common request by the communities, e.g., has been to get a reduction in their electricity bill, given that the energy is being produced where they live, and they suffer any negative externalities caused by the project). Recently, however, the situation has been changing because the communities have started demanding a much greater role in the decision making and to determine how the planning and execution of industrial projects *in the neighborhood* creates risk for the surrounding territories. At the same time, those communities are also generating a serious risk back to the project developers, through protests, publicity campaigns, and court actions designed to delay or halt the projects. Disputes over indigenous issues in the country have delayed investments worth about 10% of GDP, according to Bloomberg estimations. The real question now is how institutionally, politically, and legally Chile will adapt to an increasing role for local community opinion and accommodate the citizen voice in the solar energy developments.

Conclusions and Policy Recommendations for Solar PV Planning in Chile

Chile is at a crucial historical moment regarding its energy development, as it urgently requires dealing with large energy needs for its growing economy in a continuous and secure manner. The country faces enormous challenges due to a mix of increasing energy demand, rising electricity costs, increasing dependence on external sources, reductions in the available capacity of hydropowered plants, and environmental concerns that makes it more difficult for the approval of new generation capacity, thus creating a serious threat to the social and economic sustainability of the country. The Chilean government recognizes that exploiting its abundant potential of solar energy could be an important opportunity to concurrently address these challenges effectively. Over recent years, direct support mechanisms in Chile show good promise in providing a coherent framework, which significantly increases the share of solar PV technology within the electricity generation system. As a result, there has been a significant interest in RES, and the accumulated investment in this sector has reached a record level in the region after several years of stagnation. Chile has become the second-largest market, after Brazil, for renewable energy investment in the South American region in 2014. Despite the improvements in many areas, to date, numerous policy challenges still exist. A closer look at the concept of sustainable development shows that the previously mentioned challenges related to lack of institutional capacity, deficiencies in resource management, and marginalization of the indigenous communities in the energy projects remain key difficulties within the sustainability framework. We identified at least three key criteria for promoting an economically, socially, and environmentally acceptable development of positive solar planning outcomes. In particular, we have argued that these three criteria are particularly critical: (a) the importance of institutional capacity; (b) resource management and, more specifically, proper Strategic Environmental Assessment mechanisms; and (c) concerns over indigenous communities.

Acknowledging the current challenges faced by the institutional frameworks and the need for serious improvements in the critical role of institutional settings in general seems to be particularly crucial. To achieve the objectives, it is clear that the Chilean government should take a leadership role and establish a prioritized strategy to develop and modernize institutional structures to truly integrate public policies and improve the quality of the interactions among an important set of different organizations, institutions, and public policies. Public institutions playing the role of key premise providers of sustainability require not only a significant improvement in their technical and financial capacity but also economic and political independence from ministries. In addition, it is necessary to force public institutions to increase their transparency level in their administrative procedures, to go forward with incentives regulation mechanisms, and to reach economies of scope in regulation. In practice, the lack of coordination between the different regulatory agencies results in clear inefficiencies. Another key institutional aspect is the integration of environmental and socioeconomic issues in the formulation and implementation of the energy policy. This includes the Ministries of Energy, Environment, Economy, and Public Works, among others.

With respect to the need for improvements on the resource management system in Chile, clear and effective project evaluation criteria must be established to avoid discretionary decisions for approving concessions. Some important measures in this respect are providing permanent concessions to solar energy developers, allowing them to evaluate the project's commercial feasibility in the long term as it is done with mining concessions, minimizing the number of secondary permissions required for concessionary grants, and controlling concessions agreements through incentives and penalties to avoid speculation problems.

One of the crucial issues with respect to the resource management system in Chile is related to the performance of the current SEIA processes, which has received significant attention over the past years. However, the question remains: How effective are the implemented SEIA methods on the overall project planning and decision process? Claims for the effect on environmental protection and ultimately on sustainable development are extremely divergent. On one hand, recent professional literature makes extensive claims for success. For example, in South America, Peru has made significant progress to improve the environmental management framework and to overcome its deficiencies. In that sense, it has approved a balanced environmental policy to ensure that environmental considerations are integrated in the development of energy projects and also that environmental priorities are reflected in the quality of life of rural and urban populations in the country. In this context, and based on international experience, the Chilean government must function as a guarantor, providing opportunities for public participation and facilitating public access to information on solar projects under evaluation in their surrounding areas of potential impact.

Apart from public–private initiatives to promote renewable energy, there is an urgent need to establish closer relations between the government, investors, and civil society actors to foster opportunities for discussion and joint approaches. The process of identification and assessment of the potential risks and impacts of each project should be consistent with good international practices in terms of using appropriate and relevant methods and assessment tools. Each alternative should be evaluated earlier, more thoroughly, and with more effective community engagement through the disclosure of project-related information and in consultation with local communities on matters that directly affect them. Recent legal and political realities in the world demand that an effective social and environmental evaluation process should be implemented in a dynamic way such that reasonable alternatives are carefully reviewed; mitigations and compensations are taken into account adequately; and it is adaptive to new insights, political goals, or societal wishes.

Another important issue relates to the social impacts of energy development. Government interventions, including regulations aimed at incentivizing investments in solar energy generation and transmission, should take into account a broad range of criteria including community and social impacts. Transparent procedures should be put in place so that impacted individuals and communities are appropriately consulted, and it should be ensured that they participate in the benefits generated and receive compensation for damages imposed. Unlike most states in Latin America, Chile ranks very poorly in terms of its legal frameworks and policies concerning indigenous peoples. As of today, Chile lacks administrative and legislative measures to recognize indigenous peoples' rights to lands and natural resources as well as to indigenous forms of autonomy or self-government within their territories. In recent decades, many countries have reformed their constitutional and legal systems to recognize the right of indigenous peoples for the protection and control of their lands, territories, and natural resources. In South America, Colombia, Brazil, Ecuador, and Bolivia are among the states which acknowledge indigenous peoples' right to ownership and entitlement of ancestral lands and territories as well as their rights to administration, usufruct, and conservation of natural renewable resources located on their lands.

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