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Prospects of concentrating solar power to deliver key energy services in a developing country

Charikleia Karakosta, Charalampos Pappas, John Psarras

National Technical University of Athens, School of Electrical and Computer Engineering, Management & Decision Support Systems Lab (NTUA-EPU), 9, Iroon Polytechniou str., 15780, Athens, Greece.

Abstract
One of today's greatest challenges is the response to the worldwide continuously increasing energy demand. The need for supply of electricity is getting greater year by year. In addition, climate change problems and the limited fossil resources require new sustainable electricity generation options, which utilize Renewable Energy Sources (RES) and are economical in the meantime. Concentrating Solar Power (CSP) generation is a proven renewable energy technology that has the potential to become cost-effective in the future. This analysis explores for Chile the potential of CSP to deliver key energy services for the country. The specific technology has a significant technical potential within Chile, but 'somehow' do not receive sufficient attention from relevant stakeholders, because of gaps either in stakeholders' awareness of the technology or in domestic research and development (R&D) and/or public/private investment. The aim of this paper is to establish a well-informed discussion on the feasibility and potential of the specific sustainable energy technology, namely the CSP technology, within a given country context and particularly Chile. It provides an overview of the fundamental (macro-economic) forces within an economy and identifies some of the blockages and barriers that can be expected when introducing a new technology.

Keywords: Renewable energy; Potential; Concentrated solar power; Sustainable development; Chile.

1. Introduction

Global warming is considered as one of the most critical problems that the environment would be faced with, in the next fifty years [1]. The use of Renewable Energy Sources (RES) is a fundamental factor for a possible energy policy in the future. In addition, Sustainable Development (SD) has acquired great importance due to the negative impact of various developments on environment. Taking into account the sustainable character of the majority of renewable energy technologies, they are able to preserve resources and to provide security, diversity of energy supply and services, virtually without environmental impact.
Generating electricity from RES represents a promising option. Despite its today's costs, increasing the supply of electricity from RES helps to reduce high dependence on imported energy and provides invaluable environmental benefits with regards to Greenhouse Gas (GHG) emissions, thus playing an important role in mitigating climate change [2]. Therefore, promoting innovative renewable applications and reinforcing the renewable energy market will contribute to preservation of the ecosystem by reducing emissions at local and global levels.

In addition, RES can potentially help fulfil the acute energy demand and sustain economic growth in many regions of the world. Indeed, renewables are gaining widespread support, notably in the developing world. Generating electricity from RES yields significant benefits. First, renewable energy technologies have a far lower environmental impact than fossil fuels and nuclear power; in this way, they contribute to reduce electricity production from conventional sources and, consequently, to slow down global warming [3]. Second, development of electricity from RES provides the chance to diversify national energy supply [4]. Third, it can have a positive impact on local sustainable development and employment [5, 6].

Nowadays, an impressive portfolio of renewable energy technologies is available [7]. Some of these produce fluctuating output, like wind and photovoltaic power (PV), but some of them (such as biomass, hydropower and concentrating solar thermal power (CSP)) can meet both peak- and base-load demands for electricity.

CSP uses renewable solar resource in order to generate electricity and at the same time it produces very low levels of GHG emissions. Thus, it has a strong potential of becoming a key technology for mitigating climate change. An important feature of CSP is that it can be combined with thermal storage capacity to store heat energy for short periods of time for later conversion to electricity or thermal use. This way CSP plants can continue to produce electricity even when clouds block the sun or after sundown, enhancing energy security [8].

CSP plants can also be equipped with backup firing from fossil fuels or biomass. The above mentioned factors give CSP the benefit of providing electricity that can be dispatched to the grid whenever needed, including after sunset to match late evening peak demand or even around the clock to meet base-load demand. Furthermore, CSP can also help integrate on grids larger amounts of variable renewable resources such as solar PV or wind power. While the majority of CSP electricity may come from large, on-grid power plants, there is significant potential for satisfying other demands as well, such as processing heat for industry, co-generating of heating, cooling and power, water desalination, household cooking and small-scale manufacturing which are important for the developing world [8].

In countries such as Chile, due to the high solar irradiance, the cost of CSP is usually lower and with good availability. Therefore, the construction of CSP can complement the Chilean sources and provide firm power capacity at a competitive cost. This could also help reduce the level of energy import dependency of the country and increase the energy security of supply for mining companies and other power consumers in the region, which (currently) rely mostly on natural gas supplies from neighbouring countries [9].

Despite the large potential in exploiting CSP in Chile, solar technologies are generally hampered by the sometimes immature status of the technology and by country-specific economic circumstances. This situation urges that both policy-makers and other market actors move towards a new energy model. Chile has recently promoted ambitious policies for enhancing energy efficiency and developing its remarkable natural potential for renewable energy. This potential includes a wide spectrum of renewable energy sources, ranging from mature technologies such as small and large-scale hydropower and biomass, to emerging technologies, such as solar, ocean and wave energy [10]. The Chilean government, having recognised the strong short- and long-term potential of RES in Chile, has recently adopted a wide-ranging approach, including a law for the development of non-conventional renewable energy, specific financial support measures, assessment studies and R&D activities [11].

Since electricity demand in Chile is expected to increase over the next 20 years, a significant opportunity to incorporate more renewable energy production into the Chilean energy grid arises [12]. RES can certainly play an important role in fulfilling the energy needs of Chile and the country could also strengthen the efficient use of energy as a strategic goal of SD. Chile has vast water resources and good slopes to exploit them. The southern part of the country is rich in biomass (firewood), while strong winds throughout the country provide another possible energy source. In addition, the north of the country, and especially the Atacama desert, is rich in solar energy, which could be used for thermal energy and electricity production. Chile also has 10% of the world's active volcanoes, making it possible to exploit geothermal energy. Finally, with more than 4.000 km of coastline, Chile has a vast potential for producing electricity from ocean and wave energy [11].

Currently, only hydropower and biomass are being used at a large scale, unveiling the possibility for further development of RES. Chile has several RES options with significant potential of reduction in GHG emissions that have partly or not at all been utilised. It is also important to pinpoint that, within the open market economy of Chile, mostly private investments pave the way for implementing projects in the field of power generation and other sectors [13].

In the above framework, the paper presents an analysis that explores for Chile, the potential of CSP to enhance the country's energy security as well as to achieve sustainable development. The analysis below is a preliminary attempt to establish a well-informed discussion on the feasibility and potential of this particular sustainable energy technology within a given developing country, namely Chile. It provides an overview of the potential of Chile's electricity sector and identifies blockages and barriers expected to hinder the growth of this new technology.

Apart from the introduction, the paper is structured along four sections. An analysis of Chile's energy picture, in terms of the current status of the country's energy and electricity sector, as well as for the situation regarding RES development is presented in the second section. The third section assesses and discusses the CSP current status in the country. Further on, the fourth section assesses the CSP potential through a detailed presentation of a simulation of a CSP project in Chile. Finally, the last section is the conclusions, which summarizes the main points that have arisen in this paper.

2. Overview of energy situation in Chile

2.1 The energy sector

Chile consists of thirteen administrative regions[1]. The country borders with Argentina to the East and Peru and Bolivia to the North and Northeast. The population is highly urbanised and lives primarily in the central area/regions in and around the Region Metropolitana.

Chile's power sector underwent a radical regulatory reform in the 1980s that resulted in the implementation of a competitive market model for the generation, transmission and distribution of electricity [14]. Most of the regulatory functions for the energy sector, which include tariff regulation, policy and strategy proposal and formulation, service standards, operational criteria for sector enterprises and supervision of electricity dispatch, are at most undertaken by the National Energy Commission (Comision Nacional de Energia - CNE). CNE also implements indicative planning and may recommend state financing for major energy projects that are not being pursued by the private sector [15]. Given the importance of the power sector to the whole country, the environmental commission, local municipalities and a number of other ministries such as those for transport, housing, economy, agriculture and mining are among other state actors that participate in the decision making for power sector developments.

Hydropower has historically been Chile's single largest power source. Droughts, however, have periodically curtailed hydropower production, causing supply shortfalls and blackouts. In response, the Chilean government began in the 1990s to diversify its energy mix to become less reliant on hydropower, mainly by building natural gas-fired power plants [16].

Chile's energy mix relies mostly on oil (56%), secondly on renewables (22%), with biomass and hydro representing 16% and 6% respectively and natural gas and coal accounting for 11%. A basic characteristic of the Chilean energy context is the substantial share of domestically produced hydroelectricity in the country's primary energy mix, which amounted to 23,5% in 2007 [11]. A second characteristic of the Chilean energy sector is its dependence on fossil fuel imports. As Chile has few indigenous fossil fuel resources, except for some coal and about 1,65 Mtoe of domestic oil and gas production, mostly in the Magallanes Region, this dependency makes it vulnerable to supply interruptions and price volatility. In 2007, Chile imported close to 80% of its total primary energy supply in the form of oil, gas and coal [17]. The external dependency has been exacerbated due to concerns on security of natural gas supplies. Recent and frequent natural gas supply reductions via pipelines from Argentina, where "between 20% and 50% below contracted daily volumes" [18-20] had been supplied, indicated the severity of the situation, which was caused by the fact that the imports were concentrated almost exclusively on one supplier. This was the case until the arrival of liquefied natural gas (LNG) in July 2009. In 2007, crude oil imports (approximately 230.000 barrels/day) came from Brazil (25%), Ecuador (23%), Angola (20%) and Colombia (17%), while coal imports (5.8 million tonnes) came from four major sources: Colombia (34%), Indonesia (26%), Australia (22%) and Canada (11%) [11].

The main characteristics of the Chilean energy system can be summarised as follows [21]:

[1] Chile's 13 administrative regions are from north to south: I: Tarapaca, II: Antofagasta, III: Atacama, IV: Coquimbo, V: Valparaiso, RM: Region Metropolitana, VI: Libertador General Bernardo O'Higgins, VII: Maule, VIII: Biobio, IX: Araucania, X: Los Lagos, XI: Aisen del General Carlos Ibanez del Campo, XII: Magellanes y Antartica Chilena.

- The majority of the energy comes from a combination of large scale hydropower projects and imported fossil fuels.
- Strong dependency on foreign import, especially on fossil fuels (oil and natural gas).
- Consolidated market price-driven energy market, in the hands of several large private international firms.
- Energy consumption has increased at an average of 7% annually, with production barely keeping pace with the increase in demand.

As regards the percentage of CO_2 emissions per sector in Chile, the transport sector is responsible for most of Chile's CO_2 emissions (40%), followed by the energy sector (32%) and industrial sector (20%). The residential sector is responsible for 5% of the country's emissions, while the commercial, institutional and agriculture activities are responsible for about 3% [22].

2.2 The electrical power system in Chile

The Chilean electricity grid provides nearly 30% of the country's total energy supply. It is divided into three subsectors: generation, transmission and distribution, with a total of 31 generating companies, 5 transmission companies and 36 distribution companies [23]. In total, the electricity sector supplied the country with 56,8 thousand GWh in 2008 [13], while demand had a growing rate of 6,7% over the last 20 years [24]. In accordance with the economic activity of the country, 37% of electricity is consumed by the mining sector, followed by the industrial sector (31%), residential sector (17%) and the commercial and public sectors (14%) [24].

There is a high level of concentration within the Chilean electricity market. For example, in 2006, 89% of the public supply installed capacity of the Central Interconnected Grid was owned by three companies and their subsidiaries (Endesa, 51%; Colbún, 20%; AES Gener, 19%). A further 12 companies owned the remaining 10% [25].

Chile has four interconnected electric systems and several stand-alone power generation units with a total installed capacity of 13.114,3 MW in 2008 [17]. The four grids, which are shown in Figure 1, are: The Northern Interconnected System (Sistema Interconectado del Norte Grande - SING), the Central Interconnected System (Sistema Interconectado Central - SIC), the Aysén System (Sistema de Aysén) and the Magallanes System (Sistema de Magallanes).

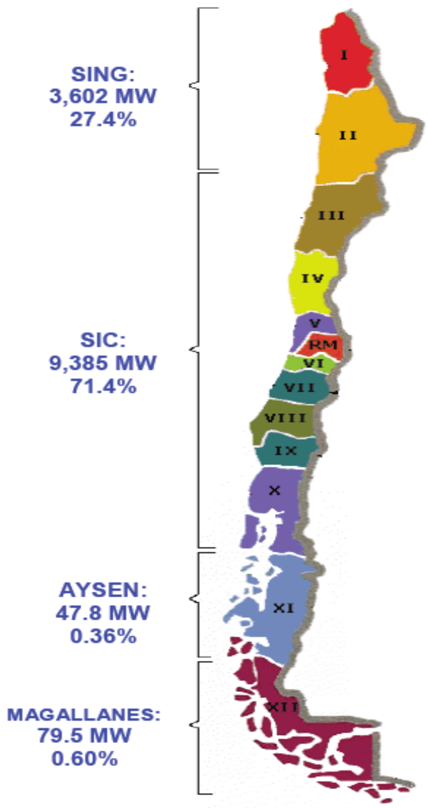

Figure 1. Installed electrical capacity per grid and region in 2008

Source: TIS 2009 [17]

There are two main interconnected systems, which together represent 99% of all the subsystems. The Central Interconnected Grid (SIC) provides 71.5% of the country's electricity and supplies over 90% of its population. The Northern Interconnected Grid (SING) provides 37,4 % of electricity and mainly supplies the copper mining industry. The remaining 1 % of installed capacity is shared between small subsystems in more isolated areas—the Aysén Grid and the Magallanes Grid. There is no interconnection between the subsystems [17].

Over the next 20 years, electricity demand in Chile is expected to increase at an annual rate of 5,4 % [13]. These demand projections, in conjunction with greater technological maturity, a fall in the cost of clean energy production, Chile's strong dependency on imported energy sources, price increases in fossil fuels, future restrictions on greenhouse gas emissions, and growing public opposition to large, conventional energy generating projects (large-scale hydroelectric and coal-fired power stations) are all elements that combine to create a significant window of opportunity to incorporate more renewable energy production into the Chilean energy grid.

2.3 RES in Chile

Chile has considerable potential for renewable energy production, especially from wind, solar, geothermal and marine sources. However, some 40% of electricity generated in Chile comes from imported fossil fuels and most of the rest from large-scale hydroelectric projects. According to the CNE [25], in December 2007, 3,1% of the installed capacity of the national electricity grid came from renewable energy sources, mainly biomass and, to a lesser extent, small-scale hydroelectric projects. Figure 2 shows the percentage of installed renewable energy capacity.

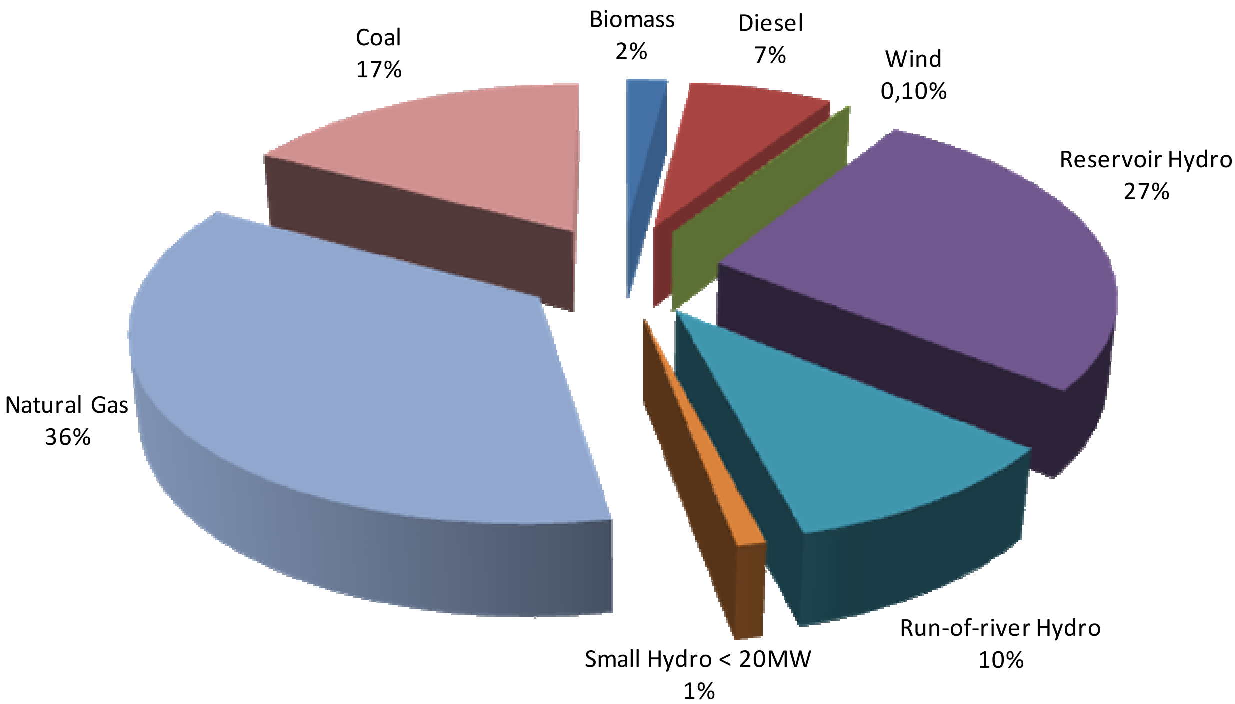

Figure 2. Installed electrical capacity per grid and region in 2008

Source: IISD 2010 [21]

In fact, Chile began recently to implement concrete measures to incorporate renewable energy production into the national grid. These include regulatory instruments, such as the 2008 Law No. 20.257 that establishes a minimum national quota of clean energy production (5% of commercialized energy from 2010 increasing to 10% by 2024), which is an indication of incipient support to the development of the sector [21]. Also, over the last couple of years, schemes have been developed to offer incentives and low interest loans to pre-investment in clean energy projects. In view of the above, and in accordance to Law No 600 (1974), numerous foreign direct investments have also been made in the clean energy sector over the last years, mostly by private companies, such as Endesa Eco (18 MW wind farm and 9 MW small-

scale hydro), Idener (4,7 MW small-scale hydro), SN Power (46 MW wind farm – CDM project) and Generadores Eólicos de Navarra (20 MW wind projects and 11MW small-scale hydro) [21].
Clean energy is a new, though an emerging market in Chile and it shows significant growth prospects. In fact, between 2007 and 2009 clean energy installed generating capacity (MW) in the SIC grid almost doubled, and according to CNE reached 4% of the total electricity grid supply in 2009 [25]. Moreover, in September 2009, the Environmental Impact Assessment System (Sistema de Evaluación de Impacto Ambiental-SEIA), as shown in figure 3, had records of 59 renewable energy projects, either approved or in progress, with a total generating capacity of over 1.700 MW, representing 17% of a total of 10.225 MW capacity, with the majority of projects involving wind power [21]. In addition, nearly all the country's electricity generation companies are developing or considering projects of this nature. New companies have already been set up with the sole purpose of starting such initiatives and further more hope to follow suit in the near future [11].

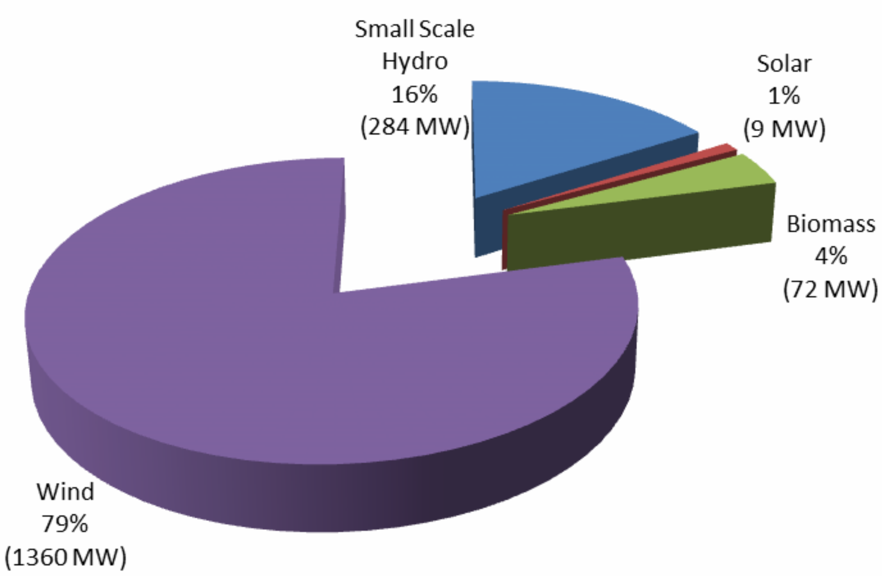

Figure 3. Investments in clean energy projects registered in the SEIA
Source: IISD 2010 [21]

The CNE has also drafted a Plan of Action on Climate Change (2008-2012) recommending the further installation of 8.244 MW installed capacity by 2019. Of this total, 783 MW, or 12,7% corresponds to clean energy production through wind power (5,3%), small-scale hydroelectric (2,2%) and geothermal (2%) [21]. This, however, is a recommendation which is not likely to be followed in the end.
It is important to emphasize that most future scenarios point towards greater integration of clean energy production. This derives from the fact that on one hand, the 2008 Law No. 20.257 establishes a quota for clean energy participation in the national grid of 5% of sales from 2010, rising to 10% by 2024 and on the other hand, in a strategic discussion on the Chilean electricity grid organized by a group of institutions, representatives of numerous national stakeholders formulated different scenarios for the electricity sector for 2030, all of which concluded in greater participation from clean energy production [25]. These scenarios, although predicting a high participation of clean energy in the energy mix involving electricity production, with percentages varying between 14% and 48% (wind, geothermal and solar energy are considered to provide the most significant contributions), still regard conventional energy, such as large-scale thermoelectricity, as the principal energy producing source, whose installation capacity (MW) will almost certainly increase, raising concern as to environmental consequences (GHG emissions etc.) [26].

3. CSP status in Chile

Solar technologies in Chile are generally hampered by the sometimes immature status of the technology and by country-specific economic circumstances, *e.g.*, fossil-fuel subsidies versus import tariffs on renewable energy hard ware. OECD [27] describes several issues that inhibit the deployment of solar thermal technologies. Although the paper does not address solar thermal technologies for electricity generation (*i.e*. CSP) most of the observations for solar thermal for heating technologies hold also for CSP in general. Besides the conventional technical barriers related to solar thermal energy, that in most cases and under an assumed set of circumstances (*i.e*. solar irradiance) are minimised and/or manageable, the economic, institutional, legal and cultural/behavioural barriers have proven to be the most persistent for the deployment of solar thermal technologies. Specifically in Chile, the barriers for clean and renewable energy production can be summarised as following [21, 28]:

- High economic risk of clean energy projects
- High market concentration impedes new stakeholder entry
- Failure to incorporate external factors and other impacts
- Access to financing
- Lack of knowledge and capacitated human capital
- Bad coordination between institutions
- Lack of adequate technical studies
- Network connection issues

In the North of Chile the Atacama Desert belongs to the world's driest deserts with a very strong solar irradiance of about 4.828 kcal/m^2 day. The CSP technology as such is highly compatible with conventional thermal power generation [29]. Using CSP as a hybrid option with conventional thermal power generation significantly reduces flexibility issues as opposed to stand-alone CSP units. However CSP is usually coupled to a thermal store when stand alone to give power round the clock. Given the fact that most of Chile's mining activities take place in the Northern Atacama region, where almost all power is generated via conventional (coal or natural gas fired) thermal units, the construction of CSP could potentially reduce the high level of energy import dependency of the country. In addition, there would be an increase in energy security of supply for mining companies and other power consumers in that region, since the reliance on the (currently) volatile natural gas supplies from Argentina can be reduced (depending on contractual off-take agreements) [30].

Given the size of the Atacama Desert and its high annual average solar radiation, CSP is likely to have significant potential in the Northern part of Chile. Several CSP initiatives and activities already take place in countries such as India, Morocco, Spain, Iran, South Africa, Jordan, Egypt, and the USA, mainly in and near desert regions where solar irradiance is generally high and the potential conflict with alternate land-usage is marginal. Chile, having realised the potential of CSP, has also taken interest in promoting this technology, both on public and private level. More specifically, the Ministry of Energy, having set aside an area of state-owned land, is about to open a public bidding for the construction and operation of a 10 MW CSP pilot plant in northern Chile. The tendering procedures are scheduled to begin in the first quarter of 2011 [31]. In addition, Chile's National Commission on Energy (CNE), together with the National Renewable Energy Laboratory (NREL) of USA and others, is establishing a new Renewable Energy and CSP Center to serve as a clearinghouse of information and analytic tools and leading source of expertise on renewable energy technologies and policies for Chile and, once it is up and running, for the region. NREL will be providing support for the CSP solicitation process and technical assistance for the Renewable Energy Center [32]. On a private level, the two companies GDF Suez and Solar Power Group have agreed to jointly develop a 5 MW CSP power plant which will supply superheated steam to the Mejillones coal-fired plant (150 MW) in the North of Chile. Through the project, the power plant will reduce its consumption of coal, decrease its CO_2 emissions and increase its fuel efficiency. The next step involves the finalisation of permits, with the intention for the pilot plant to be in operation in early 2012 [33].

4. CSP Potential in Chile: A simulation

In Chile, the significant amount of excess installed capacity in the Northern grid (SING) could be a major barrier for the deployment of CSP. Nevertheless, as domestic power demand is likely to grow and as an interconnection with the SIC grid is under consideration, additional CSP-based thermal capacity surely has a near-term deployment potential. An interconnection between the SING and SIC grids could also provide an additional daily flexibility advantage of CSP (day[2]) in combination with (stored) hydropower (night). Moreover, by increasing installed capacity and by increasing the load factor of the already installed capacity within the SING grid, Chile could potentially become a net exporter of

[2] Additional daily flexibility could be created via storage of excess heat produced during daytime for producing power at night via heat recovery, for example by underground storage of heat.

electricity within the region [11]. With respect to the case of Chile, there seem to be sufficient technical design options available for possible future CSP deployment.

Although given the fact that technology components of CSP plants are proven, large-scale deployment of the technology in its current business and political environment strongly depends on the specific economics, political will/ambition and finance. Despite the technical potential, there are specific elements that are currently not in place to allow for efficient and effective deployment of CSP. An integrated power grid interconnection design, aside from specific CSP plant design (either stand-alone or CSP-conventional thermal hybrids), is required to optimise the energetic, environmental and economic efficiency of new capacity additions, such as CSP [30]. Increasing the load factor of installed capacity in the SING grid combined with measures to address immediate short-term supply fluctuations are strong factors that shape the economic environment for potential CSP deployment in the Atacama region [16]. Several possible scenarios are possible in this respect. As natural gas supplies to the power plants connected to the SING grid remain volatile, domestic action to enhance security of supply could spur coal usage and/or in combination with CSP. This scenario would call for immediate and rapid action with regard to the development and deployment of CSP. The expected level and characteristics of idle capacity (mostly natural gas will stand idle) could function as an important barrier to economically viable development of CSP, especially when additional power demand centres (i.e. no interconnection with SIC grid) are not found [34]. The current situation (2010), however, is that large-scale CSP deployment is likely to be uneconomical without additional incentives mainly due to the overcapacity within the SING grid though there are good arguments for the infrastructure link between the networks [35]. The potential for distributed generation is also not clear.

In another plausible scenario, natural gas supplies are delivered on time and at contracted volumes. The appropriate policy and public action to such a scenario would provide some additional time for adequate design, development and deployment of CSP and other renewables and/or (additional) interconnections. Currently, it is expected however, that even if natural gas supplies are steady there still is a certain level of excess installed capacity available within the SING grid [11]. In this case again creating (additional) interconnections either national (SIC grid) or international (*i.e.* to Bolivia, Peru and/or Argentina) will prove to be an interesting course of action if one wants to deploy CSP.

The discussion above portrays some of the fundamental forces that determine the macro-economic environment for CSP technology implementation in the Atacama Desert. Although a CSP market chain does not exist within Chile, there are several market players currently active in the region (*i.e.* mining companies, power utilities, transmission system operators, industrial investors) that could perform various roles, either within the (future) CSP market chain and/or within the enabling environment [14]. Furthermore, given the current concentrated nature of power demand and supply within the SING grid, co-ordination and co-operation on the development and deployment of CSP in this region should be relatively straightforward as most market players can perform multiple functions, as power supplier, power demand, and/or investor. Supply chains are not complex as this is a thermal power technology.

After having set up a CSP market chain, where potential technology suppliers are also involved, the discussion is likely to focus on factors such as the dispatch regime, preferential grid access regime, guaranteed off-take and/or long-term supply contracts, exemptions and appropriate incentives (fiscal, rules and regulations, international emissions trading via CDM, *etc*.).

At the micro-level (*i.e.* individual project), there are several issues to be resolved before a large investment in a (new) technology is made. After the technology assessment (*i.e.* which technology is suitable?), the project design often focuses on technical and financial aspects (*i.e.* project lay-out, technical features, return on investment, CAPEX and expected OPEX, *etc*.). In most cases, such micro-economic issues are up to the scrutiny of the project developer and potential investor as it often involves commercially sensitive information [36]. One aspect of project design that is often still missing in the micro-economic environment is a project specific GHG-reduction potential calculation (see below for a project simulation).

CSP could also be used to displace part of the combustion of coal at a thermal power plant as a coal plant has a higher baseline emission level compared to a CSP plant. For this simulation, a stand-alone CSP plant is considered where the solar-based power generated mainly displaces natural gas and coal fired thermal power (grid emission factor) when supplying to the SING-grid. In order to illustrate the GHG reduction potential of a CSP plant in the Atacama desert it is estimated that the SING grid has a baseline emission factor of 1,5 of that of the SIC grid (596 tonnes of CO_2-eq. per GWh/y [=EFsic] x 1,5 = 894). Since no recent estimate from a PDD or recent documentation could be retrieved, this estimate is solely provided for illustration purposes. Nevertheless, given the fact that the SIC grid produces electricity based on about 50 % hydropower and 50 % conventional thermal power (mainly natural gas) and that the conventional thermal capacity in the SING grid (100 % thermal) has a large coal base, this estimated emission factor is fairly conservative.

Considering a stand alone CSP plant with a 64 MW capacity (similar to the proposed Nevada Solar One Plant[3]), which is contracted to supply 129GWh annually a rough estimate can be made of the GHG emission reductions that can be realised with this technology in Chile. If 129GWh of power produced from the SING grid is replaced by CSP generated power the estimated GHG emission reduction per annum (given the estimated emission factor) would amount up to 115 ktonnes of CO_2-eq. per annum (i.e. about 2,3 Mton of CO_2-eq. for a period of 20 years).

The data chosen for this project simulation do not exactly reflect the conditions in Chile where the solar irradiance, load factor, OPEX and CAPEX could be different and the total potential could be much higher. Nevertheless, this CSP plant example gives an idea of its GHG emission reduction potential. Assuming a linearly increasing project performance directly proportional to an increase in scale a 640 MW CSP plant is estimated to reduce up to about 1,15 Mt CO_2-eq. per annum.[4]

The potential power from CSP plant is very high as they can be modular, do not need much land and desert conditions give high insolation levels. For example, for the TRANS CSP project[5] it is expected that "Starting between 2020 and 2025 with a transfer of 60 TWh/y, solar electricity imports could subsequently be extended to 700 TWh/y in 2050. High solar irradiance in MENA and low transmission losses of 10-15 % will yield a competitive import solar electricity cost of around 0,05 €/kWh." In this fashion, CSP presents an opportunity for development in the south and for south-south technology transfer and trade (Table 1).

Table 1. Atacama CSP project simulation

Atacama CSP GHG reduction project	
Sector: Renewable Energy / Energy Efficiency Type of Project: Renewable Energy project Implementation Area: Chile, Atacama desert	
Assumptions / estimations	
SING Emission factor (EF_{SING})	894 CO_2-eq.
Stand alone CSP plant capacity	64 MW
Annual power supply	129 GWh
Project's lifetime	20 years
Results	
GHG emission reduction per year	115 kt CO_2-eq.
Total GHG emission reduction	2,3 Mt CO_2-eq.

5. Conclusion

This paper presented an overview analysis carried out in Chile in order to explore the potentials for GHG emission reductions by moving away from the currently proposed path of exploiting the new coal reserves in the south of the country.

Specifically, the analysis explores the use of CSP in the Atacama desert. Given that this would require investment in a connection between the north-south grids, which would have its own advantages, the potential for CSP with thermal storage would be very high and the GHG emission reductions for even just one plant of modest size are explored. This analysis, by its nature, was only an indication of what could be explored in country energy service strategies and indicates one direction in which engagement of country stakeholders could be obtained to be able to consider alternative low carbon futures.

To sum up, CSP constitute very promising alternative in order to deliver key energy services for the country of Chile and play a very important role in contributing to a developing country's SD. Particularly:

[3] http://www.renewable-energy-world.com/display_article/294300/121/ARCHI/none/none/1/CSP-lifts-off:-Nevada-Solar-One-comes-to-life/

[4] Increasing the size of a project could create several scale advantages in terms of construction costs, etc. which generally improves project economics.

[5] TRANS-CSP, 2006, http://www.dlr.de/tt/desktopdefault.aspx/tabid-2885/4422_read-6588/

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- CSP technology could serve as a tool for Chile to face the challenge to find additional energy supplies to fuel continuing economic growth and to replace the costly diesel oil that is now widely used in power stations that were built to run on gas from Argentina.
- This technology could help Chile to pursue diversification in terms of energy sources and suppliers to enhance energy security, through the active development of indigenous solar energy.
- The technology could also be a significant boost to RES growth in the country, help reduce GHG emissions in the future and contribute largely to meeting the goals of Law No. 20.257 regarding clean energy production.

Finally, despite the country's significant solar potential, CSP technology has up to date not been promoted as should, mainly due to gaps in stakeholders' awareness of the specific technology, as well as lack in domestic R&D and/or public/private investment.

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Charikleia Karakosta is a Chemical Engineer of the National Technical University of Athens (NTUA, 1999-2004) with a M.Sc. in Energy Production and Management (2004-2006). She is a PhD candidate at NTUA in Management & Decision Support Systems Laboratory, School of Electrical and Computer Engineering. Her research focuses on energy planning and modelling, decision support systems, energy management and policy, and climate change and Kyoto GHG emissions reduction Flexible mechanisms (CDM, JI and ET). She has participated in several research and consultancy projects in the fields of environmental policy, climate change, management and energy modelling. She has 27 scientific journal publications in international journals, 15 announcements in international conferences and articles published in magazines and books.
E-mail address: chkara@epu.ntua.gr

Charalampos Pappas is a is a Mechanical Engineer of the National Technical University of Athens (NTUA, 1999-2005) with a M.Sc. in Energy Production and Management (2005-2007). He is a PhD candidate at NTUA in Management & Decision Support Systems Laboratory, School of Electrical and Computer Engineering. He conducts research focusing mainly on areas of renewable energy, energy efficiency, energy management and policy, as well as decision support systems. He pas participated in research projects, such as "RES and RUE Stimulation in Mountainous - Agricultural Communities towards Sustainable Development" and has a chapter publication in a Greek book.
E-mail address: chpappas@epu.ntua.gr

John Psarras is Professor in the School of Electrical and Computer Engineering of National Technical University of Athens (NTUA) and Director of the Decision Support Systems (DSS) Laboratory. He has been the project director, project manager or senior researcher in numerous EC and national projects acquiring over twenty years experience in the areas of energy policy, national and regional energy planning, energy and environmental modelling, promotion of energy and environmental friendly technologies, energy management, decision support and monitoring systems. Currently, he is the Director of the EC project "Creation and Operation of the EU-GCC Clean Energy Network". He has more than 100 publications in international journals in the above mentioned related fields.
E-mail address: john@epu.ntua.gr