Heat and Dust

The Solar Energy Challenge in Chile

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CHILE OFFERS UNIQUE CONDITIONS FOR THE development of solar energy solutions. The new government is drawing up an ambitious road map for the development of solar energy. Some visions include the positioning of Chile as a regional solar energy exporter. This article examines this trend, based on the development of the power sector, the power market, analysis models, innovation opportunities, and the public policies implemented over the past ten years. It provides an overview of the solar energy scenario for Latin America and examines the technical challenges faced by the various solar technologies, and it discusses transmission systems and storage solutions. The issues of citizen empowerment, community engagement, and sustainable development in the context of solar energy development in the region are discussed along with the need for development of the human capital required to address alternative solar energy challenges from a technical and social standpoint.

Chile is an Andean nation on the western coast of South America with a population of approximately 17 million people. More than a third of the population live in the centrally located capital city, Santiago. The country occupies a narrow strip of land that

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stretches more than 4,000 km from north to south, crossing the world's driest desert, a Mediterranean central valley, and extensive temperate forests before morphing into a rugged, glacier-studded archipelago in the extreme south. Such geographic variation has created a rich variety in Chile's culture and natural resources. In the two centuries since its independence from Spain, its economy has been closely tied to the land, especially through agriculture and the extraction of nitrates and copper.

Chile presents unique conditions in terms of solar energy potential. According to several studies, northern Chile is one of very few regions in the world with annual global irradiance values exceeding 2,500 kWh/m^2 (Tucson, Arizona, exhibits a value of 2,080 kWh/m^2). Its skies are also exceptionally clear, with an annual average clearness index that at 0.72 is close to the world's maximum of 0.8.

An overview of Chile's solar energy potential is shown in Figure 1. Figure 1(a) compares the energy potential of South America and Europe, demonstrating the high solar energy potential of the Atacama Desert. Figure 1(b) presents three maps associated with the Chilean solar energy potential, in which the following situations are highlighted:

- ✔ The map on the left shows the annual plant factor distribution in accordance with a color code (red = high, blue = low).
- ✔ The central map uses the same color code but incorporates land-use constraints, such as minimum distances to urban areas, rivers, coastlines, railways, and so on; maximum distances to the electricity network and access roads; and a maximum terrain slope of 5%.
- ✔ The map on the right incorporates an additional constraint: those locations with a plant factor greater than 0.24.

In this way, for each region in the country the number of hectares of well-suited locations can be identified. For example, in the case of the Arica and Parinacota Region (the first one, going from north to south), they reach a total area of 450,864 hectares. Thus, the estimated solar potential for electricity generation in the Atacama Desert (situated within the first four regions from north to south) is nearly 1,000 GW, or five times the present peak load of all South America.

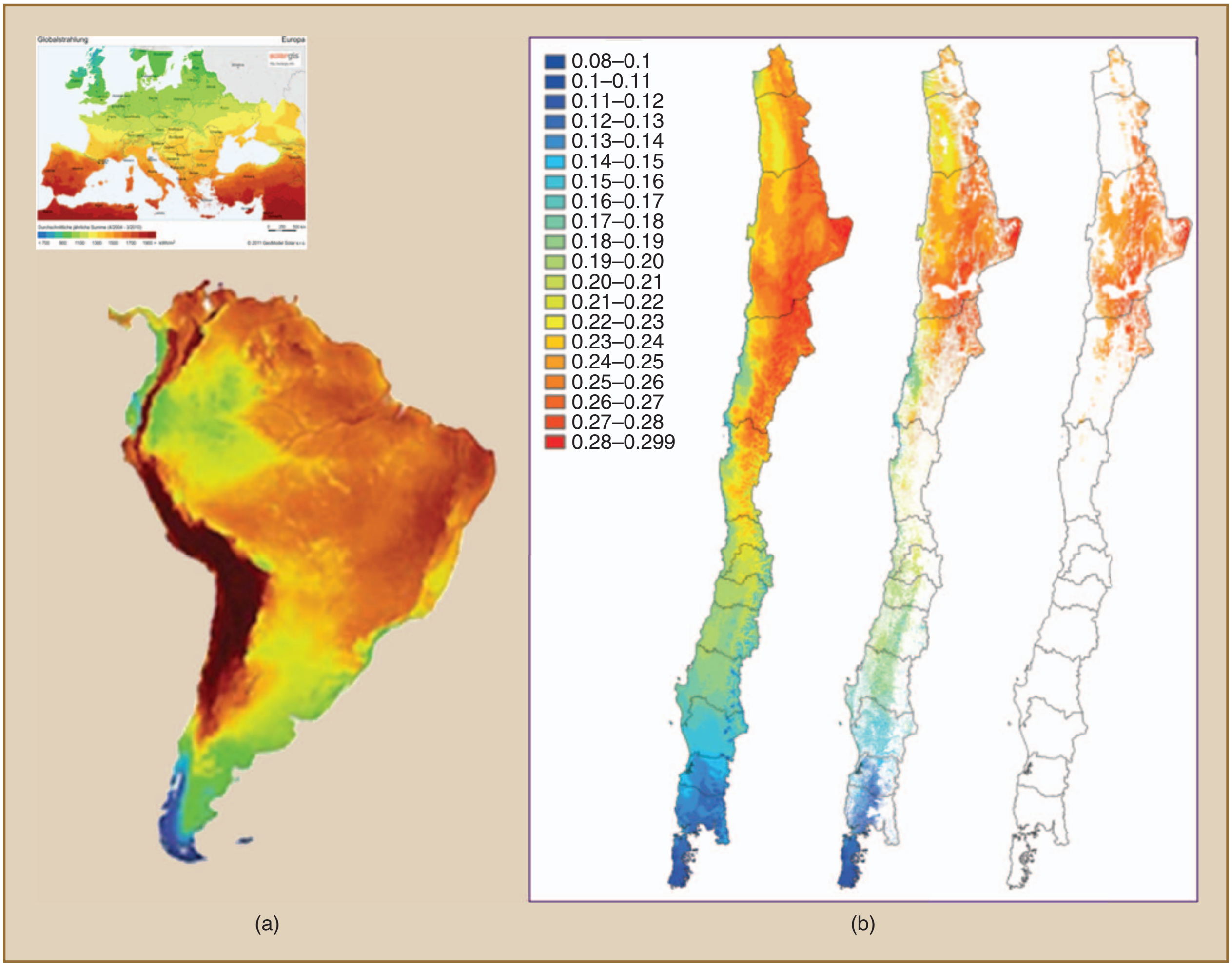


figure 1. Chile's solar energy potential: (a) compared with that of Europe and (b) annual plant factor distribution, with various constraints added moving from left to right (source: Chilean Energy Ministry).

Solar Energy Development in Chile

The Atacama Desert has attracted miners and explorers since pre-Columbian times. Nitrate deposits were first discovered and used by the indigenous peoples of the Atacama, but commercial exploitation only began in 1866, in the interior of Antofagasta. In 1870, José Díaz Gana discovered the silver mines at Caracoles, also in the Atacama Desert, near present-day Sierra Gorda. Both nitrate and silver production demanded large amounts of water for the miners as well as the hundreds of horses and mules that provided the workforce. This water had to be brought by mule-drawn wagons from either the high Andes or small watering holes near the coast. In this context, the engineer Charles Wilson built the world's first large-scale solar desalination plant in Las Salinas. The plant had around 5,000 m^2 of basin-type solar stills (see Figure 2). These provided about 20,000 L of desalinated water per day, using the briny water that existed in local wells. This still was the largest of its type worldwide and marked the beginning of solar energy use in Chile.

From that initial date, despite its large potential in the context of heating systems, solar energy was only used directly for the large-scale evaporation of salt brines for nitrate and lithium salts production, as well as the drying of agricultural production. In recent years, due to a government subsidy, its use for domestic hot water systems has become more common. Starting in 2012, the mining industry began to apply large-scale solar fluid heating in electrowinning processes.

With respect to electricity production, photovoltaic (PV) systems were only used for off-grid rural use and telecommunications, standalone lighting systems, and some commercial buildings. In 2012, Chile had an installed solar capacity of only a little more than 1 MW in PV systems. PV capacity is now growing more rapidly, however, as a consequence of the developments described below.

Since 2006, several factors have caused Chile to have one of the higher electricity prices in the region:

- ✔ The end of low-cost natural gas from Argentina has had a large impact, beginning with supply cuts in 2004 and forcing the construction of two large LNG terminals in Chile.
- ✔ Citizen empowerment has led to the demand for better services and the consideration of citizen groups in policy decisions. This has in turn led to lawsuits that have blocked power generation projects, especially those based on coal-fired plants and large-scale hydroelectric projects.
- ✔ From 2007 to 2011, most new, large-scale power plants from the private sector were based on diesel fuel; at the same time, fossil fuel prices have skyrocketed.
- ✔ There have been significant decreases in rainfall in central Chile over the last 40 years, with prolonged droughts lasting several years. Figure 3 shows the decreasing trend of stored energy in the system's principal hydroelectric reservoirs over the last 15 years.

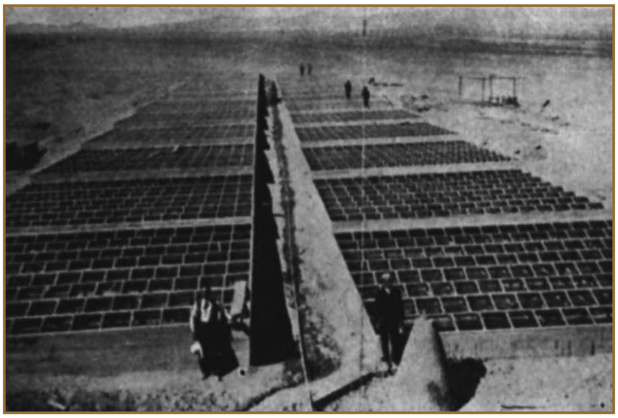


figure 2. The first solar energy desalination system in Chile, 1872 (source: J. Hirschmann).

In this scenario of high energy prices and uncertainty, both government and private actors have been increasingly interested since 2010 in integrating renewable energy technologies into the energy mix. The government has recently introduced a renewable energy generation requirement (20% by 2025). Likewise, distributed small-scale generation has also became a

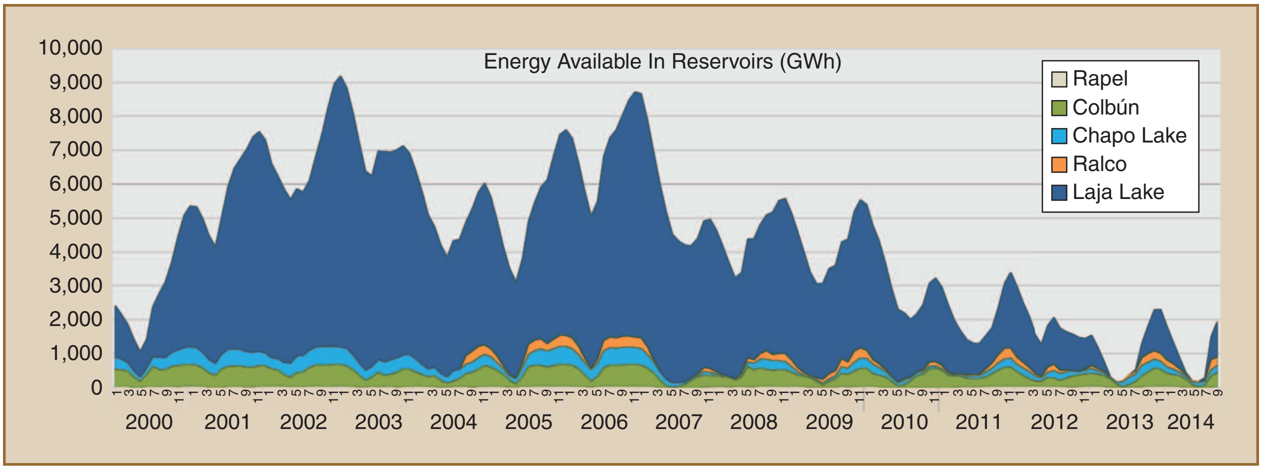


figure 3. Stored energy (GWh) in the main Chilean hydroelectric reservoirs, 2000–2014 (source: Systep).

> The solar energy challenge for Chile has been presented using a multidimensional approach consisting of six major areas to be addressed.

topic on the energy agenda; in 2012, a new law to facilitate net billing service for residential-size energy producers was passed.

Some of the world's first unsubsidized solar energy sales materialized in northern Chile in 2012. Solar energy in Chile currently has close to 220 MW of installed capacity, with an additional 570 MW under construction. Moreover, projects whose environmental qualification has been approved total more than 8,000 MW. With respect to the existing Chilean solar energy projects, Figure 4 provides a breakdown of their land use, and Figure 5 shows their plant factors.

The slightly above-international-average land use values of 2.4 ha/MW (NREL 2013) and 3.02 ha/MW in Chile are justified by the use of single-axis tracking systems due to the region's high direct radiation index.

Chilean solar power plants exhibit an accumulative average plant factor of 21%. These early results are high when compared with those observed in countries such as Germany, which are around 10%. In addition, most of the new Chilean power plants entered the system during the past winter season, which had a low radiation index. An annual average plant factor in the range of 25% is expected after the first learning phase.

The thermal use of solar energy has also been developed in recent years, not only for residential and commercial use but also in the form of huge facilities used by the mining industry.

Biomass, wind, and small run-of-river power plants have also been actively developed since 2008. Today, the total installed capacity of local renewable resources (excluding hydropower plants over 20 MW) is close to 1,800 MW, which represents nearly 10% of Chile's total installed electricity capacity and almost 10% of its annual electricity production.

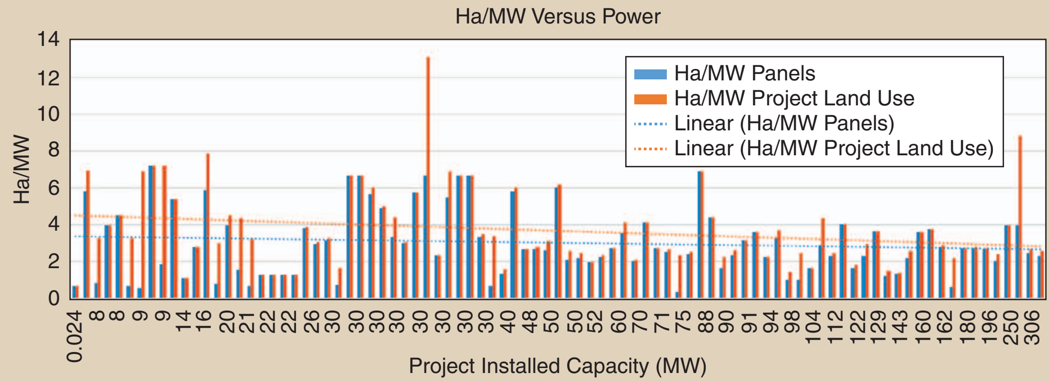
The Solar Energy Challenge

A high-penetration scenario for solar energy in Chile brings a number of challenges, which are summarized in Figure 6. In fact, the challenges relating to large-scale solar energy development exist along several dimensions. They concern not only electricity production goals but also socioenvironmental development, heat production, green chemistry based on solar energy, the impacts on local industries and products, and access to water. They are described below.

Electricity Production

Electricity production is the most visible application of solar energy. In fact, solar resources in Chile can not only fuel sustainable development in Chile but also supply electricity for export to other South American countries. Figure 7 shows one vision for the future exportation of Chilean solar energy.

In this scenario, foreseen for 2035, 30% of the electricity consumption in South America can be supplied by



	Panels (Ha/MW)	Project Land Use (Ha/MW)
Average	3.02	3.69
Standard Deviation	1.8	2.1

figure 4. Land use of existing solar power plants (source: Environmental Impact Evaluation System).

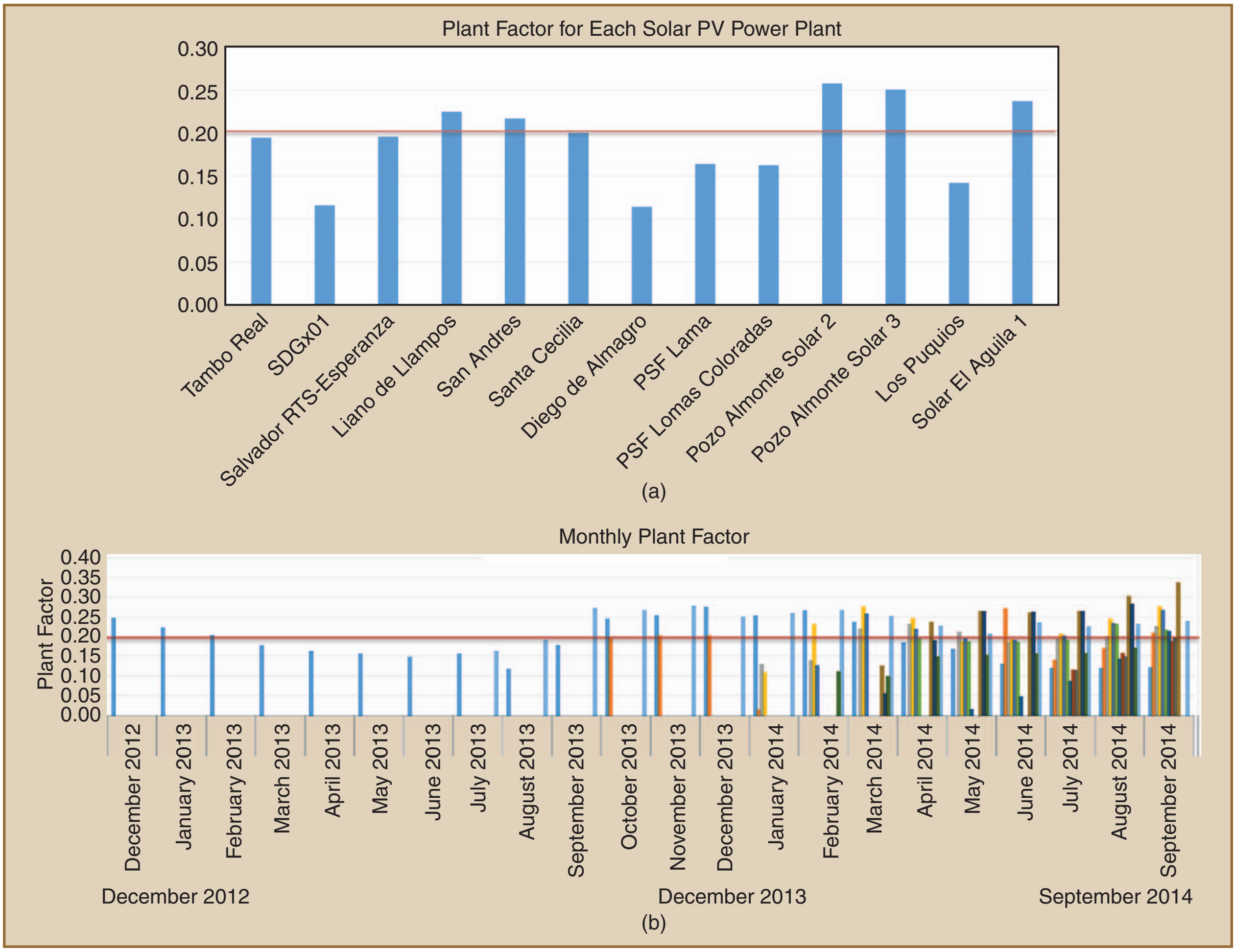


figure 5. (a) The plant factor of existing solar power plants and (b) the monthly plant factor, December 2012–September 2014 (source: CDEC-SIC).

solar energy plants located in the Atacama Desert with a total installed capacity of 200 GW. To accomplish this, 6,000 km^2 or 15 locations measuring 400 km^2 each would be required. This represents less than 1% of the Chilean continental surface and not quite 5% of the available space in the Atacama Desert.

The technical challenges facing such a large deployment of PVs in Chile include the variability of PV electricity supply as it relates to the need for firm and continuous supply to mining facilities, as well as concerns about grid stability. The first issue can be addressed using combinations of PVs and concentrated solar power (CSP) with thermal storage, PV and wind generation, PV and pumped hydro storage, hybrid PV-diesel plants, and the use of small hydro generators as reserve capacity, along with controllable loads (mining pumping systems, desalination plants, pump storage, and so on). In addition, demand response can concentrate energy requirements during sunny hours. In a country with a longitudinal grid topology, concerns about grid stability can be addressed by the PV industry and "grid-friendly" utility-scale PV plants employing power plant controllers, dynamic voltage power management, frequency droop control, and fault ride-through capacity.

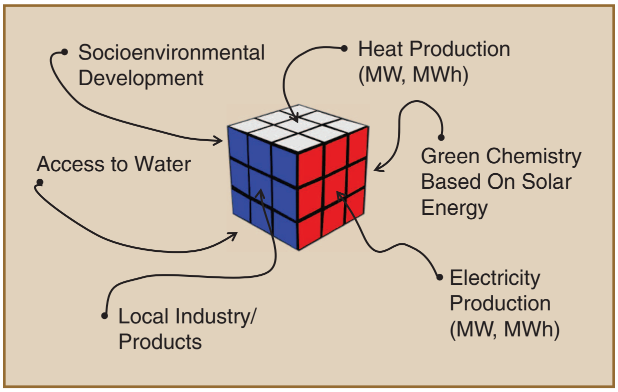


figure 6. Multidimensional challenges for solar energy development in Chile.

Figure 8 illustrates two generation expansion scenarios for the Chilean interconnected power systems. If assumptions about future investment costs for generation technologies are

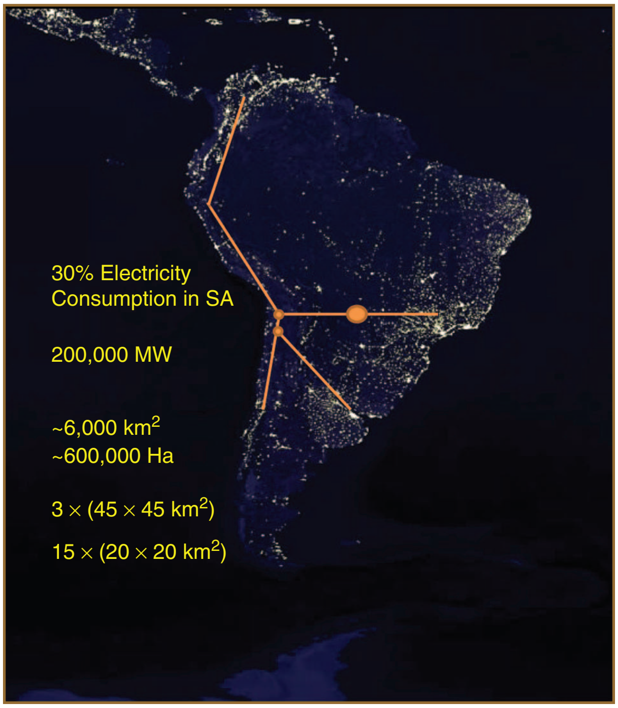


figure 7. One vision of solar energy development in Chile: it could supply 30% of electricity demand in South America by 2035.

varied, alternative future trends for solar energy can be identified. In the case of a low-investment-cost scenario, a systematic penetration of solar energy starting in the year 2019 would be possible.

It should be noted, however, that the PV output from plants in the Atacama Desert is unaffected during most of the year by cloud-induced fluctuations, and therefore such controls will not be necessary there. Further, the first interconnection between the northern and central interconnected systems is being planned for 2017. The storage capacity of hydro units in the south of Chile will thus be available for solar energy compensation in both systems.

In the case of Chile, PV deployment has been focused on medium- and large-scale power plants, which is the opposite of what has occurred in other countries where distributed generation has played a significant role (i.e., Germany, Australia, and Italy). Nevertheless, as mentioned before, in 2012 the government implemented a law facilitating the supply of surplus energy to distribution networks by small generating units (less than 100 kW). In fact, this law lets regulated clients that have installed electrical generating equipment for supplying their own electricity needs, using nonconventional renewable energy or efficient combined heat and power (CHP), to feed electricity they have generated into the distribution network under a net billing scheme. Nowadays, the rules for applying this mechanism have been clarified, and there is a great deal of expectation about the results. In this context, PVs appears as the key technology to be deployed, but such expectations are to a large extent aimed at commercial users, as the mechanism does not imply subsidies and most residential users do not have the means to afford investments of this type. Finally, along with the rules, a technical standard for the connection and operation of such facilities at both the low- and medium-voltage levels has been developed.

Heat Production

Solar energy is not only recognized as a source of electrical power but also as a heat source. As described above, its early development was associated with heat instead of electricity. In the case of Chile, heat production based on solar energy is related to the mining industry. Many copper production processes present a high heat demand; in fact, there are successful examples of heated water production for electrowinning processes such as the Pampa Elvira Solar project, with an annual production of 51,800 thermal megawatt-hours (MWht). Nevertheless, this is not a unique application of

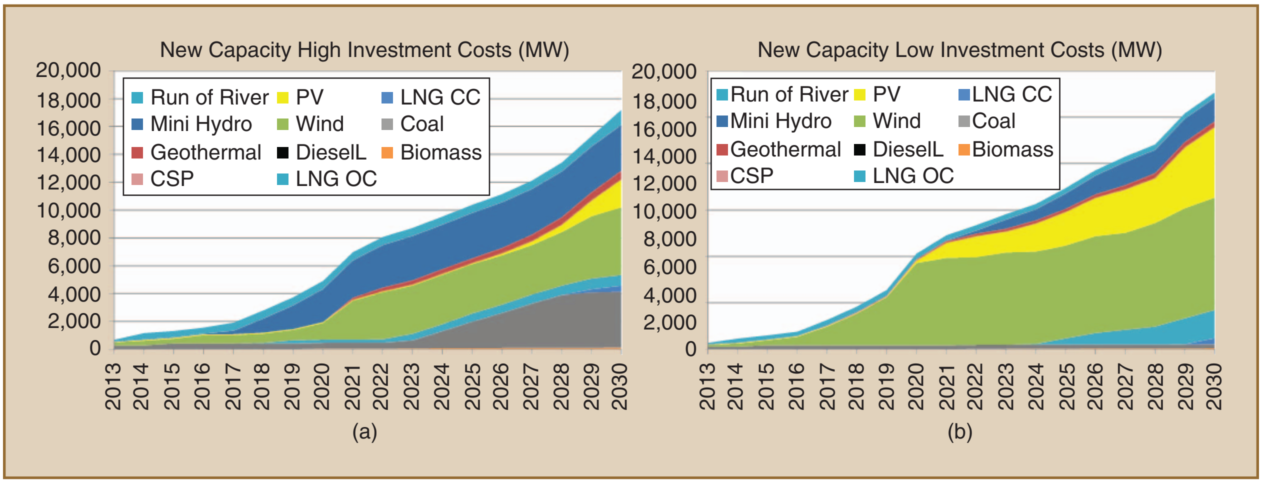


figure 8. Generation expansion scenarios with (a) high investment costs and (b) low investment costs (source: GIZ Energy Ministry, Chile).

heat production for mining processes; there are other initiatives being promoted as well. For instance, solar cogeneration offers different deployment alternatives integrating CSP and the mining process, where the former would function as a condenser in the thermal cycle. In addition, conditions in the Chilean north offer a unique opportunity for the deployment and testing of new technologies such as concentrated photovoltaic (CPV), where both products—heat and electricity—can be incorporated into productive processes.

On the other hand, at the household level, solar heating systems have been widely promoted and implemented. The Chilean government has created a subsidy that incorporates the solar heating system cost into new housing development programs, avoiding the extensive use of gas or electricity to heat water for human use.

Local Industries and Products

To make the Chilean north a key area for the deployment of solar energy, efforts are being focused not only on promoting the development of power and heat plants but also on providing an adequate platform so that technological development and innovation related to solar energy are linked with local industries and products. There are opportunities for local industry development not only in service provision but also in specific product development. Overseas PV equipment manufacturers, for instance, have not taken into account the particular conditions of the Atacama Desert (its very high irradiation/UV level, dust, coastal fog, altitude, and so on) in their design processes; the production of PV modules and CSP plants specifically designed for these conditions represents a business opportunity. Moreover, considering the region's high copper cathode manufacturing capability, PV cells that incorporate this metal are being studied.

Access to Water

The Atacama Desert has the world's highest water scarcity, and this is a challenge to be overcome at any level of development. This fact heightens the importance of the development of solar energy–based technologies that allow water treatment systems for the following applications:

- ✔ decontamination and disinfection of natural waters
- ✔ treatment of residual industrial wastewater
- ✔ solar desalination of seawater and brackish water.

Socioenvironmental Development

Effective stakeholder engagement will contribute to maximizing the positive impacts of solar energy while reconciling its objectives with the community's needs. In this sense, solar development planning should be geared to taking into account stakeholder concerns and, if necessary, adapting certain activities accordingly.

The strength of the relationship that can be developed between the community and the technology developers will be critical for its successful consolidation and sustainability. In this context, local communities are identified as key stakeholders with whom a foundation of trust must be built. In the specific case of rural areas, a coconstruction approach should include the following criteria: the area's geographic and socioeconomic features, the level of organization and cohesion of the community, the main problems and interests it faces, and the presence and type of leadership in the community.

Green Chemistry Based on Solar Energy

Solar energy can be the main driver and energy source for the design of products and processes that minimize the use and generation of hazardous substances. Subproducts of the mining industry and new fuels for power generation are envisioned for this area.

Conclusions and Future Developments

This article discusses a number of aspects of the development of solar energy in Chile and the current challenges faced. As a consequence of the lack of natural gas from Argentina since 2004 and other issues and the corresponding increase in electricity prices, an opportunity for the massive introduction of solar energy technologies has been identified. In this sense, the solar energy challenge for Chile has been presented using a multidimensional approach consisting of six major areas to be addressed, all with the goal of making the north of Chile a key area for solar energy development.

Acknowledgments

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For Further Reading

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Biographies

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