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# The state of solar energy resource assessment in Chile

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ABSTRACT

The Chilean government has determined that a renewable energy quota of up to 10% of the electrical energy generated must be met by 2024. This plan has already sparked interest in wind, geothermal, hydro and biomass power plants in order to introduce renewable energy systems to the country. Solar energy is being considered only for demonstration, small-scale CSP plants and for domestic water heating applications. This apparent lack of interest in solar energy is partly due to the absence of a valid solar energy database, adequate for energy system simulation and planning activities. One of the available solar radiation databases is 20–40 years old, with measurements taken by pyranographs and Campbell–Stokes devices. A second database from the Chilean Meteorological Service is composed by pyranometer readings, sparsely distributed along the country and available from 1988, with a number of these stations operating intermittently. The Chilean government through its National Energy Commission (CNE) has contracted the formulation of a simulation model and also the deployment of network of measurement stations in northern Chile. Recent efforts by the authors have resulted in a preliminary assessment by satellite image processing. Here, we compare the existing databases of solar radiation in Chile. Monthly mean solar energy maps are created from ground measurements and satellite estimations and compared. It is found that significant deviation exists between sources, and that all ground-station measurements display unknown uncertainty levels, thus highlighting the need for a proper, country-wide long-term resource assessment initiative. However, the solar energy levels throughout the country can be considered as high, and it is thought that they are adequate for energy planning activities – although not yet for proper power plant design and dimensioning.



## 1. Introduction

Chile is located in the west coast of the southern half of South America. The country is a narrow strip of land twice the size of Japan that stretches about 4300 km, with an average width of about 170 km. Chile shares borders with Argentina and Bolivia to the east and with Peru to the north. The Pacific Ocean forms the entire western border of Chile, which has a coastline stretching more than 6400 km. Chile may be divided into three macro zones: In the north, the Atacama Desert stands as the driest place on Earth, with characteristic sandy and rocky terrain. It is followed by a central valley where most of Chile's population lives and where productive lands are located, having a mild climate. Continuing south, a barely populated system of islands, fiords, and low mountains with a tough, cool, and damp climate is found. Sidewise, from the Pacific Ocean, about one-third of Chile is defined by a low coastal mountain chain, followed by a central valley, and then by the rugged Andes chain. This diversity of geographical features and climates makes generalizations meaningless, and has a great impact on the availability of renewable energy sources and their proper assessment.

Chile is endowed with a wide range of natural resources, and through the production, addition of value and exports of such resources it has emerged as a successful economy. However, Chile has limited energy resources apart from hydroelectric capacity, and the internal fossil fuel production is in permanent decline and negligible. The country heavily relies on fuel imports to meet its growing energy demand, making it a growing net importer of energy. Renewable energy sources in use by the country comprise only hydroelectricity and wood-based biomass. In the best case, renewable energy sources only account for 24% of primary energy consumption, while non-renewable sources account for the other 76%. As shown in Fig. 1, the consumption of primary energy (*Ep*) has steadily increased, and it is projected to continue doing so as the

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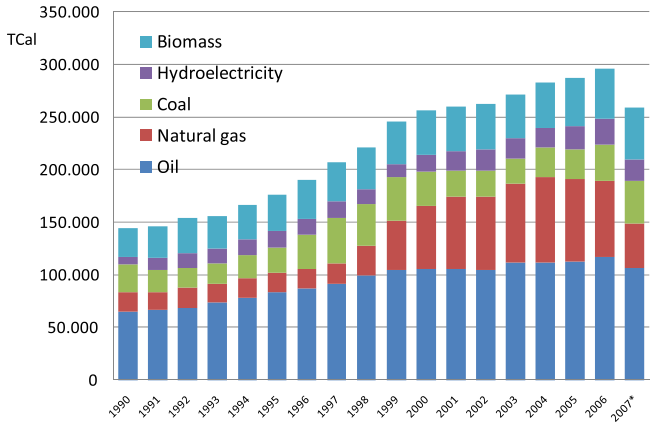


**Fig. 1.** Historical consumption of Primary Energy (CNE, 2007).

country further develops [1]. The data for 2007 is apparently incomplete, as it displays a significant reduction on primary energy consumption, mostly associated to shortages of Natural gas supply.

In the period from 1980 to 1998, before the introduction of imported natural gas from Argentina, the average annual increase of total primary energy supply (TPES) was 3.3%. In that year, the shares by energy source were 50.7% oil, 18.3% coal, 19% biomass and others, 5.2% natural gas, and 7% hydroelectricity. From 1998 to 2002, even in a shrinking economy, the average annual increase of TPES surpassed 6%. The oil share went down 10%, coal was reduced by 8.5%, biomass was reduced by 2.5%, and hydropower remained about the same. However, natural gas went up 21.3%, making a large change in the energy mix. Thus, in 1998, assuming that biomass is a sustainable resource; nearly 26% of the TPES was renewable energy, while such value was 24% in 2002. In 1980 approximately 66% of the TPES was indigenous production and 34% was imported; by 2006 this relationship was reversed. Indigenous production represented only 32% of the total. These trends are explained mainly by the following: Starting in 1982, the continuous decline in domestic crude oil production, falling from 32% to nearly 3% of total oil supply, due to dwindling off-shore resources; A major increase in coal imports, passing from 49% to 80% of supplies, as a result of the decommissioning of several mining operations that were unsustainable due to the relatively poor coal quality and low energy content, and starting in 1997, low cost natural gas imports from Argentina, which have been increasing steadily since then, making the resource the second in importance, second only to crude oil, after being practically at the same level as hydroelectricity, the least important primary energy source. Starting in 2004, Argentina has been unable to satisfy both its internal demand and the contracted exports to Chile. As a result, severe and frequent supply interruptions have forced industry and power generation sectors to switch to alternative fuels, mainly coal and diesel. Facing a scenario of continuous interruptions, Chile has developed plans for two liquefied natural gas (LNG) plants in order diversify its natural gas imports and reduce dependence from Argentinean exports, with the goal of stabilizing the supply of natural gas in the near future. The first of the LNG plants is entering operation during mid-2009. In the more recent period 1990–2005, primary energy consumption has grown at an average rate of 4.2%, with a minimum of 1.2% in 2004 and a maximum of 11.2% in 1999.

Regarding the electricity sector, in 2002, electricity generation was about 45,483 GWh, with an average annual increase of 6.3% for the period 1980 to 1998, and an average growth rate of 6.5%/year for the period 1998 to 2002. The largest consumption growth was reported in the period 1991–1997, with a rate of about 8.9%/year, which corresponds to a period of good economic performance. During 2003, the electricity generation reached about 47,800 GWh with a consumption growth rate of only 3.6%; however, it recovered to almost 7% per year during 2005 and 2006.

As seen, Chile depends in a great percentage (which is historically around 70–80%) of fossil fuels, which are almost 100% imported. It is therefore of critical importance for Chile to achieve three primary strategic goals: first, to provide adequate energy supplies in order to continue its economic growth; second, to ensure that imported energy is accessed through international markets to satisfy any requirements that cannot be met by internal fuel production; and third, to promote the development of indigenous energy sources at a sufficient rate such as needed for the substitution of imported energy resources in order to rapidly achieve energy security and a degree of energy independence. The Chilean energy policy tries to integrate these three strategic goals, and one mechanism that has been designed consists in the application of mandatory renewable energy quotas for power generation. In 2008 a new law was passed, which requires that a minimum of 5% of electricity generation starting in 2010 must come from what in Chile is called "non conventional renewable energy" (*ERNC – Energía Renovable No Convencional*), meaning small-scale hydro, wind, geothermal, biomass, and solar. Then, a gradual increase will lead to a 10% participation of renewable energy in the electricity generation mix by 2024 [2]. A basic premise of this regulation requires all renewable energy sources to be analyzed and their availability properly assessed, in order to ensure the viability of the policy. Within renewable energies, solar energy seems to be a good alternative for development in Chile, mainly due to the available solar radiation in the country, and associated climatic conditions, which are perceived to be better than in other locations where solar energy conversion systems are in use today.

### 1.1. Renewable energy potential

Chile is thought to be abundantly endowed with renewable energy resources: hydro, geothermal, wind, and solar. However, no large scale renewable energy resource assessment has been conducted for wind and solar, and therefore, any energy planning effort that considers these renewable sources is seriously impeded for the time being. In what concerns to this work, solar power is used scarcely, mainly through photovoltaic panels in rural electrification and also in a growing market for solar water heating applications, which by 2009 had a cumulative surface of less than 10,000 $m^2$. The total contribution of solar energy to the energy mix until 2009 is therefore negligible. In contrast, the Atacama Desert in the northern part of the country is one of the best regions for solar energy, based on energy density data from several sources as in [3,4]. Unfortunately, the population in the vicinity is rather scarce, which would force the implementation of energy distribution schemes in order to make any solar-generated energy supply available to the population and industries located in the central part of the country. However, northern Chile concentrates most of the mining activities which comprise the country's main economic activity, and therefore there is ample demand growth for electricity and industrial heating and cooling, which may be possible to supply in fraction by renewable energy systems.

Solar energy resource assessment in Chile dates from the 60s, when efforts were conducted by Universidad Técnica Federico Santa María by compiling data from around 90 pyranographs and Stokes–Campbell devices, spanning a period of about 20 years. Most of this data has a relatively large uncertainty level proper of the outdated sensors, thus making it unsuitable for energy planning at the national policy level. However, the monthly mean data is thought to be useful for solar water heating applications, and is