CHAPTER 10

CHILE AND THE SOLAR REVOLUTION

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Chile has unique characteristics that enable it to develop a globally competitive solar industry. Its vast terrain in the north part of the country has the highest solar radiation on the planet. This solar radiation is in the same region as the country's larger energy consumers, such as the mining industry. Mineral resources, such as copper and lithium—the main raw materials of the sustainable energy revolution to which Chile is transitioning—are also found in this region.

In 2014, when the solar revolution in Chile began, a sustainable supply of electricity was critically lacking. Electricity was generated from a mix highly dependent on imported fossil fuels, primarily coal plants. At that time, the share of solar energy in total energy production was only 1%.[1] Moreover, in 2013 the electricity supply price for householders was US$161 per megawatt-hour (MWh),[2] one of the highest in the Latin American region. The electricity sector had stagnated for 10 years after a crisis in 2004 when Argentina stopped exports of natural gas to Chile.[3]

Chile's public opinion was against the development of more coal plants, but there was also strong opposition to the construction of the large hydropower dams in the south of the country.[4] The solar energy produced in the Atacama Desert was not available for consumption in the central and southern regions. There was no interconnection between the electric systems of the north (SING) and those of the central-south (SIC).[5] High prices, an energy mix dominated by fossil fuels, and scarce competition were a concern from the public policy point of view.[6]

Today the situation has changed radically; one of the main contributors to this transformation has been solar energy production. By December 2017, the installed capacity of renewable energies in Chile (excluding large hydropower systems) reached 19% of total energy production. Solar power represents half of renewable capacity.[7]

The role of government has been crucial in triggering this change. The Energy Agenda of 2014 set up a clear strategy to take advantage of solar resources.[8] The country's Energy Policy 2050, launched in 2016, aims to make Chile a solar energy exporter by 2035.[9]

Why is the Atacama Desert so special?

According to a survey of the Strategic Solar Program,[10] the Atacama Desert area presents unique conditions, including an average annual direct global radiation equal to 3,500 kilowatt-hours (kWh) per square metre (m2) and a horizontal global radiation level of 2,500 kWh/m2 per year. This is one of the highest radiation levels in the world. The Chilean Desert has more than 100,000 square kilometres (km2) of clear, cloudless skies, with an average annual precipitation

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of 2 millimetres (mm) and 4,000 average hours of sun in a year. Medium temperatures over the summer are below 30°C and the ultraviolet B (UVB) radiation is 65% above the highest European level.

These are excellent conditions for supplying solar energy. Using only 6,000 km2 of the Atacama Desert there is enough room to place 200 gigawatts (GW) of installed capacity of solar energy that can supply 30% of the electricity demand in South America.[11] Moreover, the Atacama Desert holds the largest lithium reserves in the world, estimated at 7.5 million metric tonnes. This represents almost half of the world's reserves.[12]

The Atacama Desert is also home to the Chilean copper industry, which consumes large amounts of energy. Chile's share of the world's copper production was around 26% in 2016;[13] copper is one of the country's major exports. Since the mining industry comprises a large portion of the demand for electricity in Chile, an opportunity for mines in the north to obtain a sustainable energy supply from a nearby source is important.

These unique conditions present important challenges that must be met for Chile to take full advantage of the potential benefits of using solar as a competitive renewable energy source. One of these challenges is the need to develop new materials that behave suitably in the radiation levels of the Atacama Desert. Another important issue that must be addressed is how to reduce the soiling effect.[14] Difficulties in introducing larger proportions of variable renewable sources into the electricity system are also evident. By taking these challenges into account, it will be possible to introduce solar energy into industrial processes, particularly in the mining sector. This is a prerequisite to developing a successful local and sustainable solar industry.

Because of the extreme conditions present in the north of the country, regulations for technologies exposed to desert conditions must be developed. These conditions include the effects of the whole spectrum of radiation, the effects of the low atmospheric pressure due to altitude, abrupt changes in ambient temperature, the effects of dust (the soiling effect), and so on.[15] In turn, these conditions also present the opportunity to take advantage of direct solar radiation for applications of concentrated solar power,[16] both to reduce costs and to store thermal energy in molten salts that allow energy savings 24 hours a day.

The public role in the solar revolution

In 2014 the government of President Michelle Bachelet launched an Energy Agenda focused on solving the critical problems of the country's energy sector: high energy prices, low investment in new electricity capacity, and an energy mix that depends on fossil fuels.[17] Part of that agenda included developing a long-term energy policy and establishing goals for 2035 and 2050.[18] After a wide participatory process, the consensus was that Chile does not want just any kind of development, but one that is inclusive, equitable, and respects both the environment and social harmony. A transformation was needed.[19] In this context, innovation emerges as a great opportunity for the energy sector, which is a key element of the competitiveness of the country.[20]

The aim of the Energy Agenda is to make Chile an exporter of solar technology and services by 2035; it would specialize in solar technologies for high radiation and desert conditions. By 2050—in order to satisfy especially the South American future demand for innovative products and services, it plans to accomplish this through the different energy innovation focus points identified.[21] In this way Chile's energy sector will address local challenges and also contribute to the diversification of the economy.[22] In order to implement the actions needed to pursue this objective, the Chilean government has developed a collaborative process through the Chilean Economic Development Agency CORFO to draft a 2025 Roadmap called the Strategic Solar Program,[23] which included participation by over 100 government, corporate, academic, and civil society representatives. This Roadmap seeks to take advantage of the Atacama Desert's unique features to develop a national solar power industry with technological capabilities—one that is export-oriented. To this end, an initial portfolio of 50 initiatives was identified to cover the gaps of the industry, with a total budget of US$800 million for the period 2016–25.[24] See the next section of the chapter for more details about the initiatives underway in this programme.

The main objectives of the Strategic Solar Program are to reduce the levelized cost of photovoltaic technologies for the Atacama Desert conditions from US$80/MWh by 2015 to below US$25/MWh, add 3,000 local jobs to the more than 40,000 new jobs in the local industry, reduce 4.5 million metric tonnes of

Figure 1.
The Solar Energy Program development pillars

SOLAR ROAD MAP

STRATEGIC GUIDELINES

TECHNOLOGICAL DEVELOPMENT	INDUSTRIAL DEVELOPMENT	STRENGTHENING QUALITY INFRASTRUCTURE FOR SOLAR ENERGY
› Solar technology center • Desert Module and System technology program • Thermal energy storage systems program • Solar desalinization program • Solar funds program • Advanced Human Capital program	› Open innovation platform › Financing innovation challenges › High-tech investment attraction program	› Climate characterization › Metrology network › Regulation standards › Conformity assessment schemes › Drafting of labor skills profiles

Cuenca del Salado Solar Corridor

Solar Technology District

Source: ComiteCorfu, 2017, available at http://www.programaenergiasolar.cl/english/.

CO_2 per year, and introduce 100 companies into the solar industry value chain by 2025.[25] Considering the results of the last bidding process in 2017,[26] where offers were received with an average for renewable energy prices of US$32.5/MWh, it is possible to exceed the targets.

Initiatives underway through the Solar Energy Program

In 2016, a series of actions, focusing on the following areas, were undertaken by the Strategic Solar Program to implement the 2025 Roadmap (Figure 1):

- Technological Development,
- Industrial Development, and
- Strengthening Quality Infrastructure for Solar Energy.[27]

The most important initiative in the Technological Development branch is the desert module and system technology programme[28]—the so-called **AtaMoS-TeC (Atacama Module and System Technology Center).**[29] The AtaMoS-TeC is one of the Solar Roadmap initiatives that brings together the government, national and international companies, and technology centres in a partnership to implement a portfolio of research, development, and innovation (RDI) projects to develop photovoltaic systems created specifically for desert conditions, The objective of AtaMoS-Tec is to adapt and develop new materials, components, and operation and maintenance (O&M) services for photovoltaic systems, thus ensuring their durability and performance under desert climate conditions.

covering a gap in the knowledge of its own features for solar power generation. The standard technology in the industry has not yet been developed for the extreme conditions of the Atacama Desert. The objective of AtaMoS-Tec is to adapt and develop new materials, components, and operation and maintenance (O&M) services for photovoltaic systems, thus ensuring their durability and performance under desert climate conditions. It will also contribute to the installation of technological capabilities and, in partnership with international companies, foster the creation of a national business ecosystem for the solar power industry. By 2015 there were seven companies identified for solar energy distributed installation, 13 project development companies, and eight companies experienced in large solar power plant construction.[30]

The initiative has already begun, with a joint lab with technological capabilities for obtaining data on critical climatic variables (radiation, UVB, temperature, corrosion, etc.) and developing solar modules adapted to local conditions. There is also a project underway for manufacturing a Desert Module (DEMO) to demonstrate growing efficiency and durability. Technology baselines for drafting standards and creating compliance evaluation systems for photovoltaic technologies under desert conditions are also being developed. For that purpose a consortium of 20 firms and research centres, both national and international, have agreed to work together for the next eight years on these challenges.[31] Finally, DEMO is expected to have specialized services for the O&M of these systems, as well as the development of balance-of-system technology innovations, including component integration, assembly systems, and power inverters.

The **International Solar and Mining Institute of the North (IISM)** began operations in 2018.[32] The Institute aims to develop solutions for specific industry challenges on environment as well as cost and competitiveness issues, based on technological knowledge and technical capacity. The IISM was created to apply and combine existing technologies and develop new ones. It uses a cost-effective and practical approach for and with industry in a continuous improvement process with its business environment. It focuses on industrial development in a broad sense, including services and the development of new business models. It will perform RDI according to the roadmaps for the Solar Program and for the mining sector, always with the participation of the private sector. The IISM is expected to supply simulation services for systems and new technologies, to develop small-scale prototypes, and to test new materials and equipment. Its main beneficiaries will be the local solar industry,[33] with pilot programmes and monitoring and product certification of systems and competences. The IISM is fundamental to strengthening technology transfer and trade by selling and licensing technologies and materials and by fostering spin-offs and the design of new business models.

For the Industrial Development area, an **Open Innovation Platform for Financing and Innovation** has been established.[34] This project aims to develop a virtual supply-and-demand interactive platform as well as a specialized team in charge of studying the main energy-related problems, needs, and opportunities in the national industry so they can translate their findings into business innovation opportunities. It also contemplates a specialized team in charge of incentivizing participation by local suppliers and advising them on the construction of innovative and value propositions to take advantage of those opportunities. The objective is to contribute to closing the existing information and knowledge gaps between suppliers and consumers of energy solutions and to facilitate access to financing in order to materialize the proposed innovations.

To build Quality Infrastructure, and considering the gap between local knowledge and needed understanding of optimal conditions for solar power generation,[35] an **Optical Metrology Lab** was opened at the University of Santiago.[36] Some of the identified gaps are the weak supply of calibration instruments and poor radiometric and photometric standards.[37] This lab is expected to have quality measurements and be able to supply geo-referenced information to the solar industry.

The Strategic Solar Program also has planned global actions such as the **Cuenca del Salado Solar Corridor.**[38] The aim of the Corridor is to study and test technical, social, and productive solutions that allow a massive adoption of solar energy in the cities of Chañaral and Diego de Almagro in the Atacama Region.[39]

One initiative for the future is the **Solar Technology District (DTS).**[40] The concept, which builds on the experience of the Moroccan Agency of Sustainable Energy,[41] refers to the development of territories covering large areas that have been chosen for their optimal conditions for solar power generation, subdivided into lots, and awarded to energy-generation companies in a concession for the development, construction, and operation of solar power plants using different technologies. A Technology Master Plan will determine the choice of technologies and the total installed capacity in these districts. Optimization will occur through criteria that include the technology mix that best contributes to stable energy supply at competitive prices, and with the promotion of the participation by local companies as suppliers. Chile has no record of anything similar being implemented in the past; fostering the deployment of solar energies with a relevant increase of domestic suppliers is an ambitious undertaking. Under current conditions in the Chilean energy market, the first task—a difficult one—will be to obtain a long-term contract for electricity supply.

To introduce the Chilean solar industry into the global energy market it will be important to participate in different international initiatives. Chile's researchers and firms have limited experience participating in international groups dedicated to the development of solar technology. However, Chile has recently joined the International Energy Agency´s **Photovoltaics Power System Programme (PVPS),**[42] as well as the **Solar Power and Chemical Energy Systems Energy Technology Network (SolarPaces).**[43] The objective of both these organizations is to share first-hand information on photovoltaic and concentrated solar power technologies.

Because of the lack of competition in Chile's energy sector, public funding for RDI in energy has been a key driver for research and innovation in Chile because private spending historically has been limited.[44] Several policies have been implemented in order to incentivize private-sector funding (tax exemptions, co-finance loans, etc.), but with the country's current level of development, public funding will continue to play an important role in the short and medium term. In terms of public funding, in February 2015 a special fund—the **Strategic Investment Fund (FIE)**—was created. The FIE supports initiatives aimed at improving productivity, diversifying the economy, and increasing the value added of the national production, with a focus on solar energy among others.[45] Additionally, within the framework of the **Mission Innovation** collaboration programme,[46] Chile has committed to doubling its budget in clean energy R&D to US$9 million by 2020, up from US$4.5 million recorded in 2015. The programme also promotes higher levels of private-sector investment in transformational clean energy technologies by opening calls for proposals from companies to develop specific solutions for the solar industry.

The future of the Chilean revolution

Since 2014, photovoltaic systems with a capacity of 1,776.41 MW have been installed, boosting the photovoltaic component of the total electricity mix from 0.01% to 4.4% by 2017.[47] By 2030, the share of solar energy in total electricity production is estimated to reach between 13% and 22%.[48] Chile currently has the largest solar energy generation capacity in Latin America. Chile also has new technologies that allow it to concentrate solar power, thus providing storage for this type of energy.[49]

What can be expected in the future? Recently, as part of the Ministry of Energy's long-term energy planning process for electric transmission expansion,[50] five installed power mix scenarios over the next 30 years were considered.[51] The five scenarios, which describe possible shares of different sources of power by 2035, are the result of a process involving cross-matrix analysis considering the following drivers: social willingness for projects, energy demand, technology changes in battery storage, environmental externalities costs, investment costs for renewable energy technologies, and the price of fossil fuels. All the scenarios show greater participation of solar power and a more diversified mix of energy sources. By 2035 the most optimistic scenarios for renewable energy show that at least 30% of installed capacity will be solar, including both photovoltaic and concentrated solar power generation systems. That will represent more than 10 GW of photovoltaic generation over the current 2.1 GW, and more than 1.2 GW of concentrated solar power.[52]

Because of the unique conditions of the Atacama Desert, the recent interconnection of the electric systems (SIC and SING) that links the north with the centre and south of the country has been a major change in the electricity market.[53] This was achieved after four years of planning and construction. One of the important goals of the interconnection was the opportunity for more competition that renewable sources can bring to the energy market. The SIC-SING interconnection opens the possibility of an international interconnection with Peru and Argentina. A more integrated system complements the development of the photovoltaic and concentrated solar power potential in the Atacama Desert.

Next challenges

Energy Policy 2050's goals are clear: to generate 60% of power from renewables by 2035 and 70% by 2050. These objectives are crucial to attaining the 30% reduction in emissions by 2030—as committed to under the Paris Agreement.[54] The five scenarios based on the long-term energy planning process show that solar and wind will be the main drivers of electricity supply in the upcoming years.[55] This situation generates special challenges for Chile's local solar industry.

First, it is important to be prepared to have a large proportion of variable renewable energy.[56] Results from previous studies, such as the *Energías Renovables No Convencionales* (ERNC, Non-Conventional Convertible Renewable Energies) Roundtable, show that Chile can have at least 30% solar and wind generation with the current level of flexibility of its power systems.[57] The main source of flexibility in the Chilean market is provided by hydropower generation. Then the country has time to prepare for a greater penetration of variable renewable energy, but actions have to be taken soon. A proper transmission expansion, as well the interconnection with neighbour countries, can help. But that might not be enough. For example, different sources and technologies for storage will also be needed.[58]

Distributed generation has just started to grow in Chile but, considering the potential of the country, it is very likely that distributed solar generation can play an important role in the future. The market will need to deploy new infrastructure on smart grids to take full advantage of this opportunity.

Taking into consideration the high potential of solar generation in Chile,[59] which is estimated at more than 1,640 GW of photovoltaic and more than 550 GW of concentrated solar power,[60] there is an opportunity to use solar energy for other purposes, such as electric mobility and solar fuels.[61] To do this, Chile intends to become a leader in zero-emission mobility,[62] taking advantage of the clean energies of its electrical generation mix and its lithium sources, which comprise the main input needed to develop a new energy storage industry.[63] Another opportunity lies in the generation of hydrogen as an energy vector, for new low-emission mining and for other applications. In 2018, a technology programme was launched by CORFO to develop mining extraction trucks powered by hydrogen, either by mixing hydrogen with diesel,[64] or by powering the trucks with fuel cells.[65]

Chile has already begun its solar revolution and will continue to deepen it. One of its most important challenges is the appropriate integration of increasing amounts of variable renewables into the electric system, which still needs a more flexible power system. In order to develop successfully, new technologies and standards are required that are specially designed for the Chilean desert and extremely high radiation conditions. It is also necessary to foster open innovation processes where entrepreneurs, universities, and research centres provide solutions to specific challenges, and to train the workforce with a new set of skills. These open processes and workers with appropriate skills are needed to contribute to Chile's greater economic development—development that is sustainable and inclusive, where innovation will be the main link to continue on the path of clean energy.

Notes

1 Comisión Nacional de Energía, 2017.

2 Ministerio de Energía, 2016.

3 IEA, 2018.

4 Consejo de Defensa de la Patagonia Chilena, 2013.

5 The Norte Grande Interconnected System (SING, *Sistema Interconectado del Norte Grande*) serves the desert mining regions in the North; the Central Interconnected System (SIC, *Sistema Interconectado Central*) serves the central part of the country.

6 IEA, 2018.

7 See https://www.cne.cl/estadisticas/electricidad/.

8 Ministerio de Energía, 2014a.

9 Ministerio de Energía, 2016.

10 For information about the Strategic Solar Program, see http://www.programaenergiasolar.cl/english/solar-committee/atacama-desert/.

11 Calculations made by the Solar Energy Research Center are available at http://sercchile.cl/.

12 USGS, 2018.

13 Corporación Chilena del Cobre, 2016.

14 Fundación Chile, 2015a. 'Soiling effect' refers to the accumulation of dirt on solar panels. This effect can have a significant impact on the performance of solar systems, particularly in areas—such as in the Atacama Desert—with a large amount of dust or pollution and low or nonexistent rainfall.

15 Fundación Chile, 2015a.

16 'Concentrated solar power' uses mirrors or lenses that reflect and condense light, which is converted to heat that can be stored.

17 Ministerio de Energía, 2014a.

18 Ministerio de Energía, 2016.

19 Ministerio de Energía, 2016.

20 Ministerio de Energía, 2017b.

21 Ministerio de Energía, 2016.

22 Ministerio de Economía, 2014.

23 See Chile's Solar Energy Program website (in English): http://www.programaenergiasolar.cl/english/. Information about CORFO is available at http://www.english.corfo.cl/.

24 Fundación Chile, 2015b.

25 Fundación Chile, 2015b.

26 The results of the bidding process are available here (in Spanish): http://www.licitacioneselectricas.cl/wp-content/uploads/download-manager-files/Acta-Adjudicacion-Oferta-Economica.pdf.

27 Fundación Chile, 2015a.

28 More information on the Technology Development branch of the Solar Program is available at http://www.programaenergiasolar.cl/english/solar-road-map/tecnological-development/development-technological-photovoltaic-systems-deserts/.

29 More information is available (in Spanish) at http://www.programaenergiasolar.cl/lanzamiento-de-atamos-tec-consorcio-publico-privado-busca-desarrollo-de-tecnologias-solares-en-chile/.

30 Fundación Chile, 2015b.

31 See more here (in English): http://sercchile.cl/en/serc-chile-implementara-atamos-tec-iniciativa-que-fomentara-la-industria-solar-local/.

32 For more information about the International Solar and Mining Institute of the North (IISM), see http://www.programaenergiasolar.cl/english/solar-road-map/tecnological-development/international-solar-mining-institute-iism/ (in English).

33 A directory of all beneficiary companies in the local solar sector is available at http://industria.enlacesolar.cl/directorio-sector-solar/.

34 For more information on the Open Innovation Platform for Financing and Innovation, see http://www.programaenergiasolar.cl/english/solar-road-map/industrial-development/open-innovation-platform-financing-innovation/ (in English); see https://fch.cl/proyecto/sustentabilidad/brilla/ (in Spanish). See also http://www.programaenergiasolar.cl/english/solar-road-map/industrial-development/open-innovation-platform-financing-innovation/ (in English).

35 See http://www.programaenergiasolar.cl/english/solar-road-map/strengthening-quality-infrastructure-solar-energy/.

36 See http://www.fisica.usach.cl/laboratorios/laboratorio-metrologia-optica.

37 Fundación Chile, 2015b.

38 For more details, see http://www.programaenergiasolar.cl/english/solar-road-map/global-initiatives/solar-corridor/ (in English).

39 Observatorio de Ciudades UC, 2016.

40 More information is available at http://www.programaenergiasolar.cl/english/solar-road-map/global-initiatives/solar-technology-district-dts/ (in English).

41 More information about Morocco in this context is available at http://www.masen.ma/en/.

42 For more information about the IEA's Photovoltaics Power System Programme, see http://www.iea-pvps.org/.

43 More information about SolarPaces is available at http://www.solarpaces.org/.

44 Consejo Nacional de Innovación para el Desarrollo, 2017.

45 Ministerio de Economía, 2017.

46 Mission Innovation involves 22 countries and the European Union. It aims to strengthen and accelerate public and private global clean energy innovation. Each participating country will seek to double its governmental and/or state-directed clean energy R&D investment over five years. New investments would be focused on transformational clean energy technology innovations that can be scalable to varying economic and energy market conditions.

47 Comisión Nacional de Energía, 2017.

48 Ministerio de Energía, 2017d.

49 See https://cerrodominador.com/.

50 Ministerio de Energía, 2017d.

51 Data and results are available at pelp.minenergia.cl (in Spanish).

52 Ministerio de Energía, 2017d.

53 Coordinador Eléctrico Nacional, 2017.

54 Ministerio de Medio Ambiente, 2017.

55 Ministerio de Energía, 2017d.

56 'Variable renewable energy' is a renewable energy source that fluctuates, such as wind and solar sources.

57 Ministerio de Energía, 2015.

58 See http://valhalla.cl/.

59 The total power capacity by January 2018 in Chile was 22.57 GW and solar was 1.8 GW (Comisión Nacional de Energía, 2017).

60 Ministerio de Energía, 2014b.

61 According to Bloomberg New Energy Finance, the Chilean solar power capacity represented less than 1% of the capacity of overall Central and South America the same year, 2015.

62 Ministerio de Energía, 2017b.

63 Ministerio de Minería, 2015.

64 See https://www.corfo.cl/sites/cpp/convocatorias/2017_pt_combusti%C3%B3n_dual_hidr%C3%B3geno_%E2%80%93_di%C3%A9sel.

65 See https://www.corfo.cl/sites/cpp/convocatorias/movil/2017_pt_equipos_mineros_celdas_de_combustibles.

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