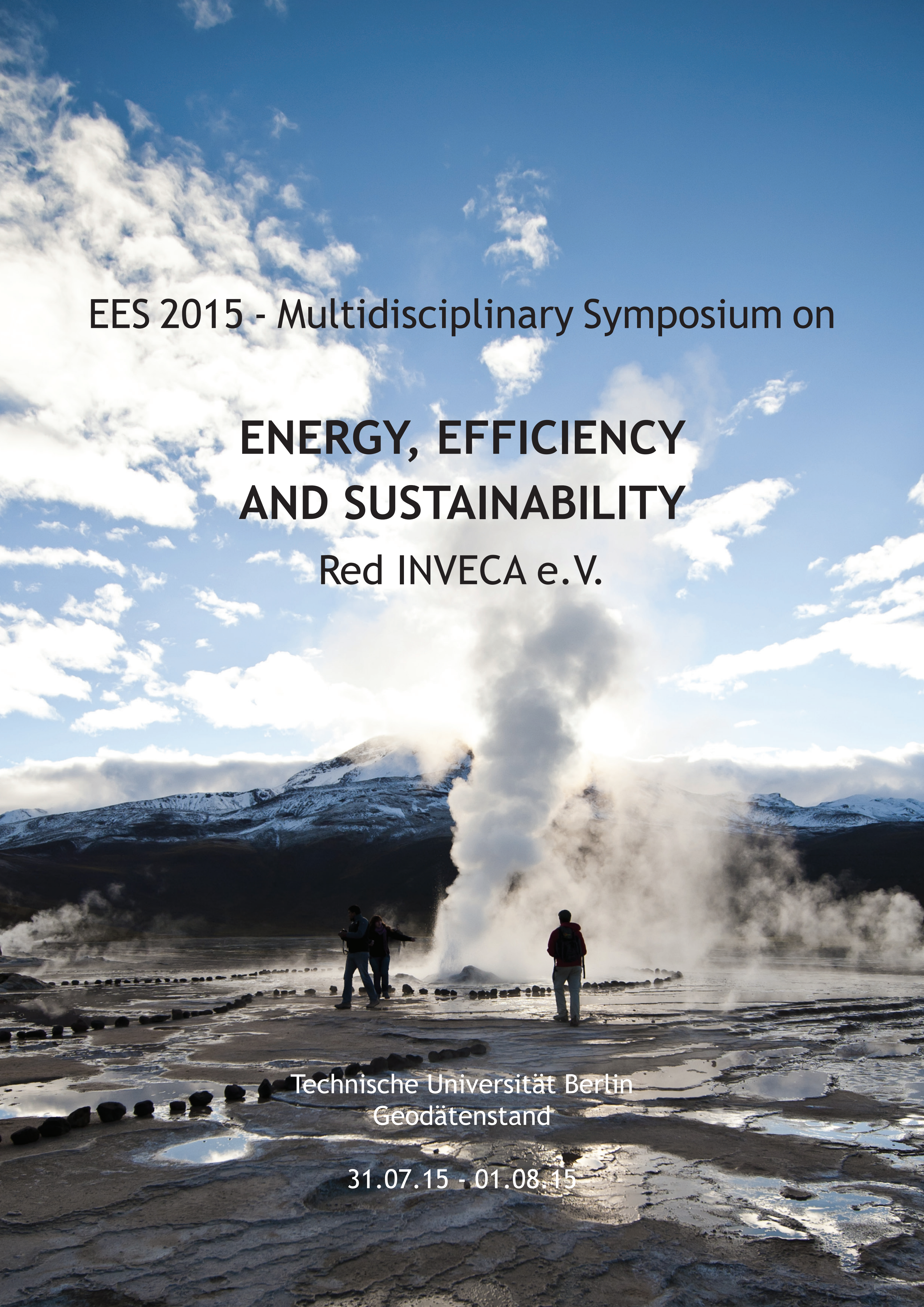

EES 2015 - Multidisciplinary Symposium on

ENERGY, EFFICIENCY AND SUSTAINABILITY

Red INVECA e.V.

Technische Universität Berlin
Geodätenstand

31.07.15 - 01.08.15

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PREFACE

The Network of Chilean Researchers in Germany, Red INVECA - www.redinveca.de organizes the Multidisciplinary Symposium on Energy, Efficiency and Sustainability - EES 2015. This event provides a scientific exchange forum for technical and social research approaches related to the development and use of energy technologies, energy efficiency and the environment as well as social, political and economic aspects.

The main purpose of this event is to bring together researchers, students and practitioners to discuss and share new advances and developments in fields related to generation technologies, efficient and sustainable use of energy, as well as socio-political and economic aspects and their impact on society. Red INVECA's main target audience is composed of researchers, professionals and Chilean students, who are developing research in Germany. At the same time, our event is aimed at the scientific community and authors in general were invited to participate by presenting technical works. EES 2015 has also aimed at offering a space for discussion on its own future and lay the foundation for future activities based on the debate and participation in this first event.

The organization of EES 2015 is led by Red INVECA with the kind support of the Embassy of Chile in Germany, Chile Global, Pro Chile, Ingeniare - Revista Chilena de Ingeniería, Technische Universität Berlin, and especially Barthen Ingeniería.

The Scientific Committee is composed by distinguished scientists of various disciplines and affiliations, to whom we are indebted for their hard work and continuous engagement: Dr. Alex Berg, Prof. Dr. Kristopher Chandía, Dr. Pablo Ferrada, Dr. Stefan Gehler, Dr. Jan Hagemann, Dr. Frank Marten, Dr. Ronny Martínez, Dr. Hugo Romero, Dr. Janosch Schobin, Dr. Thomas Stetz and Prof. Dr. Claudio Vásquez, who carefully rewieved the articles and provided useful comments and feedback.

The Organizing Committee is composed by Renato D'Alençon, Dr.-Ing. Darío Lafferte, Leopoldo Saavedra, Alejandro Harbach, Carolina Guerrero and Inés Soto-Reyes. Red INVECA e.V. provided wide support in the organization by means of its Directive Board and Communications Section.

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The Solar Platform of the Atacama Desert, Chile

Natural laboratory for in situ tests and applications of solar technologies

Pablo Ferrada*[1], Cristóbal Parrado[1], Aitor Marzo[1], Carlos Portillo[1], Edward Fuentealba[1]

ABSTRACT

In order to face Chile's energy needs, the creation of a research platform, the Solar Platform of the Atacama Desert (PSDA), has been proposed. The PSDA aims to lead the Antofagasta Region to become a national and international referent in applied research on solar energy technologies. It is expected for the middle term that companies settle the place with their technologies and that the Region turns to a technological hub promoting the use of solar energy in the country. In this paper, a report on the ongoing activities regarding the PSDA is given. The PSDA will be a platform for solar resource radiometry, photovoltaics and concentrated solar technologies. So far, the PSDA is in a first stage where a terrain of 100·80 m^2 has been defined to install instrumentation, and photovoltaics plants of different technologies. The global horizontal irradiance has reached values up to 1185 W/m^2 measured a day in summer 2014-2015. Solar GIS predicted an annual solar horizontal irradiation of 2578 kWh/m^2. A prediction of the energy yield, performance ratio and Levelized cost of energy was given for a mc-Si plant, which is currently under construction. These values resulted in 1810 kWh/kWp, 70% and 26.8 US$/kWh.

Keywords: Atacama Desert, Solar Resource, Solar Energy Technologies

I. INTRODUCTION

Chile is a long and narrow country in South America with approximately 17 million inhabitants. The population concentrates in the central part of its territory. In the capital live more than one third of the population. The import of primary energy and electricity in Chile is 60 % having significantly increased in the last decade [1]. This energy is mainly produced from fossil fuels such as coal, petcoke and gas (liquefied natural gas, LNG). The mining industry has large needs for electricity and heat (e.g. 90 % of the Northern electric system (SING). A constraint for metal mining and smelting operations is cost of electricity and scarce water. It is in the north of Chile where the mining industry mainly consumes energy. This fact coincides with the existence of the Atacama Desert, the driest desert in the world. Thus, a unique opportunity for the massive use of solar energy is presented.

The Atacama Desert corresponds to a land area comprising 1000 km from 30ºS to 20ºS along the Pacific coast with a surface close to 105,000 km^2 occupying north of Chile, south of Peru, southwest of Bolivia and northwest of Argentina. Mean temperatures keep between 10 and 20 ºC for winter and 20 to 30 ºC for summer. It is characterized by an extreme aridity and scarce rainfall. Maximum air temperature maintains below 38 ºC [2].

According to published studies regarding the solar radiation [3], the Atacama Desert exhibits the highest solar irradiation values in the world. DNI values of 3800 kWh/m^2 are reached only in the Atacama Desert.

II. A SOLAR PLATFORM

The implementation of solar energy technologies has grown in the last years with the construction of new commercial photovoltaic (PV), concentrated solar power (CSP) plants and solar thermal installations. The operation of these solar facilities requires the design, mounting, monitoring, inspection and maintenance. An important issue arises from the interaction between the technology and the environment. Thus, a scientific study is required to ensure lifetime and correct functioning.

In order to provide the conditions and a place to perform applied research on solar energy, implement PV and CSP plants, and to develop solar technologies, the Solar Platform of the Atacama Desert, PSDA, was started. The PSDA is located 80 km to the southeast from Antofagasta at an altitude of 1100 m above sea level (Fig. 1).

Fig. 1: Location of the PSDA.

The Antofagasta Center for Energetic Development (CDEA, see http://www.cdeaua.cl/), as part of the University of Antofagasta (UA), is leading the PSDA project. So far, the first stage is under implementation. Further research topics, which will be dealt at the PSDA, are been carried out in the coastal zone of the Atacama

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Desert. One of them is the quantification of the solar resource and the monitoring of PV plants.

The CDEA keep a strong relation with the Solar Energy Research Center (SERC). The UA is part of SERC (see www.sercchile.cl). SERC aligns with the goals of the PSDA to produce a deep change in Chile with use of solar energy [4].

A. Concept of the PSDA

This project is within a global initiative that aims to establish a R&D platform in the 80 hectares obtained in concession by the University of Antofagasta (UA) and the regional government, the Atacama Platform of the Atacama Desert. The idea of the PSDA is to attract developers by giving technological conditions and basic services, consisting of office infrastructure, accommodation, meeting rooms, basic laboratory for tests and analysis, security services, access to technical and professionals (associated to CDEA), to facilitate the decision of technological developer partner and settle at the PSDA. Currently, the PSDA is inserted as the in-situ laboratory for the development of solar technologies within the Solar Strategic Program driven by the Chilean government.

The main goal is to establish a research facility dedicated to solar energy in the Atacama Desert. The PSDA is to become the basis for the massive introduction of solar energy into the Chilean energy matrix and a mainstay to bring Chile to a world-class technological hub. The PSDA can provide Chile the instance to develop and to export expertise regarding solar technologies and applications. The contribution can be regional with a long term economic diversification of a business related to solar energy in regional and national context.

B. Business model

The PSDA is a non-profit project. The business model in Fig. 2 can be expressed as Canvas Business Model where the clients are Chilean citizens, national and international institutions, universities and external research centers.

C. Research tasks and results

A number of tasks have been defined in three areas: Radiometry, PV and CSP. With regard to radiometry, four groups are recognized [5]:

- Provide an accurate database by checking instrumentation and measurement, and calibration task;
- Atmospheric and solar resource studies;
- Optical characterisation of surfaces;
- Develop or improve instrumentation with different applications (e.g. to measure the atmosphere attenuation of solar radiation in solar tower plants, or instrumentation to measure surface temperatures in solar furnaces [6]).

In the area of PV, first tasks have to do with the monitoring and evaluation of PV plants. For this purpose is very important to accurately measure the solar radiation and recalls the importance of the radiometry area.

PV plants of up to 10 kWp have been studied for a period up to 3 years. So far, most of them are installed at the coastal zone of the Atacama Desert. Another place where PV plants have been monitored is inside a mining company. Finally, plants installed in the Andean Plateau (San Pedro de Atacama) have been also studied.

With regard to these investigations with PV plants, the performance ratio affected by dust accumulation (soiling) and temperature has been studied in [7]. Initially, these results correspond to the coastal zone of the Atacama Desert where humidity is present. This effect can be suppressed to a large extent with PV plants installed at the PSDA. Another investigation gave values for the cost of electricity (Levelized Cost of Energy, LCoE) of plants also at the coastal zone of the Desert [8]. Such a studies will be performed at the PSDA as well and also the causes of performance degradation. Thus, further tasks include:

- Precise inspection of PV plants with IV curve tracers.
- Characterization of optical properties of PV glass.
- Determination of the physical-chemical properties of the accumulated dust on PV modules.
- Inspection o PV plants with Current-Voltage IV tracers, IR cameras and electroluminescence.
- Study of bifacial PV modules
- Grid integration

One of the main challenges for the operation of solar plants in northern Chile is the load profile. Its shape is mostly flat requiring an accurate study. PV and CSP can be combined with storage systems. An investigation of different scenarios combining PV with wind power in the North Interconnected (SING) and Central Interconnected System (SIC) did not show a real advantage. The problem may reside in the flat load profile. In this study, it was pointed out that PV plants alone can achieve a high penetration [9]. Accordingly, the development and implementation of storage systems is needed.

Consequently, PV and CSP plants have a fundamental role in the PSDA. For CSP, according to several researches, the Atacama Desert has one of the highest Direct Normal Irradiation (DNI) in the world [10]. This fact converts CSP plants in optimal candidates to test the technology on PSDA. Calculation showed LCoE values around 19 cUS$/kWh when the system has a gas-fired back up and thermal energy storage (TES) [11]. An economic analysis to project the LCoE between 2014 and 2050 of a 50 MW CSP plant with five different salt compositions of for TES was performed. The simulation was made for two different scenarios, IEA BLUE Map and Roadmap Scenario, showing results compared to the leaders of CSP market USA and Spain. The calculations of LCoE pear each combination of salt are almost 47% and 30% lowest than USA and Spain respectively [12]. In another research the LCoE for three different situations in Atacama Desert was estimated: A conventional PV plant with 8 hours of operation, conventional CSP plant with 15 hours of TES and for a hybrid plant with 6 hours of PV operation and 18 hours of CSP operation [13]. Calculations are presented until 2050, and for the two mentioned scenarios. The PV+CSP plant has a range between 14.69 cUS$/kWh for 2014 and 7.74 cUS$/kWh for 2050. According to Fraunhofer, these values are highly competitives with the LCoE of the leaders in the Solar Market [14].These facts convert to Chile in a country with a great potential to the Solar Energetic Market and contribute to the development of new Chilean Energy Policy with view to the 2050.

In early 2015, CDEA begins the collaborations with the Institute Universitaire des Systèmes Thermiques Industriels (IUSTI) with the purpose of research in solar-thermal systems. IUSTI it is a joint research center of Aix-Marseille Universtité and the Centre National de la Recherché Scientifique (CNRS). The researches areas of IUSTI are related with heat transfer, physical transfer, flows mechanics, multiphase and reactive, shockwaves and detonations. Actually, the two centers are working together in the computational simulation of residencial solar-thermal systems. The first step in was to measure the performance of Solar Collectors in typical residential buildings in Marseille. In order to quantify the contribution of solar energy to the energetic residential systems, two outputs are proposed, LCoE and $C0_2$ emissions. It was measured the most sensitives initial parameters according the proposed outputs, obtaining sensitives values for regulation and control parameters. The discount rate is other influence parameter in the LCoE calculation. The second part will start with the measure of the performance of the current model in a different location. The new location corresponds to the PSDA and it is expected to obtain lower LCoE values according to the high DNI in the place. A bigger amount of solar energy will contribute to rise the saved $C0_2$ amount and look for the optimization of these systems. The third part will be the construction of a scale prototype in the PSDA with the purpose of compare the results of the computational model with the experimental results. The importance of the residential solar systems has attracted the attention of new future collaborators. The School of Engineering & the Built Environment of Edinburgh Napier University was present in the current research, assisting to several meetings in order to made contributions to the optimization of the systems. The high knowledge of the group it has opened the possibility to diversify the solar research in the PSDA, improving a new field of Building Efficiency in the CDEA.

III. PV PLANT EVALUATION

The worldwide indicator to evaluate PV systems is the performance ratio (*PR*). It defines how effectively a PV system converts solar radiation into electricity considering the solar resource availability and relating to the nominal

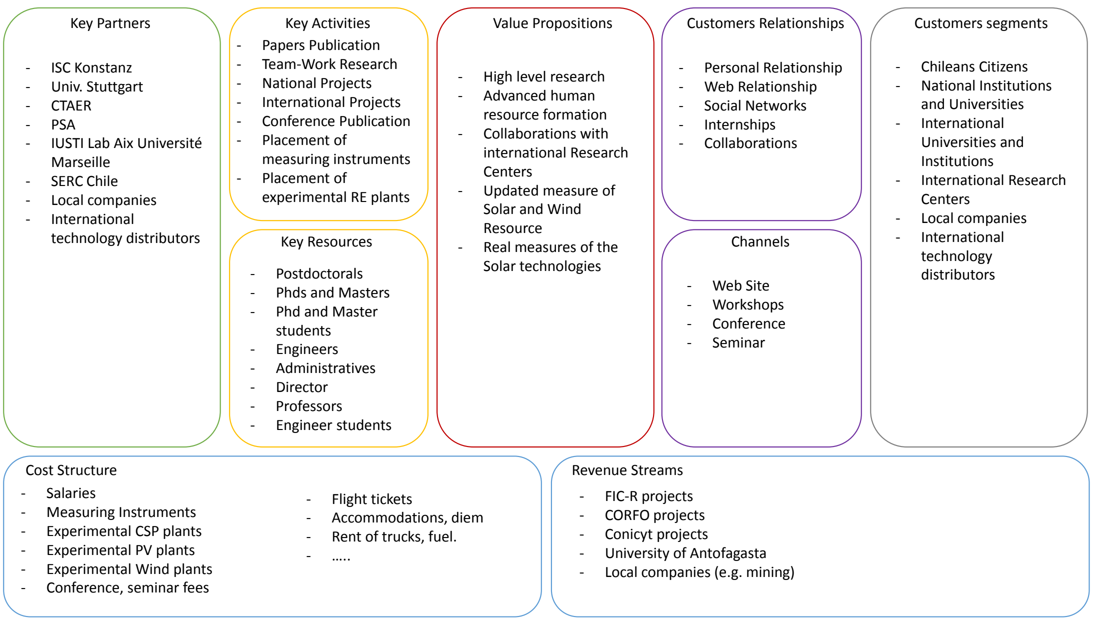

Fig. 2: Business model.

(name plate) power [15] According to international standards [16], *PR* is calculated as the ratio of the energy yield (Y_f) to the reference yield (Y_r) as equation 1 shows. The Y_f is obtained by dividing the energy produced by the modules at the AC side in kWh to the power of the PV system (power at standard testing conditions, P_{STC} in kWp). Finally, the Y_r is the quotient between the irradiation *H* at the plane of array (H_{POA}) in kWh/m^2 and the irradiance at STC (G_{STC}), i.e 1 kW/m^2.

$$PR = \frac{Y_f}{Y_r} = \frac{E_{AC}}{P_{STC}} \Big/ \frac{H_{POA}}{G_{STC}} \tag{1}$$

The Levelized cost of energy is another instrument to evaluate an energy technology and to compare it with other sources. It is equal to the sum of all costs during the lifetime of the project divided by the units of energy produced during its lifetime [17]. Mathematically it is calculated as the quotient of the total cost by the total energy produced as Eq. 2 shows:

$$\text{LCoE} = \frac{\text{Total Life Cycle Cost}}{\textit{Total}\ \text{Lifetime Energy Production}} \tag{2}$$

The LCoE can be further expressed as follows:

$$\text{LCoE} = \frac{\sum_{t=0}^{T} \frac{C_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{E_t}{(1+r)^t}} \tag{3}$$

In Eq. 3, C_t is the net annual cost of the project, which includes the investment, operation and maintenance (O&M) costs paid along the project [18-20]. E_t is the energy generated in a given year. In the denominator *r* is the discount rate, *t* stands for the year number. Finally, *T* is the life of the project (in years).

Currently, there are two PV plats under construction at the PSDA. A 7.22 kWp mc-Si based and an 8 kWp CdTe thin film plant. In this work, results regarding the solar resource measured at the place of the PSDA were used to estimate the energy production and the LCoE, only for the mc-Si plant. For the LCoE calculation incentives can be included [18,21]. However, in this work, they were not taken into account.

IV. RESULTS

A PV plant based on mc-Si modules with a total capacity of P_{STC}=7.22 kWp installed at 20º and a monitoring system was used to estimate the energy production, performance ratio and LCoE.

A. Solar resource and ambient temperature

The daily irradiance and ambient temperature for the PSDA were obtained from Solar GIS data and are shown in Fig. 3. While for summer the average of GHI was 8.5 kWh/m^2, for winter it was 5.5 kWh/m^2. Remarkably, there were many days in summer at which GHI could reach 9 kWh/m^2. Conversely, minimum values in winter were still above 4.5 kWh/m^2. Taking the sum, the cumulated GHI of a typical year was *H*=2578 kWh/m^2. The mean ambient temperature (T_{amb}) was 19ºC.

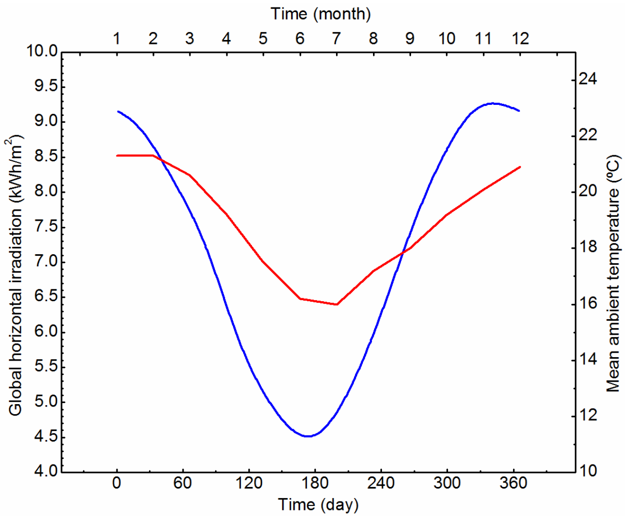

Fig. 3: Daily GHI and mean T_{amb} at the PSDA.

B. Energy yield and LCoE

The energy produced was obtained using Eq. 1 knowing the yearly irradiation and P_{STC}. The used performance ratio was the maximum possible value for these modules and was obtained from an online catalogue [22].

Taking into account the yearly degradation (*d* = 1%, given by the manufacturer) for the power output of the modules, the maximum, mean and minimum energy yield, Y_f, was 1865 kWh/kWp, 1924 kWh/kWp and 1982 kWh/kWp. Using these values, the annual performance ratio ranged between 72.4% and 76.9% with a mean value of 74.6%. Note that for the estimation, no soiling effects have been taken into account.

For the LCoE calculation, PV modules, inverters, structures, sensors (temperature, irradiance and anemometer), protections and cables were included. As the total costs and energy values are known the LCoE for a 20 year-period resulted in 25.2 US$/kWh (1 US$=647.50 CLP).

In case soiling effects are considered, dust accumulation may produce a decrease in the solar radiation available for conversion producing a decrease in the generated current. Moreover, temperature may also affect the output voltage. Both effect may result in a performance ratio reduction and thus, a lower energy yield [7,8]. In those investigations, the *PR* value changed at a rate up to -4.2 %/month for a coastal desert climate.

Recalculating the energy yield, performance ratio and LCoE, it came out that their values become Y_f=1812 ± 55 kWh/kWp, *PR*=70.3 ± 2 % and LCoE=26.8 US$/kWh (1 US$=647.50 CLP).

V. CONCLUSIONS

In this work the Solar Platform of the Atacama Desert (PSDA) was presented in the framework of research performed at the university sector and research canters. The first stage of the PSDA has taken shape and has the main goal of establishing a research facility dedicated to solar energy in the Atacama Desert. It is foreseen that the PSDA becomes a basis for the massive introduction of solar energy into the Chilean energy matrix. It aims to attract developers by giving technological conditions and basic services which facilitate the decision of technological developers.

A photovoltaic plant based on multicrystalline silicon modules was used to predict the energy yield, performance ratio and Levelized cost of energy. Based on Solar GIS data, the annual global horizontal irradiation gave 2578 kWh/m^2. The prediction was carried out, first for an ideal case without performance degradation due to soiling, and second, considering 4%/month degradation. An energy yield of 1810 kWh/kWp, performance ratio of 70% and a Levelized cost of energy of 26.8 US$/kWh were obtained for the second case with soiling.

The values regarding the solar resource demonstrate the excellent conditions for the implementation of solar technologies with the potential of reducing the Levelized cost of electricity.

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Computational Fluid Dynamics modeling for aerodynamic and thermal development in the design of solar car ''Intikallpa IV''

for optimal performance and energy sustainability in race.

D. Garrido[1] P. Pacheco[1] J. Leger[1] E. Reilich[1] A. Abarcia[2]

ABSTRACT

Currently the complete development of a vehicle requires a deep technological knowledge in different areas, where the constant search for an optimal design and even more the need the use of clean and sustainable energy, become one. The iterative study using advanced calculation tools and numerical methods ranging from aerodynamic design and a cooling system for the lithium batteries until the use of composite materials in the chassis and fairing of the 'Intikallpa 4' solar car for its evolution over previous versions. All this leads to find a point where all these paths converge, resulting an efficient, reliable and lightweight car with high mechanical performance for their next race in the World Solar Challenge 2015, Australia. In order to achieve these objectives, the streamlines, pressures, turbulent kinetic energy (k) and the drag (C_d) of the aerodynamic on the car are simulated. Also are shown the temperature profile, flow velocity and energy density ($Wh*kg^{-1}$) for a cooling system of forced convection into the battery box. Finally, is subjected to an impact study 4G the carbon fiber chassis and aluminium suspension to ensure high performance with minimal weight for the solar car. These works produced a significant decrease of 42% in the frontal area, a 35% of weight and 44% of temperature on the car, achieving an improvement over the drag force ($A* C_d$), energy consume and thermal efficiency (η vs. T), respectively.

Keywords: Solar car, CFD, aerodynamic, lithium batteries, composite materials, WSC2015.

I. INTRODUCTION

Environmental pollution generated by the majority of vehicles is fairly high and many people have begun to notice a deterioration in his health due to the quality of the air they breathe. For these reasons, the transport-related research in recent decades, tend to focus on issues such as clean power generation, electric traction, decrease the use of fossil fuels, the improved of vehicle efficiency, new means of transport, to enable thus an optimum performance and the generation of zero emissions [1]. In this context it has been founded the WSC (Bridgestone World Solar Challenge), meeting since its creation to solar cars around the world to test these new technologies.

In this context it has been founded the WSC, meeting since its creation solar cars throughout the world. The career objective is to cross Australia from north to south, crossing a distance of 3,000 km, using only a battery bank with some initial load specified in the regulations of the event and the energy provided by the sun during the duration of the race. Due to the length of this and the energy restrictions, the teams needed a strategic decision about how much energy they use, how and where, during the event, making the best use of the means available. It is natural then, an optimization and control of resources is planned [2-3]. It is necessary, on the other hand, have an adequate modeling [4-6] of the vehicle and its components, in order to estimate and predict the use of the energy.

However, it is important to emphasize the everyday applications of these technologies. Today humanity in general is also facing the challenge of how to use increasingly efficient energy resources. Germany is one of the three countries announced the abandonment of nuclear energy, which today accounts for over 20% of its Matrix and hopes that by 2020 35% of its energy from renewable sources, while for 2050 provides that this percentage reaches 80%.

The present work describes the evolution in the reduction of energy consumption solar car design Intikallpa for its three versions (Figure 1), in addition to improving energy deep in his fourth and final version.

Figure 5. IK1 (Intikallpa I), IK2 (Intikallpa II) and IK3 (Intikallpa III). 2011, 2012 and 2014, respectively.

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II. ANALYSIS

A. Equations

The way to address the problem, start by modeling the physical phenomena that determine energy efficiency and dynamic performance in the vehicle in order to iterate on the design and attack the main centers of consumption.
The vehicle while traveling is interacting with the environment. In this road where there are slopes, own the natural terrain of the geographical area has resulted in the appearance of a force of gravitational origin called gradient force, conservative character and given by equation (1), where α represents the inclination of the vehicle, M is the mass of the vehicle and g the acceleration of gravity.
Furthermore, all means of transportation, just the fact of being immersed in a gaseous atmosphere and not in a vacuum, suffers drag, given by equation (2) as a result of differences in pressures on the fairing of the vehicle. It is here where each team tries to minimize through careful design, which becomes important at high speeds, so that should be considered. Where C_D represents the drag coefficient of the vehicle, highly influenced by its fairing, A_f its frontal area and v is its speed.
Finally, the wheels suffer a deformation due to the temperature and possible defects in its pressurization in contact with the imperfect ground. This will give rise to rolling force, particularly important at low speeds and always present when the vehicle is in motion. Their expression is given by equation (3), where is the coefficient f_r particular each tire model rolling. Finally the product $Mgcos(\alpha)$ is observed, indicating the dependence of this force normal to the ground by driving.

$$F_g = Mgsen(\alpha) \quad (1)$$

$$F_{ae} = \frac{1}{2}\rho A_f C_D v^2 \quad (2)$$

$$F_r = Mgf_r \cos(\alpha) \quad (3)$$

The sum of these three resistive forces given by equation (4) indicates the energy consumption in the vehicle to a constant speed, along the entire route. Thus, each day of competition the consumption is estimated to safeguard the energy captured.

$$F_R = F_r + F_g + F_{ae} \quad (4)$$

B. The route

The constant presence of external perturbations on the WSC route (Figure 2) becomes more attractive resolving this problem. These can be: orographic, mechanical, human origin and climate, responsible for the lack of energy resources, so appreciated by vehicle performance.

Figure 2. World Solar Challenge 2015 Route.

Figure 3 and 4 shown the elevation and slope of the route. It is one of the factors on energy consumption given by (1) and (3).

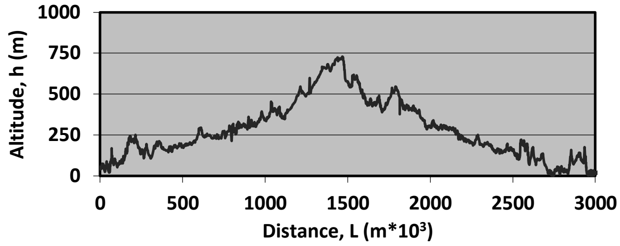

Figure 3. Elevation profile on the WSC route.

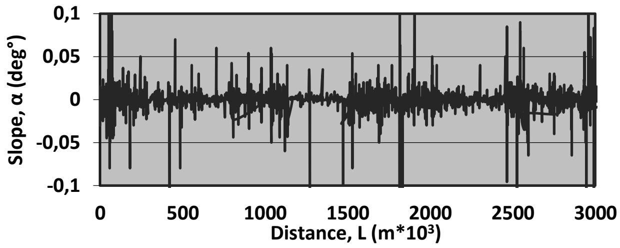

Figure 4. Slopes on the WSC route.

C. Car design

The design for its part, each year must be technically justified to analyze the conception of its construction. Each vehicle parameter is studied to improve the performance of the previous model. Techniques of CAD, CAE and CAM are used with better expertise, achieving this year the model 'Intikallpa 4' (Figure 5). Where the computational modeling of a virtual wind tunnel until use of composite materials is investigated in developing the prototype.

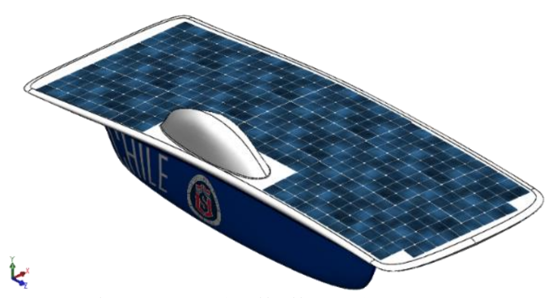

Figure 5. Solar car IK4 (Intikallpa IV).

D. CFD

CAE (Computer Aided Engineering) tools and FVM (Finite Volume Method) are used for calculate the new design of 'Intikallpa 4' and every line in the car is modeled to produce less drag (C_d) against the wind. Other factor of energy consumption indicated in ec. (2).

Thus, a virtual wind tunnel has been used to calculate the so precious aerodynamic coefficients to the car, which has determined an efficient size tunnel of 13 times the length of the car, 3 times higher and 3 times the width, so as not to affect the results by the associated boundary condition at the exit of the tunnel. The boundary conditions used in all cases shown in Figure 6.

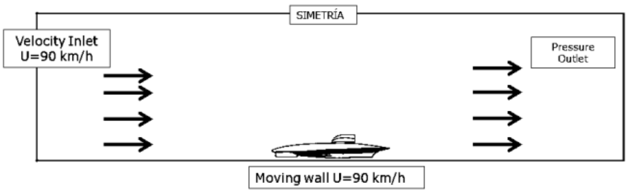

Figure 6. Boundary conditions in CFD wind tunnel.

The aerodynamic phenomenon for 3D modeling is considered an incompressible turbulent flow and isothermal parameters. The equations of fluid dynamics represented in the continuity equations (5), momentum (6), turbulent kinetic energy k (7) and speed of dissipation energy ε (8), are computed using Ansys fluent software v.15, the finite volume method (FVM) and the model of turbulence $k-\varepsilon$ Realizable.

$$\nabla \cdot \vec{v} = 0 \quad (5)$$

$$\rho\left[\frac{\partial \vec{v}}{\partial t} + \vec{v}\cdot\nabla\vec{v}\right] = -\nabla P + (\mu+\mu_t)\nabla^2\vec{v} + \rho\vec{g} \quad (6)$$

$$\rho\frac{Dk}{Dt} = \frac{\partial y}{\partial x}\left[(\mu + \frac{\mu_t}{\sigma_k})\right] + \mu_t S^2 - \rho\varepsilon \quad (7)$$

$$\rho\frac{D\varepsilon}{Dt} = \frac{\partial}{\partial x_j}\left[(\mu + \frac{\mu_t}{\sigma_\varepsilon})\frac{\partial\varepsilon}{\partial x_j}\right] + C_1 S\rho\varepsilon - C_2\frac{\rho\varepsilon^2}{k+\sqrt{(v\varepsilon)}} \quad (8)$$

The mesh used have 45 million nodes, it worked with the ICEM module size and different densities of elements (Figure 7).

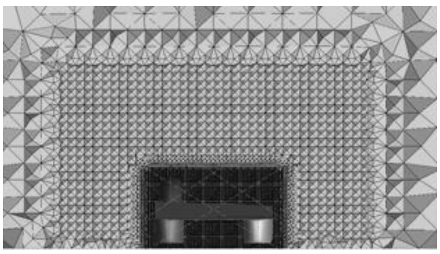

Figure 7. CFD mesh for IK3.

E. Battery System

Advanced technologies for the batteries are used (Figure 8), achieving the higher energy density, with a nominal capacity of 5600 mAh and 3.7 V in 83 grs, where get stored more energy in less weight, essential for good results in the solar challenge.

Moreover to these they are thermally modeled using a forced convection system the same outside air, thereby cooling the batteries without the need for fans and extra energy costs.

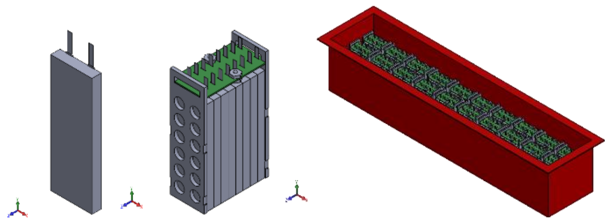

Figure 8. Cell, Module and Battery box on the IK4.

F. Mechanical Parts

The double wishbone suspension aluminum 7050-t6 (Figure 9) Is modeled using CAE tools and FEM (Finite element method), in an impact event 4G or bump on the road, ensuring remain in competition.

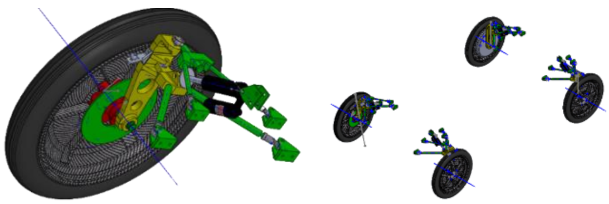

Figure 9. Suspension double Wishboneof of aluminium in IK4.

G. Composite Materials

Finally the use of composite materials and incorporating fuselage to the chassis, make further decrease the weight of the car, ensuring the integrity of the driver, in a collision event.

Early in 2011, the first design (IK1) was performed with a chassis of steel chrome-molybdenum (Figure 10b) resulting a vehicle with a weight of 230 (kg). Then through of the research was made a chassis entirely of composite materials and the use of carbon fiber was used, obtaining a vehicle with a total weight of 150 (kg) (Figure 10a).

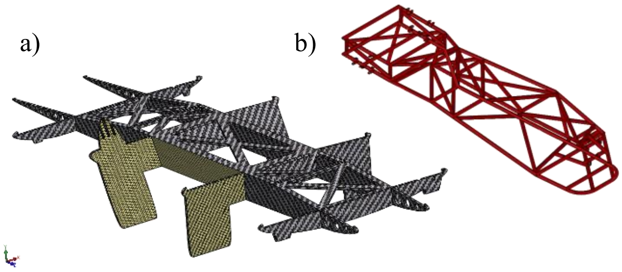

Figure 10. IK4 Chassis of carbon and aramid fiber (left) and IK1 Chassis of 4130 Alloy steel (right).

III. RESULTS

The use of CAE tools and lightweight materials such as aluminum alloys for mechanical parts, leading to lower an initial proposal for the total weight of the IK1 suspension of 45 (kg). It achieving an efficient design of 30 (kg) in components for the IK4 case, as shown in Figure 11.

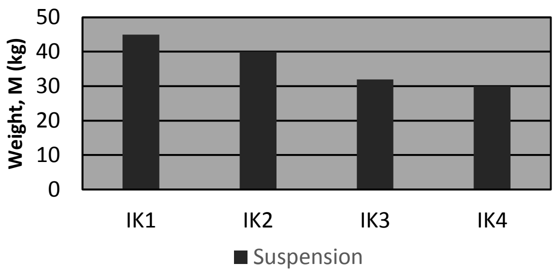

Figure 11. Weight of suspension each solar car prototype.

The design presents a safety factor of 3 for a study of the 4G about rotational axis. This for a front, side and normal force (Combined load). The study revealed the needs for ribs in the design to increase the safety factor against a side impact without increasing weight significantly.

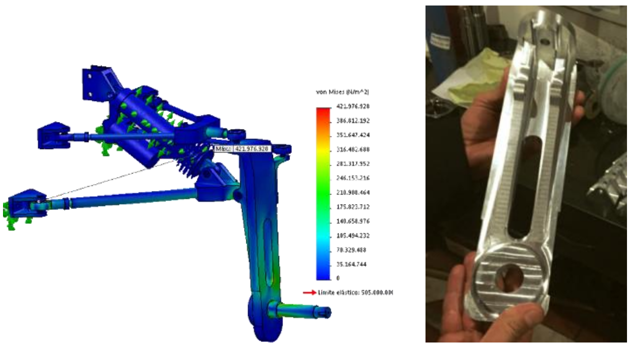

Figure 12. IK4 suspension.

Meanwhile, the use of CFD shows the presence of vortices on the vehicle, thereby evidencing possible recirculation of air, which would be negative for the energy consumption and performance in competition. This also leads to decrease spatially the design and the components into the car, thus reducing the frontal area in the design, and well vortex centers (Figure 13 and 14).

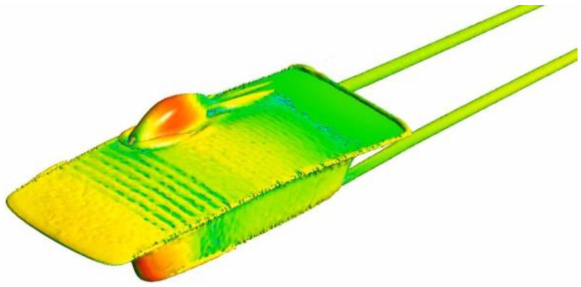

Figure 13. Isosurface of centers vortices for IK4.

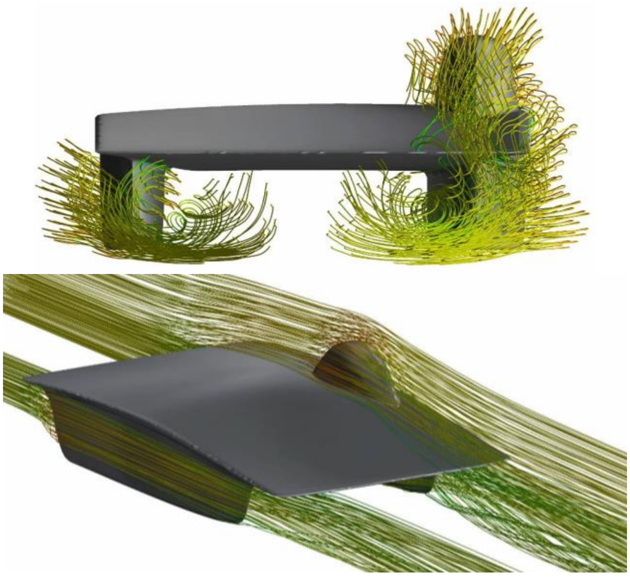

Figure 14. Streamline on IK4.

All study leads to the calculation of the values of the parameters used in the equations (1-4) for calculating the energy consumption in each vehicle, presented in Table 1.

Table 1. Values parameters used in the design of each solar car model.

Parameter	Model			
	IK1	IK2	IK3	IK4
Total mass (car + driver)	310 (kg)	264 (kg)	245 (kg)	230 (kg)
Drag coefficient	0.16	0.14	0.082	0.086
Frontal area	1.88	1.82	1.42	1.1
Rolling coefficient	0.03	2.5×10^{-3}	0.02	$<3 \times 10^{-3}$
Number of wheels	3	3	4	4

Below (Figure 15) the power curve v/s speed for each model is shown, assuming a flat road without elevations.

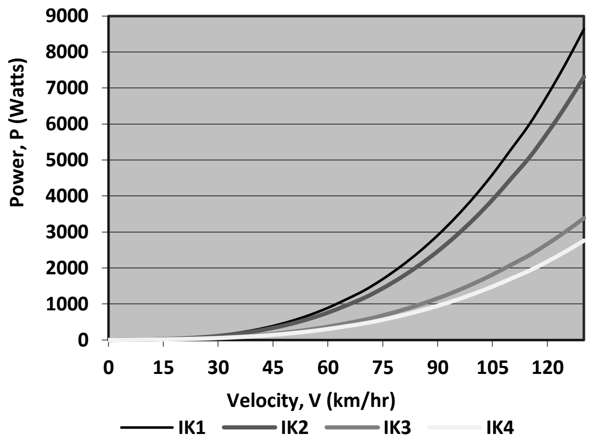

Figure 15. Curve of Power v/s velocity.

In turn, the energy consumed in the actual road (WSC) would be given by Figure 16, this for the four prototypes. Thus showing the lowest energy consumption for IK4.

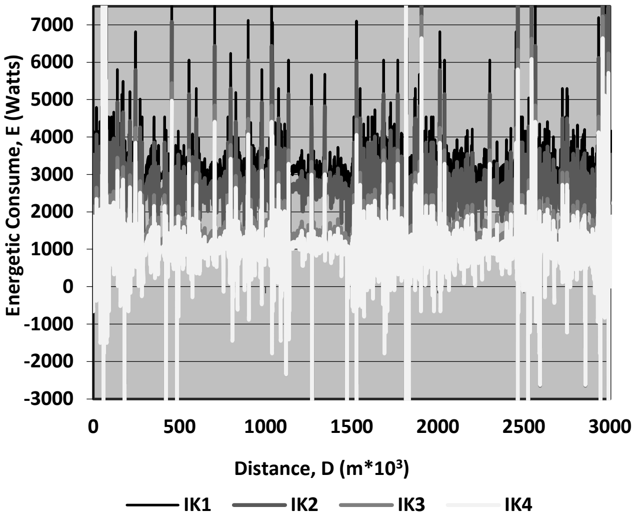

Figure 16. Energetic Consume in WSC route for all solar car prototypes.

It is shown in Figure 17, the energy distribution relevant to the route WSC, showing the influence of 85% for the drag coefficient on the total value of energy consumption.

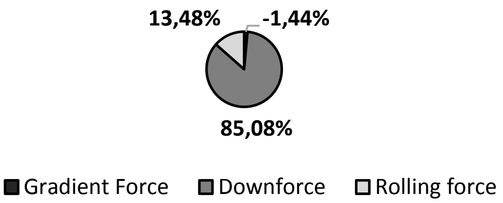

Figure 17. Distribution of Resistive forces in IK4 for WSC route.

Finally, the thermal performance of the system of forced convection over the batteries are presented. Where there is excessive operating temperatures above 40 ° C are shown.

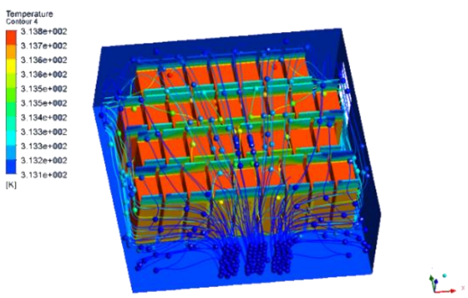

Figure 15. Temperatures for battery system using CFD.

IV. CONCLUSIONS

A better performance for solar car design Intikallpa IV is demonstrated using CDF tools to maximize energy efficiency. Get reducing a 69% the drag area (A * Cd) for the new prototype.

The design methodology used to develop the prototype of the solar car, allows the reduction of 35% in weight of the solar car, along with a decrease in the magnitude of the resistive force, which is translated to require less energy for drive more distance.

Solar car batteries are maintained at an temperature of 40° C, using only a system of forced convection, without the need to use fans or unnecessary energy expenditure. Achieve beneficial for driving longer distances in competition.

From the results of the distribution of resistive forces in the IK4 for the WSC route, the influence of the aerodynamic force in the energy consumption of the car is a 85%, revealing a domain over the others and it will be a decisive factor the competition. While rolling force is a 13% due to the use of tires with 80 psi and low energy consumption. Other hand, the force gradient is negative, which means that there are more negative slopes in the WSC route, so the weight is not predominant to win the competition would even be beneficial in descending slopes.

Future projects using the tools of calculation and numerical simulation would be useful to reduce costs and fuel consumption for conventional cars and transportation in general. They would also be beneficial for blade designs of wind turbines, tidal, water, and other non-conventional energy.

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Towards Green Growth-The influence of European product policy on innovation

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ABSTRACT

Green growth requires the redirection of innovation activities towards eco-innovations, which ideally are beneficial for the environment, for consumers and for manufacturers. Environmental policy plays an increasing role not only regarding its environmental benefits but also regarding its influence on green growth. Our study investigates the innovation impact of the Ecodesign and Labelling directives as key European policy measures to increase energy efficiency. We combine a quantitative analysis of patent data with a qualitative case study approach to investigate the impact of the legislations on a broad range of innovation activities. Our study covers a wide range of products that are affected by the regulation and investigates the factors that positively influence the innovation impact. We find that the legislations have supported market transformation towards higher energy efficiency; however, their impact on research and development of new technologies has so far been limited. In addition, we find that the stringency of the regulation plays a crucial role in innovation impact and conclude that the implementation of ambitious requirements provides incentives to innovate for companies, cost-savings for consumers and significant energy savings that are beneficial for the environment.

Keywords: Energy efficiency, innovation, Ecodesign directive, environmental policy, regulation stringency.

I. INTRODUCTION

Eco-innovations are generally expected to play a crucial role in the transition towards a sustainable economy. To simultaneously achieve the objectives of sustainability, energy security and competitiveness of the European economy, innovation is required on both the demand and supply side [1] [2].

The development and diffusion of innovations to tackle climate change require policy support. For such eco-innovations, which are logical from an environmental but not from an economic angle, a large-scale diffusion will generally not happen through unregulated markets [3]. Lately, the role of energy policy in supporting innovation has gained increasing importance both within European energy policy and in the academic debate [2] [4] [5] [6].

It has recently been observed that innovation support is distributed unequally between supply and end-use technologies, leading to a strong under-investment in end-use technologies [2]. This is also true when considering studies investigating the effect of energy policy on innovation where renewable energies have been studied rather extensively and energy efficiency has received less interest. The existing studies on the innovation impact of energy efficiency policy mainly focus on patents as an indicator of innovation, thus reflecting predominantly the effect of policy strategies on the invention stage of the innovation process [7] [8] [9] [10].

The objective of our study is to empirically analyse the impact of European product policy as a key strategy to increase energy efficiency on the development and diffusion of innovations. When investigating the effect of energy efficiency policy on innovation, it is important to observe that currently there is a so-called energy efficiency gap between the actual uptake of energy efficiency innovations and the economically optimal level [11] [12]. On the demand side, policy measures to promote innovation in energy efficiency can address the market imperfections that prevent the uptake of energy efficiency innovations. Such imperfections include information asymmetries, split incentives, lack of interaction between user and producer, lack of awareness, lack of capabilities to define needs or respond to innovation [13]. In order to capture the effect of policy on energy efficiency innovations it is therefore essential to study the impact of energy policy measures using an approach that goes beyond patent analysis and comprises the development, adoption and diffusion of innovations.

Our study addresses the impact of the policy measures on the different phases of the innovation and diffusion processes using a mixed methods approach: For the short-term development, where the need for policy intervention is found to be mainly on the market formation side, the innovation impact of the policy measures is investigated through a multiple-case study research covering a variety of sectors and manufacturers. For the long-term development, where research generation plays a major role, the innovation impact is studied by investigating the directives' impact on the patenting activities of manufacturers of regulated products.

Since the seminal work of Porter & Van der Linde (1995), the impact of environmental policy on innovation has been discussed extensively and controversially. The stringency of environmental regulation has been found to be the most influential among the various factors that influence the innovation impact of environmental

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legislation [14] [15] [16] [17]. Our study investigates the influence of the stringent regulations by comparing the implementing measures for different products.
The paper is organised as follows: Section 2 provides a short review of European energy efficiency product policy. Section 3 describes the rationale for our research approach and the choice of innovation indicators. Section 4 presents the case study research on the influence of the policy measures on market formation. Section 5 presents the analysis of the impact of the legislations on inventions. Section 6 presents our conclusions.

II. ECODESIGN AND ENERGY LABELLING

The Ecodesign directive (2009/125/EC) and the Labelling directive (2010/30/EC) are two of the main pillars of the European product policy strategy aimed to reduce the environmental impact associated with the design, manufacturing, distribution, use and disposal of products. Energy-using and energy-related products are used across economic sectors representing a rising share of the energy demand.
The Ecodesign directive specifies ecodesign requirements on energy-related products. Ecodesign requirements are minimum requirements that the products need to fulfil if they are to display the CE branding, which is a condition for entering the EU market. The original directive from 2005 covered only energy-using products and was extended to energy-related products in 2009. The requirements on the individual product groups are set in implementing regulations.
The Labelling Directive is a framework requiring producers to communicate information on the energy efficiency of products in a clear and understandable format. The directive sets the frame and is complemented with delegated acts for the product groups that are covered by the regulation.
While the primary policy goal of the Ecodesign and Labelling directive is "reducing the environmental impact of products, including the energy consumption throughout their entire life cycle"[4], the European product policy instruments have received increased interest also from an innovation policy perspective. The policy measures are expected to positively influence innovation by addressing barriers to the development and diffusion of energy efficient technologies. The product groups are characterized by different market and sales structures. These include products for the consumer market (e.g. household appliances and electronics), products that are distributed in a business-to-business market (B2B) for components (e.g. electric motors that are used in other devices), and products that are sold in a B2B market as shown in Table 1. We distinguish between products that significantly influence the company's energy consumption and products where the influence on the total energy consumption is small.

Table 1. Overview - Barriers addressed by the Ecodesign and Labelling for products with different market and sales structures.

	Barriers/ Characteristics	Role of Ecodesign	Role of Labelling
Consumer market	Consumers typically do not conduct a life-cycle-cost analysis before purchasing a product. The importance of the investment price therefore tends to be overestimated compared to the life-cycle energy savings.	Ecodesign is a strong measure to address the barrier, as products with low investment costs but high life-cycle costs are banned. However, Ecodesign does not influence consumers' choices beyond the minimum standards.	Labelling can draw the consumers' attention to life-cycle aspects and shift consumers' choices towards more efficient products. On the low efficiency end, this approach is weaker than Ecodesign, as a proportion of consumers will still choose the low-investment option, but Labelling has the potential to address the high-efficiency end.
B2B- components	For sectors where products are not sold to end users and are used as components in larger systems (e.g. electric motors and pumps, air conditioning, tyres), the line of purchase is broken in a sense that buyers are typically not interested in energy efficiency as they will not benefit from energy savings themselves. An exception to this is larger systems that are themselves regulated, e.g. tyres/emission standards or AC/EPBD.	Ecodesign addresses this barrier at least in the low end, as low efficiency products are removed from the market.	Labelling typically plays a minor role for such products and would not have a significant impact, as the lack of information is much less of an issue, because business buyers will research this for themselves.
B2B plug-in – products that significantly influence energy use	For products that are sold to companies for their direct use and that significantly influence the energy use of the company (e.g. tyres for fleet companies, AC for industrial users, servers for data centres), the buyers are usually rather well informed and rational about energy savings and take them into account in their decisions.	The impact of Ecodesign is not as strong as for the consumer and B2B-components markets, as the buying decisions are already strongly influenced by the energy efficiency of the products.	Labelling typically plays a minor role for these products.

[4]http://ec.europa.eu/energy/efficiency/ecodesign/eco_design_en.htm

	Barriers/ Characteristics	Role of Ecodesign	Role of Labelling
B2B plug-in – products that do not significantly influence energy use	For products whose energy use is small compared to the total energy use of the company (e.g. commercial refrigeration), the importance of the investment price tends to be overestimated. This is especially where the purchasing unit is typically not responsible for energy savings (split incentives).	Ecodesign is a strong measure to address the barrier, as products with low investment costs but high life-cycle costs are banned. However, Ecodesign does not influence purchasers' choices beyond the minimum standards.	Labelling can draw the attention of the purchasing unit to life-cycle aspects; however, split incentives can still hamper the diffusion of high-efficiency products.

III. METHODOLOGICAL APPROACH

The empirical analysis of the impact of the legislations on innovation and green growth requires the identification of adequate indicators to measure their influence on the development and diffusion of innovation in energy efficient products. To determine the extent to which the policy measures may support innovation in energy efficient products, we considered elements from technical innovation system analysis [18] so that the phases of technology development and specific barriers and needs for policy support of innovation are analysed.

A transition to green technologies requires, on the one hand, policy measures that foster the adoption of existing energy efficiency technologies (reducing the energy efficiency gap). On the other hand, the development of new technologies is necessary. As a first step, our study analysed the stage of technological development for each product to determine the main barriers to be addressed, both in the short and long term. This analysis was performed by studying market data, manufacturer information and conducting expert interviews.

To capture both the short and long term effects in our research approach, we chose a combination of case study research investigating the legislations' effects on market formation and patent analysis addressing the impact on technology development. This choice was based on the framework of Hekkert, Negro, Heimeriks & Harmsen (2011), which outlines characteristics of an innovation system that plays a leading role in different stages of technology development [18]. For the acceleration phase (existing technology), market formation is identified as the most important aspect. For the development phase, generation of knowledge is described as the most important function. These two features are described as follow.

IV. IMPACT ON MARKET FORMATION

The following sections describe the case study approach which is used to analyse the impact of the Ecodesign and Labelling directives on market formation and presents our main results from the case study research.

A. Case study methodology

We studied the impact of the directives on market formation using a multiple case study approach [19] to collect primary data. This approach allows for gaining in-depth insights into the causal links between the regulations and the innovation activities of the manufacturers. Our case study was based on 45 semi structured interviews (August-December 2013) with representatives from 25 companies, trade organizations experts, NGOs and member state institutions. We conducted our case studies in seven product sectors, namely lighting, heat supply, electric motors and pumps, tires, electronics and air conditioning. The selection of firms mainly focused on producers that are regulated. However, for products where relevant innovation activities occur at earlier stages of the product value chain, component suppliers were included in the sample. The aim of our case selection was to include a broad range of companies taking into account the diversity and heterogeneity of firm-level innovation responses rather than a statistically representative sample. To increase the validity of our results, whenever possible we included firms with similar characteristics as well as firms with contrasting attributes to allow for literal and theoretical replication [19]. The results were evaluated at company and sector level and in a cross-sectorial analysis to identify the most important factors leading to the implementation of an innovation friendly regulation.

B. Case study results

More than 90% of the companies stated that legislation increases market opportunities for energy efficient products. Furthermore, the majority stated that both Ecodesign and Labelling have an influence on their innovation behaviour (see Figure 1).

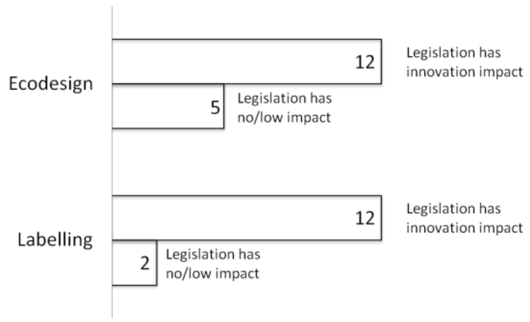

Figure 1. Distribution of companies stating that the legislations influence their innovation activities and companies that did not.

Out of 17 companies affected by Ecodesign, 12 stated that the regulation has an impact on their innovation activities. Out of 14 companies affected by Labelling, 12 stated that the legislation had an impact, whereas only 2 stated that this was not the case. It is important to keep in mind that the distribution of companies depends on our case selection and would be different for other cases. The cases

were selected with the aim of getting an in-depth understanding of the mechanisms and the factors that influence the innovation impact of the directives.
Most of the innovation activities named in the interviews were incremental changes to the production processes of energy efficient products, already in their portfolio, and/or incremental improvements of the products. For both Ecodesign and Labelling, the innovation activities that are influenced are mainly found at the deployment and commercialization stage.

C. Stringency as a main driver for innovation

The most important factor of the legislations' capacity to support innovation in energy efficient products was found to be the stringency of the legislation. In our approach, the stringency of an Ecodesign implementing measure is defined by the market share of appliances that do not fulfil the requirements at the time of adoption. For Labelling this is defined by the share of appliances in the highest populated class. The stringency of implementing measures, for both Ecodesign and Labelling varies significantly between different products.
For products where the Ecodesign implementing measures define stringent requirements with respect to the market average, the innovation impact is strong. The companies affected by ambitious requirements confirmed that Ecodesign is a strong measure to induce innovation which led companies to adapt their product portfolio to comply with the new requirements. In contrast, the companies that stated that the legislation did not have a significant impact on their innovation activities reported that only very few or none of their products did not comply with the requirements.
Within each sector, the stringency of the Ecodesign levels and Labelling classes are perceived rather differently by different companies. Producers of high-end products stated that all of their products already fulfilled the requirements at the time of adoption, whereas other manufacturers stated that they had to make significant adjustments. In sectors where the gap between high-end and low-end products is large, it is more difficult to design a regulation that is sufficiently stringent to induce innovation in the high-efficiency end, while at the same time taking into account the needs of low-end producers. This company-specific perception of the ambition of the requirements is named here "relative stringency".
For Ecodesign, we observed a nearly direct relation between the ambition of the requirements and the innovation impact (see Figure 2, left). The ambition of the requirements is reflected in the share of products that are excluded from the market when the regulation is adopted and varies widely between the different products. For instance, 90% of the circulator market did not meet the efficiency requirements by the time the directive came into force. In contrast, most of the television market was above the requirements under its directive.
For Labelling, the relationship between the ambition of the levels and the innovation impact is not so straightforward (see Figure 2, right).

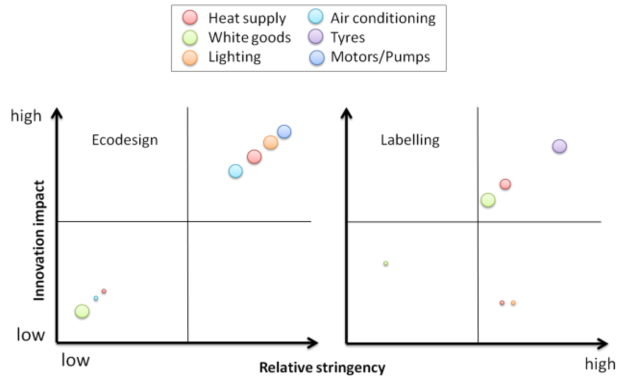

Figure 2. Relationship between the relative stringency and the innovation impact for Ecodesign (left) and labelling (right). The size of the circles reflects the number of companies that confirmed the statement within each of the different product case studies.

As for the Ecodesign, if the ambition of the Labelling classes is low, the associated innovation impact is limited. If most products are in the highest class the implementing measure becomes meaningless and no innovation impact is observed; this effect was observed in the white goods market before the introduction of the new classes. In contrast to Ecodesign, where the producers cannot sell products that do not comply, we observed that some firms reported that they had not upgraded their products to reach the higher Labelling classes.

V. IMPACT ON TECHNOLOGY DEVELOPMENT

The impact of the policy measures on the research stage of the innovation process is studied through energy efficiency patents for a selection of products regulated under Ecodesign and Labelling. The following sections present the methodological approach and the main results.

A. Methodological approach for patent analysis

The patent analysis is a three-step procedure (see Figure 3). Step 1 selects the products for analysis. Step 2 collects patent data for the selected products. Step 3 analyses the data to investigate the impact of the legislation on manufacturers patenting behaviour.

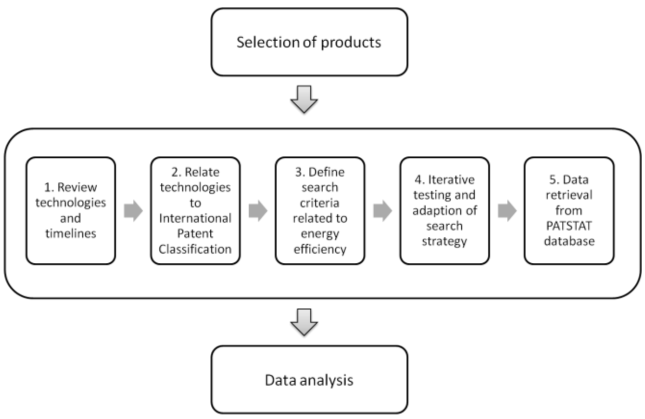

Figure 3. Methodological approach for patent analysis.

B. Product selection

Five products were selected based on the time of adoption of the implementing measures: electric motors, refrigerators, battery chargers (since 2009), dishwashers, and washing machines (since 2010). More recent measures could not be studied due to lack of data.

C. Data collection

We developed a five-step approach to collect data on patents relevant to energy efficiency:

1. **Technologies:** Technological details related to energy efficiency as well as emerging technologies were identified for each product.
2. **International Patent Classification:** Identification of the IPC classes corresponding to the technological properties analysed in step 1.
3. **Keyword search:** Keywords to define properties related to energy efficiency are identified and tested.
4. **Testing:** The search criteria are iteratively and randomly tested by sampling and analysing the percentage of false positives (patents that appear in the results but are not related to energy efficiency) and true positives (patents that are related to energy efficiency and do appear) until achieving a validity ratio of at least 80%.
5. **Data retrieval**: The patent data was extracted from the PATSTAT database.

D. Data analysis

The influence of the policy measures on the patenting activities of manufacturers was investigated by comparing the evolution of patents related to energy efficiency prior to regulation and after its adoption. Trending behaviour in patenting activities in these product groups was assessed relative to general patenting and economic trends. Sector specific developments driven by the directives were taken into account by studying the relative growth in the number of energy efficiency-related patents within the total number of patents for a given product. Time lags between research activities and the publication of a patent are considered to be less than the time difference between the announcement of a regulation and its adoption. We therefore assume that patents filed up to two years before the regulation (as well as patents filed thereafter) may have been regulation-driven, whereas this is not the case for patents filed prior to this time.

Based on the considerations outlined above, the impact of the Ecodesign and Energy Labelling directives on patenting activity was investigated by comparing energy efficiency gain and standard deviation. The patenting activities are considered to be influenced by regulation if the energy efficiency gain exceeds the standard deviation.

1. **Energy efficiency gain:** The difference in the percentage of patents related to energy efficiency for a given product before and after the regulation: If the regulation has an impact, the percentage of energy-efficient related patents should increase. In order to take into account both the fact that companies start to innovate around 3-5 years before the regulation comes into force and the fact that patents are claimed around 1-5 years after the innovation activity was initiated, the value is calculated by taking the mean of a three-year time span. For the value with regulations, the three years up to the regulation is considered. For the value before regulation, the previous three years are considered.
2. **Standard deviation:** Typically the number of patents fluctuates from one year to the other. The difference between the relative amount of patents before and after regulation is therefore compared to the standard deviation of the patent statistics in the time span that is considered.

E. Main results

Our patent analysis focuses on the increase of the share of patents related to energy efficiency with respect to the total number of patents for each product. Table 2 displays the energy efficiency gain, the standard deviation for the five selected products and the assessment of the innovation impact. The analysis shows that no significant impact is observed for four products, and a low negative impact is observed for the remaining product.

Table 2. Analysis of the impact of the Ecodesign and Labelling on patent statistics.

	Electric motors	**Dish washers**	**Refrige-rators**	**Battery chargers**	**Washing machines**
Energy efficiency gain	1,2%	-1,9%	-0,4%	0,7%	-2,4%
Standard deviation	1,3%	5,0%	3,3%	2,9%	1,8%
Impact	No	No	No	No	low negative

VI. CONCLUSIONS

The results of our case studies show that the directives have supported market transformation towards more efficient technologies, mainly by facilitating the introduction of already existing high-efficiency technologies. Ecodesign and Energy Labelling have effectively influenced innovation behaviour regarding the market formation, adoption and diffusion of technologies. In contrast, the innovation impact is rather limited in the R&D related stages. Our patent analysis found that at the current stage the Ecodesign and Labelling legislation had no significant impact on the relative number of patents related to energy efficiency. However, it is possible that as the efficiency requirements of the regulations continue to increase, the long-term effect on the earlier stages on the innovation process may become more visible.

For both legislations, we observed a close direct relationship between the stringency of the requirements and the innovation impact. For products where the implementing regulations define ambitious requirements in relation to the market, the innovation impact is strong. In our case studies, companies that are affected by ambitious requirements confirmed that Ecodesign is a strong measure to induce innovation as products that do not comply cannot be sold. However, most of the interviewees highlighted the importance of market control, as ambitious regulation can only support innovation if it is properly enforced.

In order to define ambitious requirements, it is essential to take into account the different innovation dynamics in the various sectors that are covered by Ecodesign and Labelling. In sectors with rapid technological advancement and short product development cycles, such as consumer electronics, the long regulatory processes face serious challenges to follow the innovation dynamics, often resulting in rather lax requirements.

For Energy Labelling, the long-term incentives for companies to innovate depend on the consumer response to the legislation. Labelling has the potential to raise consumer awareness regarding the total cost of owning an appliance, including the energy use during its lifetime. However, the role of Labelling in consumer decision making depends on a variety of factors and differs between products, households and member states. Whereas Labelling can address information-related barriers, complementary measures are required to address the remaining barriers. An example for this would be innovative financial schemes to address the lack of upfront capital availability, which poses a serious barrier especially for low-income households.

Our analysis shows that it is crucial to study innovation effects of environmental policy using a mixed-method approach in order to capture the different stages of the innovation process. In particular for energy efficiency policy, it is imperative to differentiate between short-term effects aiming to reduce the energy efficiency gap and long-term strategies to drive the development of new energy efficiency technologies.

Furthermore, it is essential to study the impact of policy on innovation from a system perspective taking into account the complex interrelated agents and interactions between the different policy measures in place.

ACKNOWLEDGMENT

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An Architecture for a Self-Organized Load Control Mechanism

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ABSTRACT

The amount of power generated from renewable energy sources (RES) is expected to grow substantially in the following years. RES like wind and solar power depend on weather conditions. Therefore they are intermittent in their generation, limiting the ability to make efficient use of them. In this context, demand side flexibility raises as an alternative to increase RES utilization. Appliances with flexible operation times could begin execution at hours where RES availability is forecasted to be larger. Then, mechanisms to schedule the operation time of these appliances in order to maximize the utilization of RES generation are needed. We present an architecture that enables residential households to reschedule their appliances operation in order to increase RES utilization. Residential households receive a control signal which influences their autonomous decision on which hours of the day to begin execution of the appliances complying with individual customer restrictions. The control signal influences the system and is able to guide the aggregated behaviour of sub-sections of the low voltage power grid (micro-grid) to achieve specific load objectives. Since no interaction nor direct communication occurs between households the autonomy of customers is respected and privacy concerns are reduced. Additionally, global load objectives are achieved in a self-organized manner. Results show that our approach can increase RES utilization. Limitations and future work are discussed.

Keywords: load scheduler, renewable energy sources, demand side management.

I. INTRODUCTION

The share of renewable energy generation being fed to power grids is expected and promoted to increase in the following years [2,10]. However, RES like wind and solar generation are uncertain and intermittent, i.e. one cannot rely on a constant energy supply. Therefore, it should be utilized as soon as it is produced.

Flexibility on the demand side has become an alternative to face this issue. Appliances can be provided with flexibility intervals for their operation times e. g. a dishwasher can autonomously decide its execution time within a time interval defined by the customer [3]. We can refer to these devices as *intelligent devices*. However, utilizing load flexibility to increase RES usage leads to a complex optimization problem. From a global perspective, appliances should be scheduled in hours of the day where they can increase RES utilization, but without generating additional load peaks. From a local perspective, rescheduling should be subjected to user's restrictions. Since RES availability usually depends on weather conditions we can consider RES forecasts to improve our ability to enhance utilization of energy generation.

Approaches to face this problem can be broadly categorized into centralized and decentralized load control. In centralized control customers cede control to an intermediary. Then, a schedule for each entity within the sub-sections of the low voltage power grid (from now on micro-grids) under management is calculated [4]. However, even when centralized approaches can optimally schedule all loads within a micro-grid there are obvious issues with regard to customer's privacy and computational complexity. Hence, in a large micro-grid, with dozens of thousands of customers, the utilization of updated information to re-optimize might be unfeasible.

On the other hand, in decentralized control, customers receive incentives to adapt their consumption behaviour. In this case, computational complexity is reduced since the final schedule of all devices in the micro-grid is distributely constructed among all participants. However, these approaches can create herding effects, generating new load peaks and bring instability to the power grid [5,8]. Furthermore, most of these approaches require interaction between customers, increasing privacy concerns, and do not address real time response. Hence, coordination mechanisms for scheduling distributed loads are required, These mechanisms should preserve customers' privacy, consider real time information, and be computationally affordable.

In this paper we present an architecture and experimental results for self-organized load control (SLC) in an idealized micro-grid. In SLC load is shifted in a self-organized manner in order to increase RES usage. The process goes as follows: A centralized entity called the Micro-Grid Manager (MGM) receives the load profiles of all residential households in the micro-grid. The MGM considers the aggregated profiles and an RES forecast to derive a signal, which is broadcasted to all households. Residential households utilize this signal to autonomously reschedule their devices. This process is repeated every 15-minutes intervals throughout a simulated day and at each interval the forecast progressively resembles the real RES output. Residential households do not engage in direct communication, reducing privacy issues. Furthermore, we utilize households as an example case. Our architecture is suitable to be utilized by households, commercial buildings and apartments indistinctly. Results

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show that the system is able to respond in real time to a changing RES generation forecast. Furthermore, our SLC approach is able to increase load utilization from an uncontrolled scenario. The remainder of this paper is structured as follows: Section II presents the description of the architecture for implementing our approach. Section III presents the experimental setup for evaluating the performance of our approach. In Section IV we present our results and discuss the performance. In Section V we present concluding remarks and discuss future work.

II. ARCHITECTURE FOR SLC SCHEDULING

Our approach considers the existence of a bi-directional communication channel between residential households and the MGM. For this, households can utilize smart-meters with the ability to receive a signal from an MGM and deliver schedules to the same entity [1,9]. The process of scheduling appliances autonomously goes as follows: The control signal is utilized by the households to reschedule the operation times of their appliances. Once a household has updated its schedule, within a customer-defined flexibility interval for each appliance, it delivers its updated load profile to the MGM. After all profiles are received the MGM aggregates them and derives a micro-grid load profile. With this information and an RES forecast, it recalculates the control signal which is again broadcasted. This process is repeated in 15-minutes intervals, and we call each instance of the process a rescheduling round. Furthermore, when we move from one round to the next one, the available load to be rescheduled in the micro-grid is reduced, as some appliances have begun their operation. This iterative rescheduling process is related to receding horizon control, where at each time step an optimization process with a finite horizon is solved [4]. The time step for repetition of this process should be set in a reasonable way. For our investigation 15-minutes time intervals are used since data on RES generation has this granularity.

In Figure 1 we can observe the internal architecture of a generic residential household and the components required to respond to the signal. The *Repository* stores all relevant information to the household, including the currently active schedule and the last received signal. Additionally, details related to the appliances, like load profiles and user defined flexibility intervals are stored in the *Repository*. Once the control signal (*signal update* request) is received the corresponding module stores it in the *Repository* and requests the processing of this signal to the *Signal Processor*. The *Signal Processor* module reads the updated signal and transforms it into a vector. The values in this vector represent the desirability, from a global perspective, to shift load to specific hours of the day. Then the *Signal Processor* requests for the construction of an updated schedule, considering the current state of the micro-grid, which is expressed in the signal, to the *Rescheduler* module. This module proceeds to calculate a new time of execution (ToE) for each appliance which is available to be rescheduled, ergo, has not begun its execution. To calculate this new ToE the *Rescheduler* considers the user defined flexibility intervals of the appliances, stored in the *Repository*, and the processed signal from the *Signal Processor* module. With this information, the *Rescheduler* constructs a probability density function from which it obtains a new ToE for every appliance. Finally, the module stores the updated schedule in the *Repository* and requests the *Profile Delivery* module to send the updated load profile of the household to the MGM.

It has to be noted that we have selected households for the ease of simplicity in the explanation of the components of the architecture. Our approach is suitable to be utilized by commercial buildings, apartments as well as residential households indistinctly.

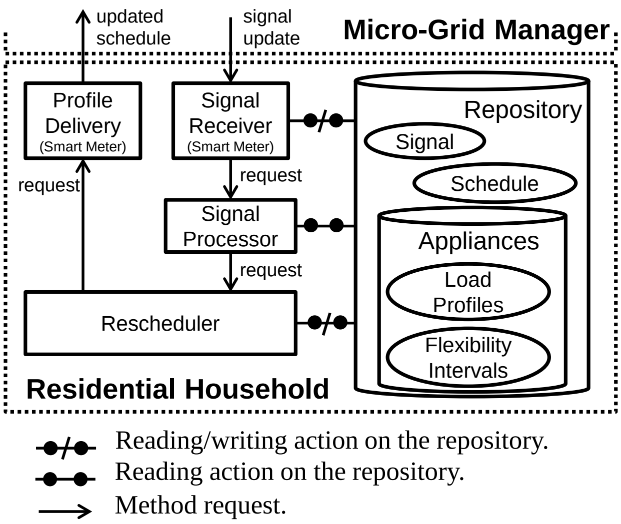


Figure 1. Internal components of a household with shiftable load features in SLC.

The internal architecture of the MGM for our load control approach is shown in Figure 2. The MGM also utilizes a *Repository*. In this case, it stores the historic information of the broadcasted signals, the current RES forecast and the current micro-grid load profile. The MGM continuously receives RES forecasts from the *Forecast Updater* module, and they are stored in the *Repository*. These forecasts represent more accurate information regarding current and future availability of intermittent generation. In parallel, the MGM also receives the updated profiles of the residential households in the micro-grid through the Schedule Receiver module. These schedules are aggregated in order to build the current micro-grid load profile.

The MGM recalculates the control signal in order to express the deviation of the current state from the desired behaviour of the system. For this, the *Signal Calculator* module utilizes a function to construct an updated control signal from the current RES forecast and micro-grid load profile. Then, the signal is broadcasted to every residential household in the micro-grid through the *Signal*

Broadcaster module and the process repeats in the following rescheduling round.

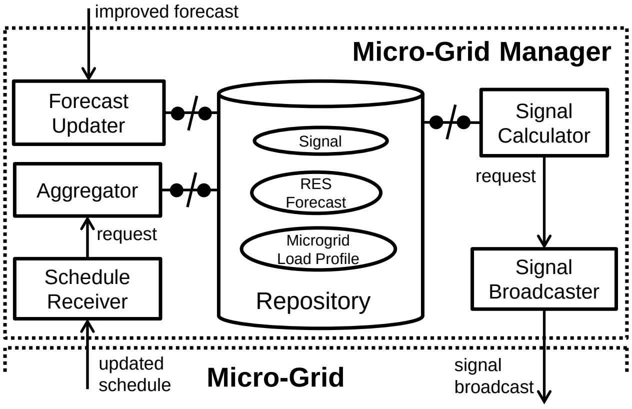


Figure 2. Internal components and communication of a MGM.

The continuous feedback loop that takes place between residential households and MGM allows the system to search for individual load schedules which, once aggregated, will progressively achieve the system's global load objectives. Additionally, this feedback enables the system to make use of new information, the updated RES forecasts, and adapt its behaviour to the new scenario. Furthermore, our system has the ability to respond reasonably to a changing objective, represented by the changing RES forecast.

Regarding privacy, our approach can be complemented by other security mechanisms, e. g. SMART-ER protocol in [9], making the profiles of customers untraceable, but allowing the MGM to have access to the aggregated micro-grid load profile.

III. EXPERIMENTAL SETUP

To test the performance of our architecture we adapted the approaches to evaluate the coordination mechanisms in [4,5,6]. Hence, to evaluate the ability of SLC to guide the behaviour of a micro-grid comprised by households with different autonomous appliances, we considered an idealized micro-grid with 6,000. Flexible load is represented by three shiftable appliances: dryer, washing machine, and dishwasher, with a micro-grid penetration of 50%, 100% and 80% respectively. We simulated a full 24 hours day divided in 15 minutes intervals. The initial execution times of the appliances are uniformly distributed within the user defined flexibility of each appliance (Table 1). In addition, we have considered that the entire residential load in the micro-grid is shiftable. We acknowledge this is an unrealistic scenario. Nevertheless, our main focus is to evaluate if through the proposed architecture we are able to influence an autonomous system to achieve specific global behaviour.

Regarding the supply side, German Transmission System Operators provide real data on wind and solar power (PV) generation in their balancing areas in 15-minute time resolution. Then, we utilized 50 RES outputs, which correspond to wind data from the balancing zone of 50Hertz ([7]) and PV data from Transnet BW ([10]) in 2013. These profiles are normalized so that they match the load of the described micro-grid.

Table 1. Flexibility intervals and shares per interval for shiftable appliances.

Washing Machine		Drier		Dish Washer	
Interval	***Share***	***Interval***	***Share***	***Interval***	***Share***
00:00-06:30	20%	00:00-08:00	20%	00:00-06:30	20%
06:30-12:00	32%	08:00-13:30	35%	06:30-12:00	30%
12:00-20:00	46%	13:30-20:00	40%	12:00-17:30	40%
20:00-00:00	2%	20:00-00:00	5%	17:30-00:00	10%

The impact of the RES forecast in the ability of the approach to increase utilization of the RES output is relevant. Therefore, we utilize the approach from [4] and added Gaussian noise to the RES outputs. In order to level the effect of different forecasts, we have artificially generated ten forecasts for each RES output through this method. In each progressive rescheduling round the forecast reduces its difference with the RES output. This can be observed in Figure 3.

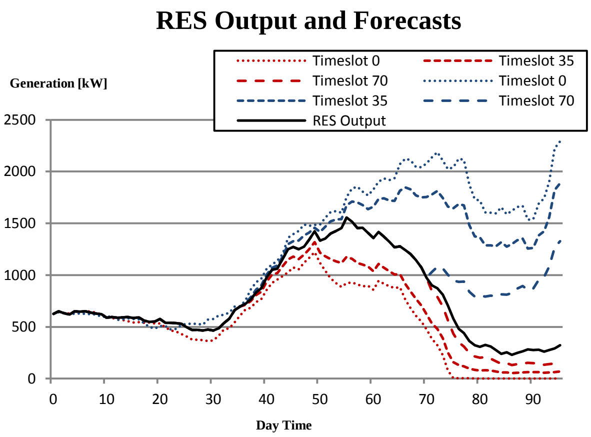


Figure 3. Good (red) and bad (blue) quality forecasts for the same RES output. The different curves depict the appearance of each forecast in different rescheduling rounds throughout a simulated day (Timeslot 0 - 00:00 hours; Timeslot 35 - 08:45 hours; Timeslot 75 - 17:30 hours). The forecasts progressively resemble the RES output.

As mentioned, the objective is to increase as much as possible the utilization of a given RES output. However, only a forecast of the final shape of this output is available. Therefore, as the time slots pass by, the system has to reschedule the available load intelligently according to a forecast which is in continuous adaptation. This implies that the objective may change in every rescheduling round.

The performance measure is the ability to increase usage of uncertain RES generation and we measure it as the percentage of *unused RES*. Since our approach reschedules the appliances with a randomized approach (using a meta-heuristic), in order to obtain statistically reliable results we performed 10 runs on each combination of RES output and each forecast. Finally, the reference scenario corresponds to the uncontrolled load scheduled at the setup of the simulation.

IV. RESULTS & DISCUSSION

A. Overall Analysis

In Figure 4 we see an exemplary run of SLC in comparison to the uncontrolled scenario. In the latter, the utilization of RES depends purely on chance, this is, the uncontrolled load profile of the micro-grid matches the RES output by coincidence. In the case of SLC, the households are influenced through the signal to modify their schedules, hence their consumption and overall micro-grid profile. Therefore, additional RES generation can be utilized, subjected to user defined restrictions of each appliance.

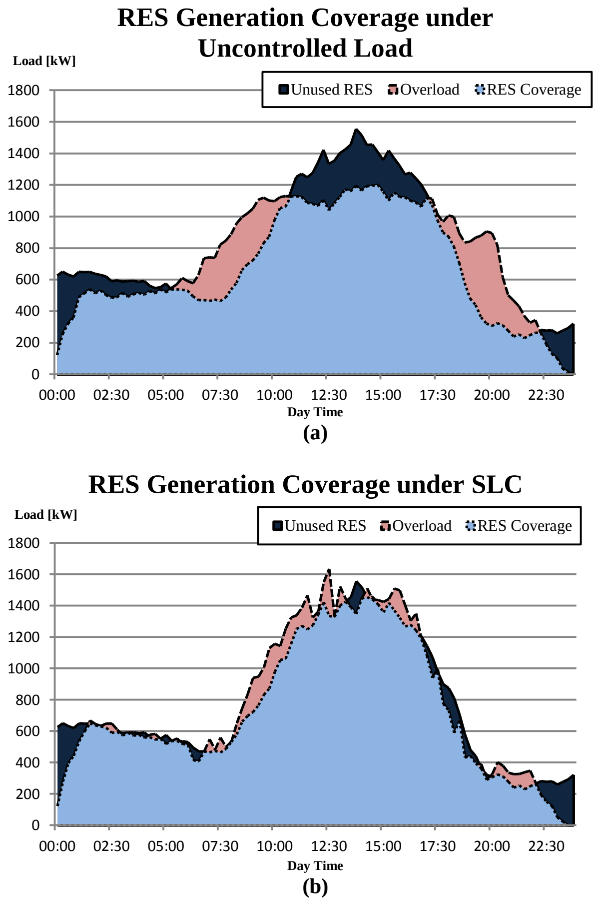


Figure 4. (a) RES output coverage under uncontrolled load. (b) RES output coverage under SLC.

The distribution of the performances for both strategies (SLC and uncontrolled load) can be observed in Figure 5. From the boxplots we can see that the interquartile distance for uncontrolled load goes roughly from 16% to 24% of unused RES, whether for SLC it goes from approximately 13% to 19%. Therefore we can infer there is a tendency for a better performance of SLC. Nevertheless, the range of all data is quite extensive for both strategies.

In order to assess the significance of the results, regarding the ability of our approach to guide the global behavior of the system we performed an analysis of the means. The normality of the data was tested through a Kolmogorov-Smirnov One-Sample test on each data set. The results presented in Table 2 reject the hypothesis that both sets of data are not normally distributed. As a consequence, we analyzed the means through a Wilcoxon Signed-Rank Test. The test was performed utilizing the tools in the *fBasics* package for the statistical analysis suite *R*. Results can be observed in Table 3.

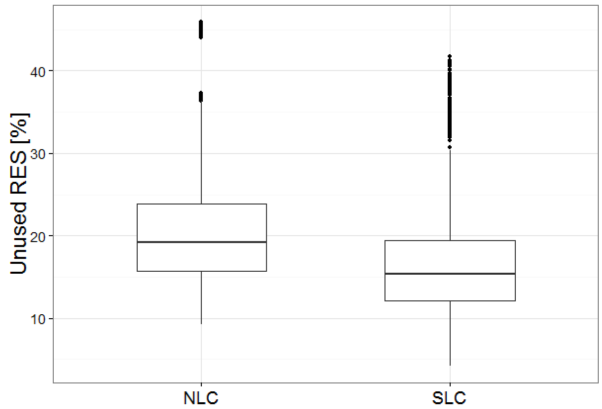


Figure 5. Boxplot describing the distribution of the datasets for uncontrolled load (NLC) and self-organized load control (SLC).

Table 2. One-sample Kolmogorov-Smirnov normality test for the samples from uncontrolled load (a) and SLC (b) scenarios. Sample sizes are of 5,000 measurements for each scenario.

Uncontrolled Load		
Statistic	D	: 0.5174
P-Value	Two-Sided	: < 2.2e-16
	Less	: < 2.2e-16
	Greater	: < 2.2e-16

(a)

Self-Organized Load Control		
Statistic	D	: 0.5171
P-Value	Two-Sided	: < 2.2e-16
	Less	: < 2.2e-16
	Greater	: < 2.2e-16

(b)

Since the P-Values in Table 3 are substantially smaller than .05, we have evidence to reject the hypothesis H0. Therefore, it is reasonable to conclude that the datasets do not belong to the same distribution. Moreover, the data suggests that dataset *x* (uncontrolled scenario) is shifted to the right of *y* (SLC scenario). As a consequence, the analysis supports the conclusion that SLC has better performance than the uncontrolled scenario.

Table 3. Analysis of the means for uncontrolled load (NLC dataset) and SLC (SLC dataset) scenarios. Since both datasets are dependent and not normally distributed, the Wilcoxon Rank Sum Test was utilized.

Wilcoxon Rank Sum Test with Continuity Correction		
Data	x : NLC dataset	y : SLC dataset
W	: 59758197	
P-Value	: < 2.2e-16	
Alternative Hypothesis	: True location shift is greater than 0.	

In order to complement the analysis, a summary of the statistical information for both scenarios is presented in Table 4.

Table 4. Summary of the performance of SLC in comparison to an uncontrolled scenario (NLC). Values correspond to percentages of unused RES.

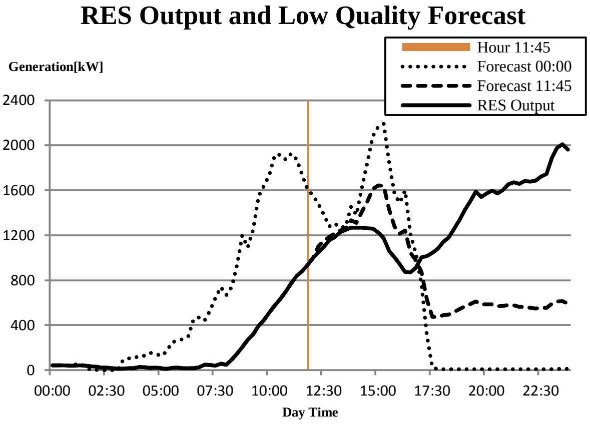
Strategy	Mean	Median	Min.	Max.	St. Dev.
NLC	20.37	19.23	9.27	45.90	6.85
SLC	16.52	15.39	4.24	41.68	7.22

B. Worst Case Scenario

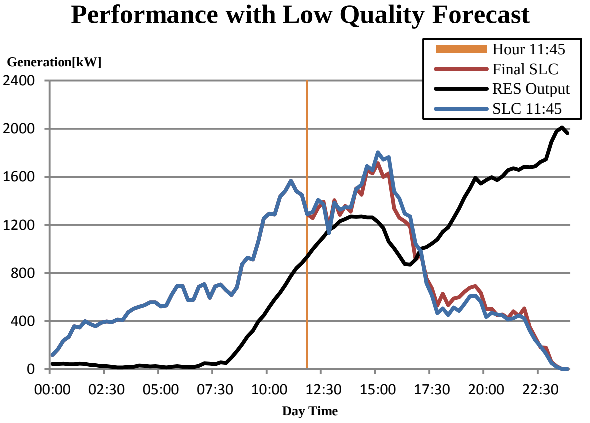
Even when results in Section IV.A show that SLC increases RES utilization, we can observe an important difference between the maximum and minimum values for both strategies. This can be explained by the different RES outputs evaluated. An RES output can concentrate much generation on times of the day where flexibility restrictions make it unreachable. In this case, SLC will not be able to make use of the load flexibility to increase utilization of the resource. Hence, performance might not be improved with respect to the uncontrolled scenario. Even worse, if we combine this situation with a low quality RES forecast, the performance might decrease.

In Figure 6 we can observe the effects of the quality of the RES forecast on the RES coverage for a single instance of the problem. Here, the forecast differs largely from the RES output. As a consequence, households are influenced to shift their load to hours where the forecast predicts a larger RES availability, even though the real availability will finally be different. As timeslots pass by, the forecast becomes progressively closer to the RES output. However, the difference for later hours in the day is still large. Therefore, the accuracy of the incentive (the signal) is only adequate for the following couple of hours.

When we reach hour 11:45, households have scheduled many appliances considering this low quality forecast. Much of this load was executed in suboptimal positions (peak between 09:00 and 11:30) influenced by bad forecasts, therefore it is not available anymore to be rescheduled at hours were the utilization of the RES output will be increased. Moreover, in Fig. 6.b it is quite clear that most of the load was scheduled to fit the low quality forecast. Nevertheless, the final micro-grid load profile shows that the system had a minor improvement in the last hours with respect to the load profile at 11:45.



(a)



(b)

Figure 6. (a) Low quality forecast and its evolution through different day times. (b) Performance of the approach at different day times for a low quality forecast.

This specific problem instance was quite hostile to our approach. Firstly, most of the RES output was concentrated late in the evening. From Table 1, we can observe that the ability to shift load to this hours is largely limited by the flexibility intervals. Second, the forecast utilized was of low quality, in the sense that it largely differed from the RES output. As a consequence, the system was misguided and the performance of SLC was worse than the uncontrolled scenario.

This example is really useful to depict the limitations of our approach. The system indeed responded in the expected way to the given context. However, if incentives are misgiven the performance of the approach will deteriorate. This situation reveals the importance of good quality forecasts, since the utilization of the final RES output could have been increased with respect to the uncontrolled scenario if a better forecast had been provided. This can be observed in Figure 7, where for the same output, a better forecast improved the utilization with respect to the uncontrolled scenario. Therefore we conclude that the main driver to increasing utilization of the RES output is the quality of the forecast.

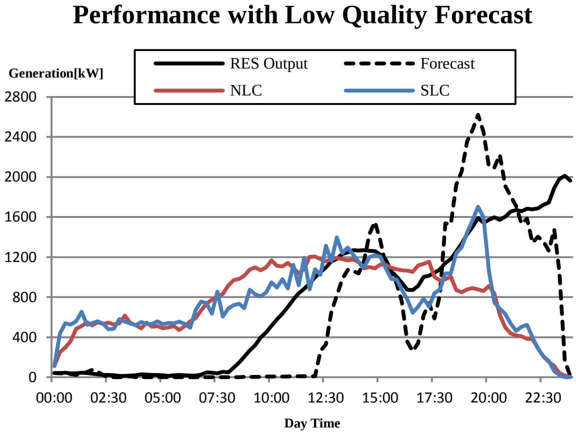


Figure 7. Performance in hostile problem instance with a semi-adequate RES forecast.

Furthermore, this problem instance depicts how flexibility intervals limit the ability of the micro-grid to increase utilization of the RES output. In addition, we can enquire that as the share of RES generation in the micro-grid increases, demand side flexibility becomes essential if we want to make efficient use of this intermittent source.

V. CONCLUSIONS

In this paper we have presented the architecture for a self-organized load control mechanism (SLC), which enables a micro-grid manager (MGM) to influence the scheduling of appliances by residential households. A signal is broadcasted every 15 minutes by the MGM, in order to guide the global behaviour of the system and increase the usage of RES generation. Residential households decide autonomously on the time of execution for their appliances considering this signal. Furthermore, the control signal is built with respect to a changing RES forecast and the current micro-grid load profile. Therefore, the signal changes with every 15-minutes interval. As a consequence, in this architecture there is no direct communication between customers reducing privacy issues. On the contrary, customers engage in communication only with the MGM which in no circumstance sends a command for an explicit action to any household. Moreover, we have utilized residential households for the ease of exposition. Our architecture is suitable to be utilized by households, commercial buildings and apartments indistinctly.

A set of experiments was performed to assess the ability of the architecture to guide the global behaviour of the system in a self-organized manner. For this, fifty RES outputs and ten RES forecasts per output were evaluated. The statistical analysis supports the argument that SLC improves performance with respect to an uncontrolled scenario. However, large differences were found between best and worst performances of the approach. By observation of a single worst-case-scenario we concluded that the main factor of low performance in our approach is low quality RES forecasts. In this case, low quality forecasts misguide the system and result in larger shares of unused RES.

Further advances on the approach include adding other loads and devices, like electric vehicles, residential PVs, and micro-CHP generation. Additionally, individual features for each residential household (like customer preferential times of execution) could be included.

ACKNOWLEDGMENT

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Potential Biomimetic Applications of Skin Analogies on the Building Envelope. A Conceptual Approach for a Light Intensity Reactive Heat Energy Screening System.

Leopoldo Saavedra[1] Werner Lang[2]

ABSTRACT

The transfer of information between nature and technology and associated potential technological applications offer a wide range of possibilities for both systemic and energy-related optimization of buildings. The building envelope plays a crucial role in the generation and preservation of a controlled indoor climate. The study focuses on detailed research of the functional properties of the building envelope. Particular emphasis is placed on the analysis of the potential of biomimetics to optimize and expand the functional spectrum of the building envelope. The aim is to investigate the capacity of future buildings to operate in a self-regulating, adaptive and symbiotic way, mediating between the outdoor conditions and the intended indoor climate. A taxonomic analysis of the building envelope is employed to select 15 functions relevant to energy efficiency and material from approximately 30 identified functions. Four functional groups are being examined in detail: dynamic air, daylight, thermal energy and humidity control. Building upon this functional classification, biological phenomena are assigned on a selective basis. The assignment of biological phenomena is carried out using a specially designed and building specific searching procedure based on the taxonomic analysis of the building envelope. The main focus is on the study of biological skins and envelopes and their potential uses and applications on the field of the building envelope. Based on the analysis and comparison of the functional properties of biological systems, potential applications of selected organismic building envelopes in the building sector are presented.

Keywords: bio-inspired, building envelope, adaptivity, biomimicry

I. INTRODUCTION

The technological advances in architecture since the 50 certainly represent a significant step in the exploration of solutions for historical as well as new defined problems regarding building design and construction. However, this is characterised by detachment of architecture from local climatic context and a high dependence on technology and energy to achieve solutions that do not necessarily lead to successful solutions [4]. The building envelope plays a crucial role in this context, acting as a modulator between two areas that often show opposed requirements. Thus, through the generation and preservation of a controlled indoor climate, the building envelope becomes a key factor in determining a building's energy consumption based on its potential in terms of design and energy performance [5; 6]. There is a vast amount of detailed research regarding the advantages and potentials of climate adaptive building envelopes [11; 18]. The transfer of information between the domains of biology and technology is associated with a wide range of possibilities [12; 13]. The potential of such applications reside not only in the formal design of novel building envelopes, but also in the systematic design of relations within these [3; 10; 13; 14]. There is nevertheless a lack of research addressing the implications and analysis of interconnected building functions and the potential of biological information transfer [1].

This work addresses the question of the potential of biological information transfer into architecture to optimize and enhance the functional spectrum of the building envelope. Initial inquiries are being made as to how future buildings could conceptually be able to operate in an adaptive way, interacting between the outdoor conditions and the intended indoor parameters [16], focusing on the analysis of the gentian flower as inspiration for a conceptual approach for/to a light intensity reactive heat energy screening system.

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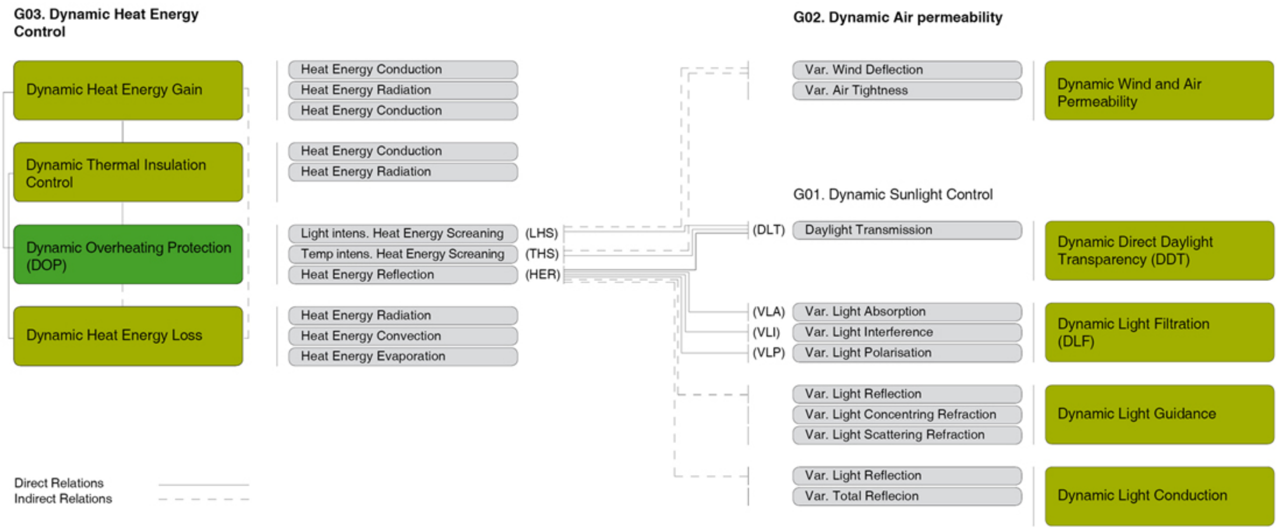

Figure 1. Diagram of relations between sub-functions (grey), showing three functional groups: G03. Dynamic Heat Energy Control, G02. Dynamic Air Permeability and G01. Dynamic Sunlight Control. The focus is on the direct relations (continuous line) of the function Dynamic Overheating Protection (dark green) with Dynamic Direct daylight Transparency**.**

II. AREA OF THE ANALYSIS

This study focuses on the analysis of the functional properties of the building envelope. The capability of the building envelope to coordinate a number of influences between the local climate and the needs of users defines functional environment. Thus, the building envelope acts as a modulator, taking information form the outside and transforming this to match the parameters for a defined and controlled indoor climate.

III. METHODS

A taxonomic analysis of the building envelope is employed to identify 15 functions out approximately 30. These have been organized in four functional groups: G01. Dynamic Sunlight Control, G02. Dynamic Air Permeability, G03. Dynamic Heat Energy Control and G04. Dynamic Humidity Control, each including a number of functions, which are subdivided in sub-functions.

The functional properties of the building envelope directly correlate to climatic parameters. This work focuses on the analysis of a standardized building envelope situated in a temperate climatic zone. Criteria defining climatic classification (Cfb) is based on the work of of Köppen and Geiger [8] and takes into account the climatic specifications of Hausladen [4].

Parameters of position and combination are being analysed using pairs of sub-functional relations to find a purposed compatible layering of sub-functions. The work concentrates on the direct relation between the sub-functions Daylight Transmission (DLT) and Light Intensity Dependent Heat Energy Screening (LHS), focusing on the last. In a further step biological information is being analysed and assigned to each of the chosen sub-functions. The analysis of biological information has been summarized on Figure 3. Main point of this analysis is the extraction of a principle, which represents the functional expression of the analysed biological phenomena. This will assist the definition of the optimal functional form within the three predefined layers of the conceptual building envelope: outer, middle and inner layer (Figure 4). Due to its energetic relevance the focus is on the sub-function Temperature Intensity Heat Energy Screening (THS) of the function Dynamic Overheating Protection.

IV. ANALYSIS OF HIERARCHY

The diagram of relations (Figure 1) shows two groups which combine different sub-functions.

The sub-function Heat Energy Reflection (HER) is positioned against Variable Light Absorption (VLA), Variable Light Interference (VLI) and Variable Light Polarisation (VLP) in a first group. The second group (Figure 3) organizes Daylight Transmission (DLT) with Light Intensity Dependent Heat Energy Screening (LHS) and Temperature Intensity Dependent Heat Energy Screening (THS), as well as with Heat Energy Reflection (HER). Due to the primary relevance of this combinations of sub-functions further analysis focuses on this second group.

Different combinations of the sub-functions HER, DLT, HLS and HTS are displayed on the combination diagram

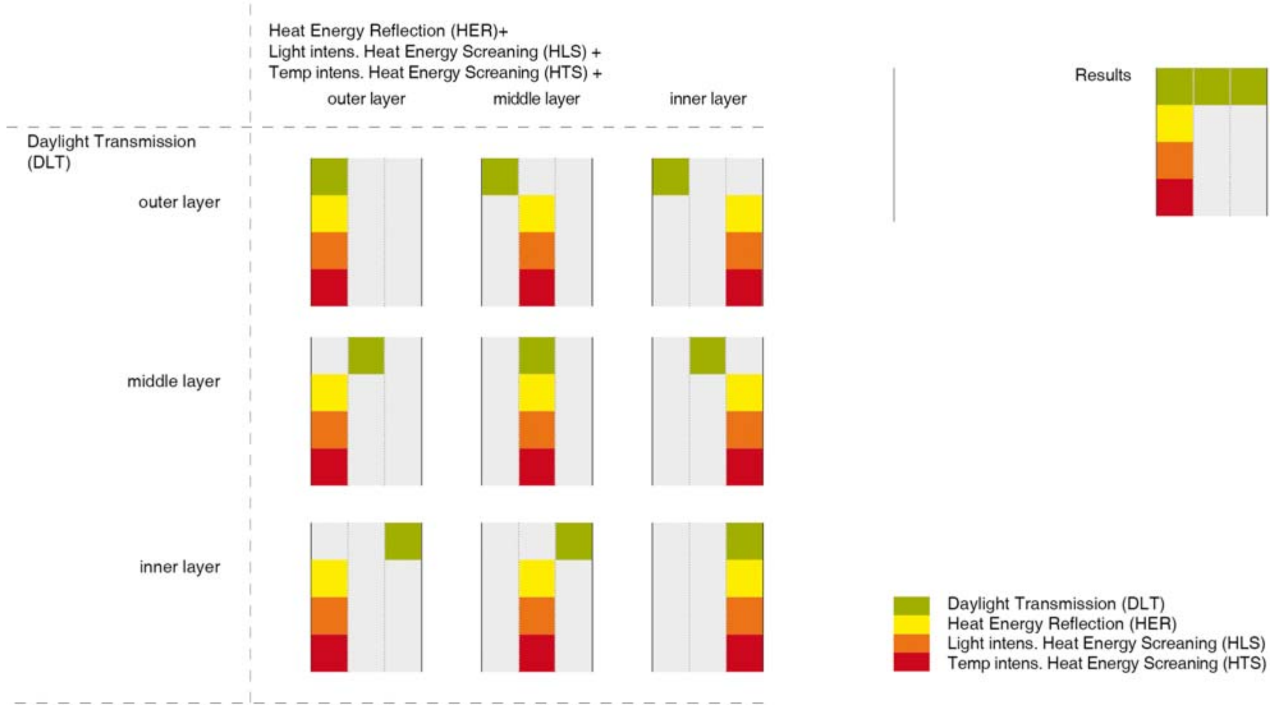

Figure 2. Order and position diagram for selected sub-functions in the building envelope. Combination for Daylight Transmission (DLT) with Heat Energy Reflection (HER), Light intens. Heat Energy Screaning (HLS) and Temp intens. Heat Energy Screaning (HTS).

(Figure 2). On the right side it is possible to see a recommended combination based on this variations.

As most common shading systems normally, at least partially, screen solar radiation by physically blocking sumlight, the function Dynamic Overheating Protection (LHS, THS and HER) and the function Dynamic Direct Daylight Transparency (DLT), could prove contradictory. In order to transmit external light to the interior without interruption, Daylight Transmission (DLT) should be situated along all three layers, outer middle and inner layer. Light Intensity Dependent Heat Energy Screening (LHS) and Temperature Intensity Dependent Heat Energy Screening (THS), as well as Heat Energy Reflection (HER), should be positioned on the outer layer, to allow them to react to solar radiation whilst it is still external to the building, and avoiding the undesirable transfer of heat energy to the interior. All three should also allow the free functioning of DLT by variating their opacity or by a dynamic modification of the reflection degree of the sun exposed surfaces. It is also necessary to determine the hierarchy, the degree of integration and the constructive order of HER, HLS and HTS to allow the simultaneous functioning of all three while functioning on the same layer.

V. ANALYSIS OF BIOL. INFORMATION

Parameters of scale, adaptivity strategy, nature of nature of flow and level of complexity as well as formal and structural parameters are shown on Figure X. Phenomena in the category meso show an active nature of flow. This indicates a possible need of external energy input to allow and maintain the functionality, which could be assisted by using passive activator systems. The adaptivity strategy on phenomena in the meso scale is predominantly morphological, presenting a functionality allowed by a change in the form of a static system without the need of excessive displacement (behaviour) or physiological modifications not suitable for a building. A higher complexity level is also present on LHS, THS and HER, indicating a potential complex composition and functionality, included in the category of mechanism. Most of the phenomena can be classified exclusively as constructions, since they are being composed out of several parts. This enables this strategies to be constructed out of varied components, as shown under the structural parameters, avoids dependence on a single technology development and simultaneously offering a broader range of combination possibilities. Formal parameters indicate the spatial complexity. Most of the phenomena are classified under volume, indicating a three dimensional formal development of the mechanisms during action.

Some species of the gentian flowers make use of opening movements based on the reversible expansion and contraction of cells. This has been demonstrated only in *Gentiana kochiana* to date. The petals with a length of about 5 cm are fused to the basal end of the flower. The top part of the petals of about 1-2 cm

		sc				as			nf		cp		fo			st	
G03. Dynamic Heat Energy Control		nano	micro	meso	macro	morphol.	behav.	physiol.	active	passive	effect	mechanism	linear	area	volume	element	construction
Function: Dynamic Overheating Protection																	
Light Dependent Heat Screaning (LHS) Gentiana, *Gentiana verna* [2] (s. a. *Gentiana kochiana*)				•		•			•			•			•		•
Temperature Dependent Heat Screaning (THS) Crocus, *Crocus vernus s.str.* [21]				•		•			•			•			•		•
Heat Energy Reflection (HER) Silver linden, *Tilia tomentosa* [17]			•	•		•			•		•	•		•	•	•	•
G01. Dynamic Sunlight Control																	
Function: Dynamic Direct Daylight Transparency																	
Daylight Transmissionp (DLT) Glasswing, *Greta oto* [18]		•				•				•	•			•		•	

sc: scale
as: adaptivity strategy
nf: nature of flow
cp: complexity level
fo: form
st: structure

Figure 3. Analysis of biological phenomena. Sub-functions with assigned biological phenomena, classified by scale, adaptivity strategy, nature of flow and level of complexity, form and structure

expands and contracts. In *Gentiana* flowers the lowermost halve of the petals are fused showing no movement, being the division area of the petals the one responsible for the movement. Analysis on both sides of the petal show a daytime expansion on the epidermis cells of the inner side of the petal. This is followed by a contraction during the night with no further changes on the outer side, concluding that movements are caused due to turgor changes, differences on the pressure against the semipermeable cells walls membrane [20].

VI. APPLICATIONS ON BUILDINGS

Figure 4 shows the building envelope being subjected to the influence of solar radiation and also shows the position within the building envelope, as well as the form derived from the strategy of each of the selected sub-functions. Daylight Transmission (DLT) is based upon the nano structural transparency of the glasswinged butterfly, achieving transparency through a bio-degradable material with similar light transmission properties for the visible spectrum as conventional materials. Light Intensity Dependent Heat Energy Screening (LHS), based on the photonastic behaviour of the gentian flower, is a mechanism able to react to a variation of light intensity, offering a strategy to deal with aspects of heat energy shielding. Some species of this flower (*Gentiana kochiana*) operate by reversible expansion and contraction of epidermis cells on petals, turgor changes [20]. A light intensity activated system is in this case of relevance due to the radiation increase related to the light intensity. This causes a potential rising of temperature on sun exposed surfaces without a necessary increase of air temperature, making the design of the surfaces in terms of pigmentation and form relevant. Furthermore it offers possibilities to achieve dynamic control over glare, optimizing the daylight conditions for users. Applied in a building envelope, this system could play a complementary role to THS.

Although this movements in plants are activated by active trigger systems and may be overviewed by sensors, it could be of interest to explore the possibility to adapt them to be passively activated. This passive activation should be combined with manual resetting to enable the interaction and intervention of the user with the system. Furthermore it is necessary to consider the integration of sensors for detecting punctual changes on light intensity and a consequent and local fine tuning of the shading system.

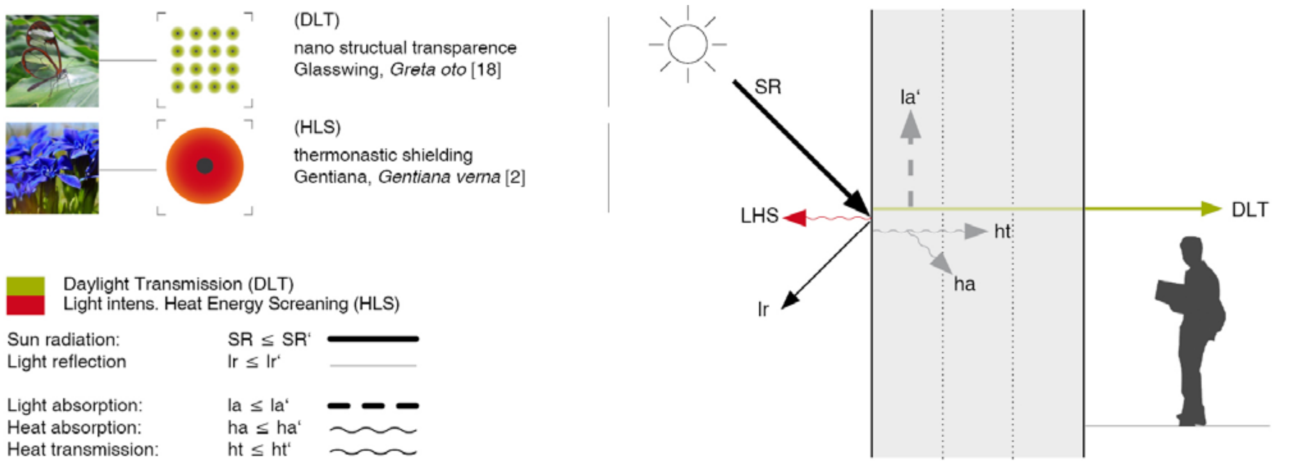

Figure 4. Correspondent strategy diagram showing form and position of the selected biological phenomena assigned to each sub-function of the building envelope.

VII. CONCLUSION

The use of biomimetics for the optimization of the functional properties of the building envelope is an area of study offering important possibilities regarding the adaptivity and self-regulation of the building envelope.

The robustness and adaptivity of biological systems are achieved partly through a number of connections and redundancies. Thus the qualitative methodological advantages of conceiving a building envelope out of interconnected functions could be significant.

The hierarchical order of the presented sub-functions and their compatibility seem to be feasible. This should be practicaly proven in a next step by a comparison of suitable materials and their physical properties as well as quantifying the climatic parameters to generate numeric simulations.

The results of this could clarify the frame of the building envelope for further research around the possible optimization regarding self-regulation and adaptivity of the function Dynamic Overheating Protection.

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Wind Gas Battery Hybrid System for Power Supply Solution in South Patagonia

Jaime Gómez[1] Darío Lafferte[2] Martin Braun[2]

ABSTRACT

This paper presents a technical and economic simulation of a hybrid wind gas system with battery storage in isolated network as power supply solution for the Chilean Patagonia. South Patagonia is sparsely populated and there is consequently no interconnected power system for this area. Therefore, human settlements and rural zones are supplied through stand-alone grids, which are typically operated with diesel or gas generators. South Patagonia enjoys an exceptional situation of state subsidy of gas due to its remote location from the rest of the country. However, since the energy crisis of the Argentinian gas 2004, the Chilean governments have tried to reduce and remove these gas subsidies. This situation could lead in the near future to high energy prices and social instability. The research subject for this paper is the Chilean village of *Villa Tehuelches* (pop. 151), which is located over 100 km from the nearest big city and currently powered by a gas generator. This work presents a reliable modelling of the wind potential for the chosen area based on measured wind speed data of a nearby wind location and MERRA reanalysis data. This analysis shows that the proposed hybrid supply solution based on real commercial devices is environmentally meaningful as well as economically profitable compared to the existing supply system and without gas subsidies. The simulations were performed with the software tools energyPRO and windPRO and their results are presented and discussed. This paper is based on a Bachelor's thesis of the University of Kassel, Germany.

Keywords: Hybrid power systems, wind energy, stand-alone grids.

I. INTRODUCTION

Wind power has become important for the Chilean electricity market with an increasing number of projects, as a reaction to the legal reforms to promote the renewable energies and the energy crises of the last decade. Chile significantly lacks its own fossil resources and is highly dependent on imported energy sources, a situation which has led to regular power shortages in the past. The Chilean energy mix is the result of the selection of low-cost energy sources due to the electricity market liberalisation, though the supply security was only ensured by signing reliable contracts and protocols and the needed technical measures, such as gas storage for the regulation of supply disruptions and the consideration of the current high energy costs, were not realised [1].

The entire Chilean power system is divided in isolated grids due to the country's geography and its huge distances. This work focuses on the Chilean South Patagonia, part of the Magallanes Region. South Patagonia is sparsely populated and there is consequently no interconnected power system. Therefore, human settlements and rural zones are supplied through stand-alone grids, which are typically operated with diesel or gas generators. Magallanes enjoys an exceptional situation of state subsidies for gas consumption due to its remote location and as an incentive to populate this area. Therefore, there is a paradoxical situation for Magallanes considering the state gas subsidies and the vast wind potential, which is the key to achieve a renewable energy based decentralised power supply for this region. Furthermore, the Chilean governments have tried since the Argentinian gas crisis to reduce and remove these subsidies. This situation could lead in the near future to high energy prices and social instability. Actually, one of the key issues is the extreme gas consumption in Magallanes, which almost reaches the level of Santiago Metropolitan's Region, although Magallanes only represents around 2,3% of the Metropolitan population.

The usual power supply based on gas or diesel generators for this Chilean region should be complemented with the integration of wind energy converters (WEC). This work exemplifies how a renewable resource could be integrated for power supply of human settlements. The research subject for this paper is the Chilean village: *Villa Tehuelches* (pop. 151), which is located over 100 km from the nearest important urban centre and currently powered with a gas generator. This work presents a reliable modelling of the wind potential for the chosen area based on wind measurements at a nearby location as well as MERRA reanalysis data for long-term correction. This analysis shows that the proposed hybrid solution based on real commercial devices is environmentally meaningful as well as economically profitable compared to the existing supply system and without gas subsidies. The simulations were performed with the software tools energyPRO and windPRO and their results are presented and discussed.

II. CHILEAN AND LOCAL CONDITIONS

A. Renewables in Chile and its legal framework

The Chilean power generation is defined as a deregulated competitive market with freedom to invest, operating under a short run marginal cost pool-dispatch regime and

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therefore, all generation technologies have to compete under equal opportunities (technological neutrality). In 2004 a legal reform process with the enactment of many laws and decrees to promote the integration of non-conventional renewable energies (NCRE) into the Chilean electricity market begun. The reforms' purpose was to procure favourable conditions and benefits for NCRE. Nevertheless, the reforms did not consider subsidies, intended only to create similar market conditions and demand the inclusion of renewables in the energy mix. The absence of clear state subsidies represents a strong economical barrier. The different climatic and geographical conditions require a separate and adapted treatment according to the local characteristics of the demand, the energy resources and the power grid structure [1]. Moreover, the unique geographic situation of the country and the existence of different kinds of natural resources imply the high potential for decentralized power systems, driven by renewable resources or with high integration rates of those.

The Chilean energy mix is currently composed of 90,41% conventional and 9,59% renewable generation, whereas Magallanes is entirely powered by fossil fuels [2]. Up to now, the only renewable source is the wind park Cabo Negro (2,55 MW), which is not connected to any Magallanes' grid and currently only supplies an industrial complex. Figure 1 shows the proportional presence of NCRE in the Chilean energy mix.

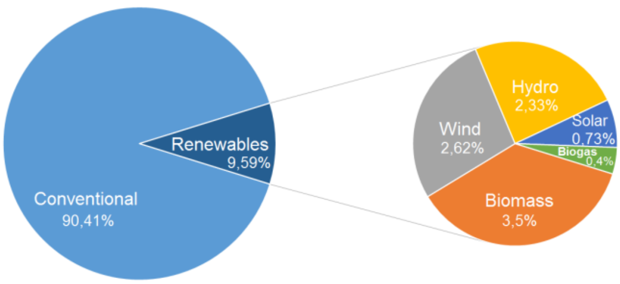

Figure 1. Proportional distribution of NCRE in the Chilean energy matrix [3].

B. State gas subsidies for Magallanes and power supply for *Villa Tehuelches*

Magallanes enjoys an exceptional situation of state subsidies for gas consumption due to its isolation from the rest of Chile and as an incentive for civil population. The consequence of the high subsidies is the extreme low gas price, which on the other hand leads to high consumption and the lack of conscience among the consumers that gas is a finite and expensive natural resource. This fact is of high importance considering the power supply of *Villa Tehuelches* (380 V, 50 Hz), which is currently run by a gas generator. The supply (private and commercial consumption) is free-of-charge for the village's inhabitants, while the village municipality covers the electricity costs. In the past, the village was powered by a diesel system with extremely high costs and a limited supply time (15 h per day). In order to save costs, a gas generator replaced the village's diesel system in 2012 after getting connected to the Magallanes gas pipeline system and thereby the supply time was extended (20 h per day). Due to technical problems during wintertime, the purchase of a second backup generator was agreed. This decision against a supply based on NCRE has been the key object of investigation: the comparison of two alternative supply solutions for *Villa Tehuelches*. One system with two gas generators and a second hybrid system based on one WEC, one gas generator and a battery have been simulated using the modelling and simulation softwares windPRO (for modelling of wind resources based on real measurement data, generic wind data and the power curve of the WEC) and energyPRO (for the simulation of the three-component hybrid energy system based on the load profile, gas prices and investment costs).

III. SIMULATION AND SYSTEM DATA

A. Time series: load profile and wind data

For the energy systems simulation the following influencing variables were used: a customers' load profile (time series of power consumption of *Villa Tehuelches*) and wind data (real wind measurement time series and time series for long term correction [MERRA reanalysis data]).

Load profile: The load profile is based on power consumption measurements from 2005. Considering that at that time the village did not dispose of a full day power supply (24/7 supply), the load profile has been adapted (estimated consumption observed by the municipality) and extended to a non-stop supply. The daily profile shows that peak consumption occurs in the morning time around 7-11 am and in the evening 6-11 pm. This applies on working days (Monday-Friday). On the weekends there is no morning peak, the evening peak is almost the same as on working days. The annual profile shows that consumption gets to its maximum during the winter period (June-September) and has the lowest rates in February due to the fact that there are less people staying in *Villa Tehuelches* during that month (holiday time).

Wind data: The basis for wind data modelling in windPRO was data of wind measurements made at a site 70 km south of *Villa Tehuelches* (measurement height: 28,5 m). The measured data were long-term corrected with the closest MERRA data (53°00`S, 70°66`W). The result of the long-term correction was a correction ratio of 0,945, which could be applied on the MERRA data (52°50`S, 71°33`W) closest to *Villa Tehuelches*. By using the flow model WAsP (Wind Atlas Analysis and Application Program), the data could be modelled to the village's position and to the actual hub height of the wind turbine, which was used to simulate the hybrid system. The result of the modelling was an average wind speed of 8,5 m/s and a quite constant wind direction West-North-West and West. In the simulation software energyPRO both variable time series (load profile and wind data) are merged in order to calculate whether there is a lack or an excessive supply of energy, meaning whether it is necessary to add another energy source (gas generator) to serve the demand or if it is possible to store energy in the battery system.

B. Technical system components

The technical components being included in the compared simulations are either two gas generators (conventional system) or one gas generator, one WEC and a battery (hybrid system). For all components the actual or estimated investment and operating costs were considered.

Gas generator (Doosan GE12TI): This gas generator type is the actual type used for power generation. Its rated power is 157 kW with a performance-related gas consumption of 43,4 m^3/h. The investment costs amount €68.844, the annual operating costs are estimated at €7.659. The gas price for the simulation was set at 0,15 €/m³ (subsidized) and 0,74 €/m³ (market price) [4]. This data was considered for both, the conventional and the hybrid solution.

WEC (VERGNET GEV MP-C; 200 kW): This WEC type has been specially developed for off-grid solutions in remote areas with harsh climate conditions. The manufacturer of the WEC grants high expertise installing hybrid systems in regions with extreme wind conditions and offers highly flexible systems proofed for off-grid connection. The VERGNET GEV MP-C is extremely robust and has a unique flexible lowering system to the ground for maintenance or in case of extreme wind. The estimated investment and annual operating costs were set at €200.000 acc. to [5]. For the hybrid system one turbine of the above mentioned type was considered.

Battery (HOPPECKE Typ 24 OPzS 3000): The storage system consists of two battery blocks with 24 units each. For the simplified calculation in the modelling software, a maximal capacity of 150,5 kWh and a load factor of 80% were considered. The investment costs were set to €102.240 [6] and include a battery management system controlling charge, dis-charge of the battery and power system stability.

IV. SIMULATION RESULTS

The technical simulation was run for one year with the premise to achieve a maximum of integration of the renewable resource and of being able to at any time of the simulation period serve the demand 24/7. The conventional option therefore requires a second gas generator in order to cover periods of maintenance and repairing. Using the conventional option, the total village's energy consumption of 667.329 kWh led to a total gas consumption of 224.516 m^3. The simulation of the hybrid solution with maximum integration of wind energy could reduce the gas consumption to 57.202 m^3. A 75% of the consumed energy of the simulated year could be covered by the WEC. There were even periods (up to one week, e.g. January 7^{th} – 13^{th}) in which the gas generator was totally replaced by the WEC and small lacks of energy supply could be taken over by the battery system which could be charged shortly afterwards using the excessive energy supply in periods of good wind conditions.

Nevertheless, the simulation also showed that there do exist periods with low wind energy supply during which the gas generator has to cover. But, with the integration of wind energy and its maximum use in combination with the battery, the system allowed short shutdowns of the gas generator. Those shutdowns mainly occurred when the difference between the total load and the load served by the WEC was lower than the minimum partial load of the generator. This observation lead to the general rule for battery use within the hybrid system:

$$P_{e\_total\,load} - P_{e\_Wind} = P_{e\_\text{rest Battery}} < P_{e\_\min Gas} \quad (1)$$

The economic simulation of both systems was based on the concept of Electricity Generation Costs for a typical project period of 20 years, considering annually increasing operation costs for each component of 2% and an increasing gas price of 7% [7] [8].

$$c_m = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{q^t}}{\sum_{t=1}^{n} \frac{W_{el\_t}}{q^t}} \quad (2)$$

where:

c_m: Electricity generation costs [€/kWh]
W_{el_t}: Produced electricity in year "t" [kWh/a]
I_0: Investment costs [€]
A_t: Operating expenditure in year "t" [€/a]
t: Current year
q: Discount factor ($q = 1 + i/100$)
i: Imputed interest rate [%/a]
n: Imputed economic life

For both options, the cost of electricity was determined with either subsidized or market gas prices. The conventional option caused comparatively low investment costs (€127.688) but high operation costs due to the gas consumption: fuel costs of €33.677 and €129.931 for the first and last year respectively, considering state subsidized gas price. Without gas subsidies, the costs rose from €166.142 to €640.992. Therefore, the conventional option's generation costs amount 0,135 €/kWh (subsidized) and 0,495 €/kWh (market price). The hybrid system involves higher investment costs (€366.084), but achieved more profitable results: 0,096 €/kWh (subsidized) and 0,189 €/kWh (market price), due to the reduced gas consumption. The simulated gas costs at the beginning of the project are €8.589 (subsidized) or €42.330 (market price) and rise up to €35.069 (subsidized) or €173.000 (market price). Table 1 summarizes the most important economic key indicators of both systems:

Table 1. Economic key indicators for the conventional and hybrid systems.

Conventional vs. hybrid supply solution				
	subsidized gas prices		market gas prices	
Energy system	convent.	hybrid	convent.	hybrid
Energy generation costs [€/kWh]	0,135	0,096	0,494	0,189
Total project costs [€]	1.935.700	1.061.675	7.583.124	2.556.790
Initial investments [€]	127.688		366.084	
Annual operating costs [€]	48.995 (2013) 152.240 (2032)	21.564 (2013) 53.984 (2032)	181.460 (2013) 663.307 (2032)	55.314 (2013) 191.922 (2032)
Fuel costs included in operating costs [%]	86,7	39,8	91,6	76,5

Figure 2 shows the developing of all operating costs for the conventional system and the hybrid system with subsidized gas prices.

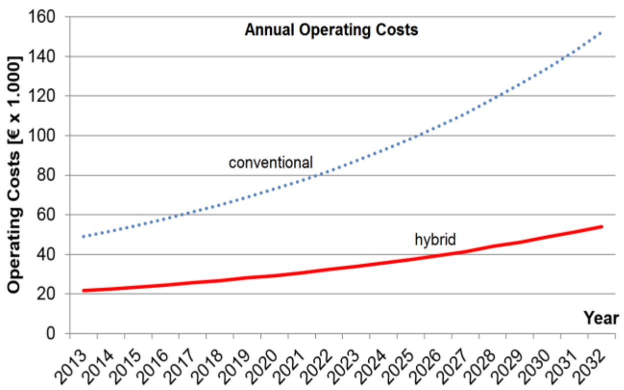

Figure 2. Annual operating costs for conventional and hybrid systems with subsidized gas prices.

V. CONCLUSIONS

This work has shown the importance of renewables as supply solution. Chile depends on fuel imports and therefore needs to diversify its energy mix in order to reduce the gas dependence. The simulations results show that the wind gas battery hybrid system is a feasible supply solution for isolated areas. It not only manages full power supply for the population while reducing drastically operation costs but also lowers risks of depending on finite and foreign resource prices which might rise in the future with changing political governance. The technical and economical comparison of the system allowed to clearly focusing on the advantages of the designed hybrid system.

For *Villa Tehuelches* the implementation of such a system (1) allows reducing operation costs, (2) allows integrating wind power as main renewable resource in Patagonia and (3) contributes to reduce CO2 emissions by decreasing gas consumption.

The designed hybrid system for *Villa Tehuelches* gives an example of how to face the difficult geographical situation of Chile and the challenging objective of raising the percentage of ERNC in the Chilean energy mix. It shows that the use of locally available natural energy sources is not only technically possible, but also economically reasonable. The use of reliable hybrid solutions presents an important part of sustainable development in the Chilean Energy Agenda. On the other hand, it has also be mentioned that there is a need to changing (1) people`s conscience of energy use and (2) state priorities concerning subsidies for finite resources towards subsidies or a more accessible system for promoting renewable decentralized small and medium sized energy projects by facilitating access to financial tools for investments.

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DOUBLE SKIN FAÇADES, TECHNOLOGY AND INNOVATION IN ARCHITECTURE

Learning from 20 years of experience in Germany

Renato D'Alençon Castrillón. M.Arch.[1]

ABSTRACT

Some 20 years ago, the development of Double-skin Glass façades (DSFs) grew in Germany as a promising alternative to address the well-known problems of curtain walls, particularly heat loss, over-heating and noise, by combining a thermal buffer and sun protection in a ventilated glass chamber. The introduction and spread of DSFs was not only based on technical innovations from the field of building physics, but also strongly fostered by a growing trend within architectural practice, including social and aesthetic values, such as the construction of a corporate image or the pervasiveness of fashionable and widely published buildings that served as examples.

In this paper, I discuss the articulation of the technical fundamentals and the social mechanisms that promoted the use of DSFs in buildings in Germany starting in the 1990s, based on available documentation from patents, industry catalogues, contemporary literature and ex-post evaluations of the buildings. I hold that DSFs make a case for a combined techno-social development, far from linear or objective, but intertwined with a cultural and social elements suggesting a new understanding of technical decisions presumed neutral. The case of DSFs shows how this process goes beyond objective technical properties or performance, and needs to be accounted for and kept in mind in order to fully understand the development and success or failure of technological innovations in architecture.

Keywords: double-glazed façades, innovation, energy efficiency, user acceptance.

I. INTRODUCTION

Traditionally, the accounts of architecture tend to explain it, either from a theoretical, aesthetic or historic point of view. A closed narrative of historical events, theoretical constructs or aesthetic fashions are offered side by side the built work or the practice to attempt a parallel that would deliver the necessary explanations and will thus allow decoding it. Less often is it explained from inside its own discipline and practice, intertwining the social and the material dimensions in a bi-directional mode, where not only external events provide a rationale for its comprehension, but also its own *dasein* acts upon reality beyond intentions or discourses and reveals its own nature. Notorious exceptions such as Lewis Mumford's classic Technics and Civilization [1] are not enough to build a systematic scholarship by any chance comparable to that of architecture historians, still regrettably stuck in the explanatory, plastic or theoretical approach to architecture history.

Technical innovations, such as acoustics or environmental performance have been barely included in the critical agenda of architecture and remain to be problematized. In particular, the properties of building envelopes were articulated mostly in an aesthetical fashion, which emphasized the plastic potentials of glazed fassades: transparency, lightness, spatial continuitybut seldom in environmental or user comfort terms.

Some 20 years ago, the development of Double-Skin Glass Façades (DSFs) grew as a promising alternative to address the well-known problems of curtain walls, particularly heat loss, over-heating and sound insulation, by combining a thermal and acoustic buffer space and sun protection in a ventilated chamber between two layers of glass (Fig. 1).

Figure 1. Bussiness Promotion Center, Duisburg, 1993. One of the earliest examples of simple double glazed façades. Arch.: Richard Rogers.

The claimed benefits of DSFs are [2]: the provision of a protected space for installing sun shading and daylight enhancing devices; the cavity is in the winter a buffer zone reducing thermal losses; the double membrane is effective in reducing noise from motor traffic.

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II. ANALYSIS FRAMEWORK and METHOD

A conceptual framework relating technology and culture in architecture is surprisingly not at the core of architectural discourses. An analytical framework to established such relation can be found in the field of Science and Technology Studies (STS), as it offers a comprehensive model for describing the process of technological innovation involved and proposes methodological tools that can be deployed for supporting a cultural-technical analysis.

Drawing from this background, two central concepts can be used in defining a conceptual background for this work: "interpretative flexibility" and "relevant social groups". "Interpretative flexibility" is a concept meaning that technological artefacts offer different meanings and are open to different interpretations for different social group. Phrased by Bijker and Pinch [3], interpretive flexibility means:

> *"Technological artefacts are culturally constructed and interpreted ... By this we mean not only that there is flexibility in how people think of or interpret artefacts but also that there is flexibility in how artefacts are designed."*

Other relevant concept is that of "relevant social groups", a socially defined group sharing a particular set of meanings related to an artefact and "closure and stabilization", the process of the relevant social groups reaching a consensus regarding the meaning of the artefact. Most importantly, the process of social group interpretation, meaning attachment, consensus, stabilization, closure, is not a linear one. Newer, better technologies are not preferred successively to older, worse technologies, but this happens in parallel with several competing technologies and in multiple directions, so that prevailing technologies cannot be considered to be best or the only one.

The method for applying this analysis framework can be summarized in three steps: 1. identifying the social groups; 2. describing the technology through the eyes of the relevant social groups; 3. establishing the interpretative flexibility of the technology.

I the following, I discuss the technical fundamentals and the relevant social groups that fostered the use of DSFs in Germany starting in the 1990s, based on documentation available from patents, industry catalogues, contemporary literature and ex-post evaluations of the buildings. Using case studies, I document and trace the introduction and spread of DSFs, which was not only based on technical innovations from the field of building physics, but also strongly fostered by a growing trend within architectural practice, intertwined with other social and aesthetic values, such as the construction of corporate image or the pervasiveness of fashionable and widely published buildings that served as examples. I hold that DSFs make a case for an intertwined techno-social development, far from linear or objective, but tainted with a variety of cultural and social values suggesting a new understanding technical decisions presumed neutral.

III. DSFs: FROM TRIAL TO UNSETTLING

Glazed façade designs have undergone in the last decades substantial innovation by integrating specific elements to adapt the mediation of the outside conditions and user requirements, both in the quality of materials and components and in the overall conception and design of the façade system. These improvements include passive measures, such as multi layered glazing, sun protections, ventilations, etc. and are articulated in as double-layered façades, ventilated façades or protected façades. The literature has come to a number of definitions for these, among which, a comprehensive one was proposed already in 1999 by Compagno [4], naming them "intelligent glass façades":

> *"The "intelligence of a façade is not measured primarily by how much it is driven by technology, but by how it makes use of natural, renewable energy sources, such as solar radiation, air flows and the ground heat in as environmentally compatible way as possible".*

A Double Skin Façade (DSF) system consists of an exterior and interior glazing, with varying insulation, ventilation and access strategies; an air cavity between the exterior and interior glazing, with natural or hybrid ventilation and thickness ranging between 10 cm to more than 2m; a shading device, placed inside the cavity for protection reasons; and openings in the external and internal skin and sometimes ventilators, which allow the ventilation of the cavity [5]. The control of the conditions of the chamber, to insulate in winter conditions and ventilate in summer conditions is the distinctive feature of DSFs. Critical issues are the choice of the proper pane type and shading device and the geometry and dimensions of the design.

Even if DSFs can be used as an added façade, with the cavities used mostly to reduce noise, contain solar shading and light redirection devices, their full potential is developed when they integrate the heating, cooling and ventilating system of the building. The most usual case is that of the building being ventilated using the cavity. This is more cost effective as it reduces the demand on the mechanical system, "*the first alternative risk being a building with a complete conventional HVAC system, with the added cost of an expensive façade*" [5].

A. Hallenseestrasse (1996): Trial and Error

One of the first buildings in using a buffer space as an insulation chamber between two glass panes in Germany is the Hallenseestrasse office building in Berlin (Archs. Leon and Wohlhage), located on a site close to an urban highway that was considered unbuildable because of noise (Fig. 2). To meet the conditions of implementation, the building consists of a first trench of 3-story concrete, the height of the retaining walls of the trench in the road, staying in parking lots and services, and an upper part of 7 floors of office floors with curtain wall facades.

Figure 2. Hallenseestrasse Office Building. View of the building from the south facade facing an urban highway made it seem useless for acoustic reasons.

On the south façade, which faces the road, is added to a double skin ventilated facade to control combustion noise and smoke, composed of two glass sheets with a 85 cm chamber with interior glazing seal double glazing (WSG) exterior with safety glass (ESG) reflecting, in addition to sunscreen roll-curtains inside the chamber (Fig. 3).

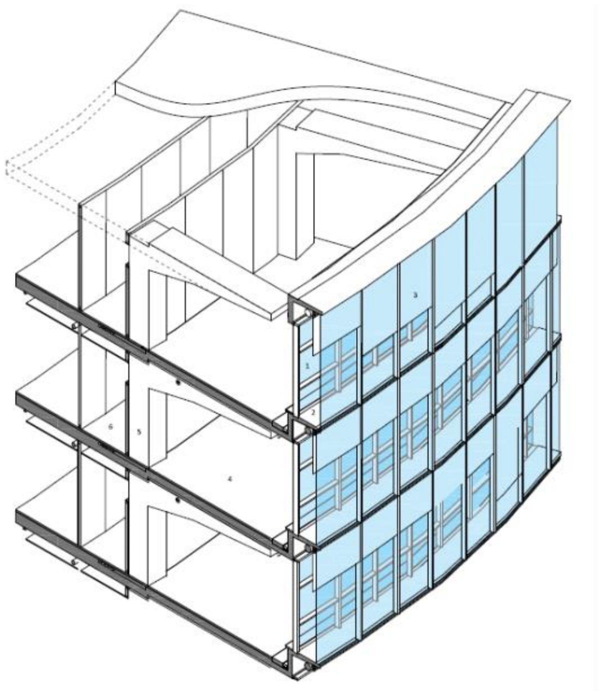

Figure 3. Hallenseestrasse Office Building, The double facade corridor allows to open windows to the chamber and to ventilate to through ducts that are housed under the overhang of the sill.

There is no direct air exchange to the outside but through the chamber which in turn mechanically assisted ventilation through air ducts closed within it. The double facade is a "corridor", i.e. horizontal partition dividing the chamber on each floor, which prevents the transfer of noise by air from one floor to another even when users can open the windows to influence the indoor individually or have contact with the outside.

Figure 4. Hallenseestrasse Office Building. Interior office space; that remains unused because of the poor environmental performance of the building: on the left; the hvac set up in an attempt to fix this.

The original purpose of the double skin in this case was to reduce the impact of road noise. This led to the overheating of the camera, oriented to the south, and the ventilation was solved by the mechanical ductwork inside, since the outer leaf is sealed. However, the camera will develop high temperatures and is a problem for users to open the windows even though they are operable, not only in the summer situation. This experience shows that even in a climate like that of Berlin, short summer (July and August) temperature average of about 18 ° and extreme rarely exceeding 28 °, overheating by solar radiation can be transformed into a problematic consideration. The problem led to the vacancy of several storeys of the building for several years, and the problem had to be resolved through the installation of air conditioning equipment to replace the original radiators (Fig.4).

B. RWE Tower (1996): a patented building

In the RWE Tower in Essen (Archs. Ingehoven, Overdiek und Partner) a choice is made for a cylindrical shape (Fig. 5) corresponding to the designer’s search for an optimal ratio between the outer skin area and volume, as compared to the pressure of wind and heat loss [6]. Vertical access is via lifts tower outside the main cylindrical volume and the floors are organized from the lifts on two service cores interior corridor access and perimeter zone office. In addition to a double glazed façade, the building has a central ventilation system in a technical storey located in an intermediate floor.

Figure 5. RWE Headquarters Archs Ingehoven, Overdiek und Partner (1996). General View.

The double facade is of box type with alternating intake and output in a single element of the façade, which delivers to the chamber through vents also placed alternately (Fig. 6). Each chamber front is a dual inlet-outlet chamber that is open to the outside through the windows above and admissions can be opened to allow direct control of natural ventilation by users over the terms of the mechanical system building. When weather conditions prevent the opening of windows, ventilation is provided by an air conditioning plant placed on an intermediate level with a capacity sized air exchange to this effect.

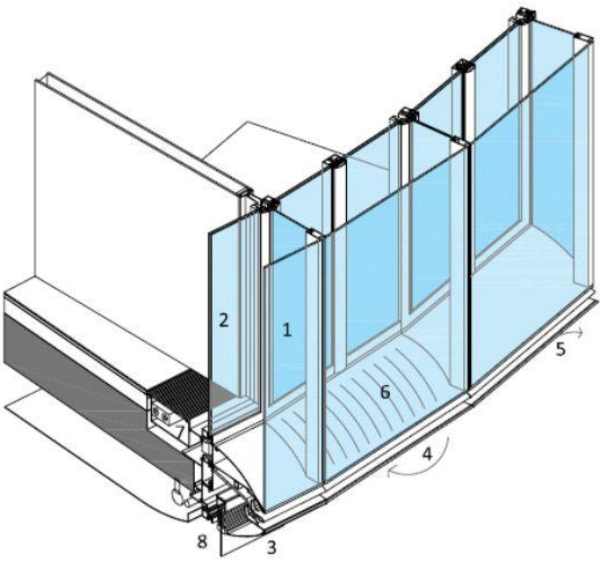

Figure 6. RWE Headquarters. Detail of the ventilated chamber inlet-outlet. 1. Double façade external glass; 2. Interior glass façade with operable window; 3. Inlet and vent to the outside of each module; 4. Admission profile; 5. Outlet profile; 6. Input grid to the chamber; 7. Heating radiators under floor level; 8. Sun protections blinds inside the chamber

In the implementation of this building, several actors can be identified to have vested interests in the development of this technology: the architects, the owners and the façade producers. The architects' interest is reflected in a self-published volume [6]:

> *"The design demonstrates a high degree of energy efficiency, recognising the constraints of natural resources, and incorporating them to advantage in the architecture and technology of the building".*

The colaboration of an industrial partner and a consultant for façades design is usual practice in a building of this maginitude. Less often is the industry's interest so strong as to be cautioned with the filing of a patent on a ventilation for a high-rise with double-façades "Lüftung für Hochhäuser mit Doppelfassade" Patent 652407a2 [7]:

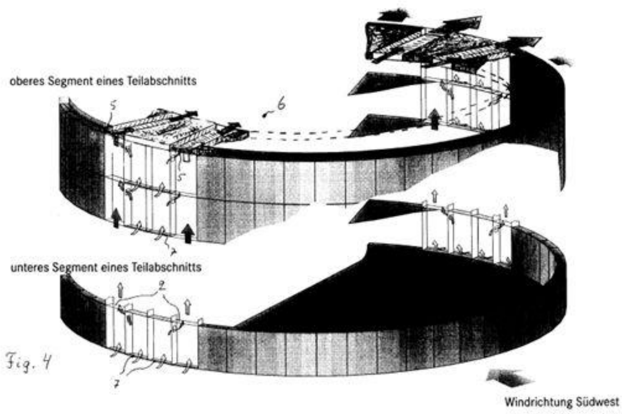

Figure 7. Descriptive from Patent 652407a2. Source: Deutsches Patent- und Markenamt (DPMA) Database DEPATIS

It is notorious from the round-shaped design in the patents documentation (Fig. 7) that it is a case-specific patent, referring to the design of RWE and not a generic solution, showing the entire system of ventilation of the façade modules and the centralized system. The building is thus in itself a full-scale trial where the industry tests a new system.

C. GSW (1999): Icon Reference for Architects

Figure 8. GSW Headquarters Berlin: double glazed ventilated façade

The GSW Headquarters, in Berlin, (Archs. Sauerbruch and Hutton) (Fig. 8) is a very representative case of DSFs because of the wide publicity it received from the architectural press. The building, completed in 1999, has been of big influence in the architecture milieu, because of its very strong and plastic image, and is one of the main responsible for the spread of DSFs among Architects (Fig 9).

Figure 9. GSW Headquarters Berlin: official publication about the building by the architects [8]

According to the authors, the natural ventilation strategy is a central component of the energy strategy. Because of the low floor-to-floor height, predefined to 3,25 m by an existing tower, the thickness of the new building was limited for purposes of natural lighting, reaching 11 m in the deepest section. This narrow plan allowed cross ventilation (Fig. 10), which was expected to allow reductions of 27°C indoors with 32°C outside, without refrigeration, using a “peak looping” system [9].

The buoyancy in the chamber cross ventilates in complement with louvered operable elements in the east façade, and with plenum floor and mechanical ventilation for extreme season situations. The system is centrally controlled with override allowance by the users. The natural ventilation DSFs in summer conditions and the insulating buffer in winter conditions are the main, alternating features that have turned them very used by architects.

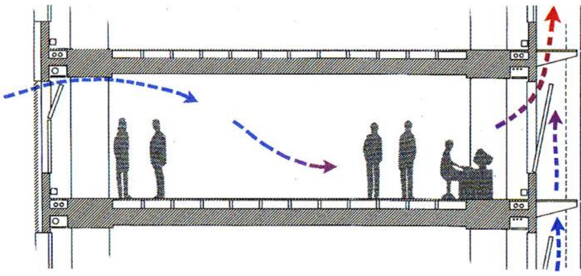

Figure 10. GSW Headquarters Berlin: Diagram of the ventilation scheme, widely published to explain the operation of the building

However, it is not yet clearly defined if and how does the system work in the summer, and further study is required to establish this for this and other DSF buildings. One of the most comprehensive post-ocupational studies about DSF was conducted by the Technical University of Braunschweig under the title EVA – Evaluierung von Energiekonzepten and considered this building as one of the emblematic cases to be studied, yet surprisingly the results of the evaluation were not published in the Final Report [10].

C. Post Tower (2002): Corporate Image

In the Deutsche Post Tower in Bonn (Murphy / Jahn Archs.) the air is tempered in the DSF cavity in the winter, or ventilated by buoyancy during the summer.
Movable panes (Fig. 11) allow for additional air admission in the chamber, which is then more porous than typical DSFs, enhancing ventilation of the chamber. The building can be naturally ventilated mainly in spring and autumn, and the mechanical system operates primarily in extreme conditions of summer and winter.

Figure 11. Deutsche Post Headquarters. The double fronted in this case is permeable on each floor with its louvered facade design, with horizontal glass hatches.

After being tempered in the intermediate buffer, the air is drawn into the decentralized air supply units (FSL, Fassaden System Lüftung provided by Trox) are placed below floor level, taking air from the double façade chamber and injecting it into the work spaces. The exhaust air is conducted to the nine story high "Sky Courts" (Fig. 12) where it is used for heating, and then exhausted centrally [11]. In addition to ventilation, the decentralized units also regulate the temperature of the intake air. The building can be ventilated naturally, mainly in spring and autumn, the mechanical system operating in extreme conditions of summer and winter.

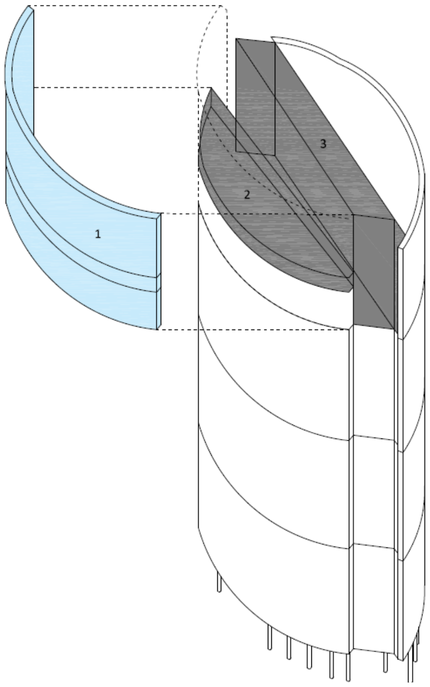

Figure 12. Deutsche Post Headquarters. Sky court scheme and 7 story high ventilated facade.

Research conducted in generic mockups by the producer indicates that the cooling loads and overall energy demand are roughly comparable to those of a central HVAC system (Fig 13). Advantages that continue to be mentioned are: lower energy requirements for distribution of the conditioned air mass; lower construction costs and simpler implementation and maintenance; individual control of the temperature and ventilation rates.

In comparison to other examples, the approach of the DSF in the Post Bank is mixed, both in the side of the DSF, by including additional ventilation possibilities with the louvered outer skin, and in the side of the mechanical ventilation, by avoiding a centralized system, sparing the space for the central units and for the ductwork in every floor level.

The building profited from the earlier experiences from other cases and included mechanical ventilation with the support of the providers, and solved some of the problems other DSFs had by breaking the height of the DSF in sections allowing the external glass to be ventilated not only at the bottom and the top.

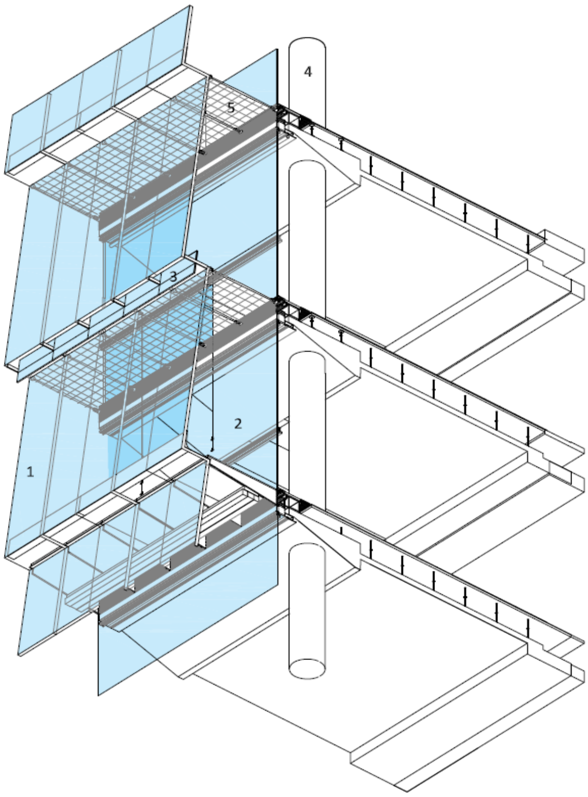

Figure 13. Deutsche Post Headquarters. Ventilated double facade multiple is high, but it can be outward on each floor through glazed hinged hatches.

Furthermore, besides the fulfilment of the goals of other actors, such as the architects and the mechanical systems providers, the building is especially important as a corporate image used by the Deutsche Post to enhance its image as a modern, dynamic enterprise (Fig 14), a usual goal for companies deciding to use glass façades.

Figure 14. Deutsche Post Headquarters. Deutsche Post Stamp presenting the HQ Building as an icon representing the corporate identity of the company

IV. EVALUATION AND CONTROVERSY

It is not yet clearly defined if and how does these system work in the summer, and further study is required to establish this for this and other DSF buildings. The abundant literature [2] [4] [12] on the study and modelling of DSFs prior to their construction, supports a general optimism regarding their qualities, in particular the idea that double façades with buffer spaces significantly improve the thermal insulation capacities of the glazed solutions, a critical item in the regulation requirements. However, these claims are controversial. Only a few contemporary authors, notoriously Dr. Gertis contested the presumed advantages of the DSFs [13]:

> *"(...) Conclusion: Simulations cannot be relied on, practical measurements are lacking. Here is a lot to catch up. It becomes, however, apparent that GDFs – apart for special cases – are unsuitable for our local climate from the building physics point of view"*

In the 2000s, several initiatives undertook comprehensive evaluations [5] [10] as suggested by Prof. Gertis, thus reflecting a widespread success of DSFs in the building industry. Nevertheless, the state of knowledge in the area was and remains not to be conclusive regarding their performance because there were only a few post-occupational studies of DSFs. These studies recognize the lack of information about the measured performance of completed buildings, the need to validate the design-stage modelling and for a general assessment of their energy demand, environmental impact and pay-back period.

V. CONCLUSION

The introduction and spread of DSFs was not only based on technical innovations and expected improved performance, but also strongly fostered by a growing trend within architectural practice, intertwined with other social and aesthetic values, such as the construction of a corporate image or the pervasiveness of fashionable and widely published buildings that served as examples. Several DSFs buildings were constructed with only a general idea about their environmental performance, on a trial and error fashion. Patents came usually after the design, consolidating a technical development that was intertwined with the design of specific buildings that served as probes.

By the time several books and studies came to document them DSFs were already an established practice within the trade. Later, other initiatives attempted to provide guidelines for optimizing their design, and although relatively scattered, attempts have also been made to evaluate their post-occupation energy efficiency, with diverging results. None of these has been conclusive about the energetic or economic validity of DSFs, neither their benefits nor their failure. The case of DSFs shows how the innovation process goes beyond objective technical properties or performance, and needs to be accounted for and kept in mind in order to fully understand the development and success or failure of technological innovations in architecture.

The same design is object of different perspectives and claims of the involved actors, namely: the architects, for whom the design is demonstrative of a high degree of energy efficiency; the façade industry for which the tower is a test site for a new ventilated façade to be patented; the owner for which the tower is an icon corporation image to be used in public relations and publicity; and the administration, dealing with the actual performance based on direct experience from daily operation and direct costs. At the same time, all of them subscribe the general claim of an efficient, ecological building for different reasons and from their own perspectives; a claim that is at odds with inconclusive evaluations and is rather a rhetorical closure of an unsettled controversy.

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Towards a sustainable electricity system in Chile

Current situation and assessment methodology

Carlos Gaete[1,5], Alejandro Gallego[2,5], Laurence Stamford[3,5] and Adisa Azapagic[4,5]

ABSTRACT

Achieving sustainable development is a priority nowadays, and electricity systems play an especially relevant role. In 2014, Chile consumed 70.4 TWh of electricity generated mainly from hydropower and thermal plants. Since 2008 Chile has experienced consistently high prices of electricity affecting the national economy. In addition, society is not inclined to support new power plants due to distrust of the environmental assessment system and the lack of public discussion. On the other hand, the electricity sector is considered the largest contributor to climate change, and therefore a plan is required to reduce its greenhouse gas emissions. Considering the economic, social and environmental challenges, this article presents a methodology for assessing the sustainability of electricity production in Chile. The sustainability of the electricity system will be assessed considering future scenarios and using tools such as life cycle Assessment (LCA), social life cycle assessment (SLCA) and life cycle costing (LCC).

Keywords: Life Cycle Assessment (LCA), electricity generation, environmental social and economic evaluation, sustainability.

I. INTRODUCTION

1.1. Sustainable Development

In 1987, Sustainable Development was defined for the first time by the United Nations (UN) as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

In achieving this sustainability, electricity plays a major role. On one hand, electricity helps to bring about efficient industrial development and social progress. On the other, current electricity systems are shaped by technologies which have negative impacts on the environment, and can generate economic and social problems. For that reason, electricity systems should be designed to overcome these issues and contribute to sustainable development.

1.2. The electricity sector in Chile

The electricity sector in Chile had, in 2014, an installed power capacity of 20,265 MW which is mainly composed of fossil fuels followed by hydropower with shares of 61.3% and 31.7% respectively [1] (see Table 1).

The generation of electricity in 2014 totalled 70.4 TWh produced by 4 electricity systems: i) Central Interconnected System (SIC by its acronym in Spanish), ii) Interconnected System of Norte Grande (SING), iii) Aysen and iv) Magallanes. The first two – SIC and SING – are the major systems, while the latter two are located in southern Chile and provide less than 1% of the electricity produced in the country.

SING is located in the northern part of the country, an area with a predominantly desert climate. It covers close to 25% of the Chilean mainland surface area yet only 6% of Chile's population lives there. The quantity of energy produced by this systems is 15.8 TWh, 67.8% of which is consumed by mining companies [1]–[3]. Electricity in SING is mainly produced by thermal power plants located on the coastline.

Table 1. Electricity generation and power capacity by source in Chile in 2014 [1], [4], [5].

Sources	**Installed Capacity**		**Electricity**	
	Gross capacity [Mw]	***Share [%]***	***Gross supply [TWh]***	***Share [%]***
Coal	4,519	22.3%	28.4	40.3%
Natural Gas	5,059	25.0%	10.3	14.6%
Oil	2,828	14.0%	3.4	4.8%
Hydro	6,430	31.7%	23.7	33.6%
Biomass	453	2.2%	2.7	3.9%
Wind	734	3.6%	1.4	2.0%
Solar	224	1.1%	0.5	0.7%
Cogeneration	18	0.1%	0.1	0.2%
Total	20,265		70.4	

The second main system (SIC) is located in the central area of the country and is the largest electrical system as it supplies power to 90% of Chile's population and extends over 2,100 km. This system is mainly composed of hydropower and thermoelectric power plants and reached an electricity generation in 2014 of 47.3 TWh [1], [2], [6].

1.2.1. Economic aspects

In the case of the SIC system, the hourly average marginal cost in 2013 was US$151/MWh and in 2014

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US$135/MWh [1]; this compares to around US$50/MWh in the USA [7]. Underlying these high prices are some structural deficits. In the case of the mentioned SIC system, during the 1990s electricity was mainly produced by hydropower causing a high volatility of prices because of variability of hydrologic conditions from one year to the next [6]. From 1996 to 2004 the use of natural gas power plants fed by Argentinian gas reduced the volatility of electricity prices, reaching a US$24.78/MWh ‘node price’ (the softened price developed for consumers in order to protect them from the higher variability of wholesale price). However, the curtailment of Argentinian gas started in 2004 reaching almost the total reduction of supply in 2007 leading to a rising of node prices up to US$103.75/MWh in 2008 [2], [8], [9]. Due to these circumstances, gas power plants had to be replaced by coal power plants. The hydropower and coal generation allowed a reduction in price volatility, but since 2008, electricity prices in SIC have remained high [8].

This may be explained by the following factors: i) High volatility of fossil fuel prices [2]; ii) The occurrence of three years of drought between 2010 and 2012 [10], iii) Lack of investment in new energy projects caused by difficulties experienced in obtaining certifications, mainly explained by environmental and public opposition in spite of less interest in investing [10] and iv) the exertion of market power (“ability of an agent to influence the price of the market” [11]), due to the existence of a highly concentrated electricity market in which three companies have historically owned up to 89% of total SIC capacity (and currently own about 76% including subsidiaries) [1], [10], [12], [13]. Several authors have established that liberalized markets can allow companies with high market share to exert market power in different ways (e.g.: through reduction of investment; over-investing in peaking technology and under-investing in base load technology) [11], [12], [14]–[16].

As SIC represents a high percentage of Chile’s electricity demand, high electricity prices become an important national issue affecting individual consumers and production sectors. Empirical results confirm that Chile's high electricity price has affected negatively the economic activity, consumption, private investment, employment, and the export sector to the industry which compete with imports and productivity [17]. The capacity of meeting personal needs is affected and production sectors become less competitive, affecting deeply the economic growth [18].

1.2.2. Social concerns

On the other hand, the electricity sector has been facing social opposition since 1992 when indigenous leaders disapproved the construction of Pangue and Ralco hydropower plants and were requested to leave their ancestral territories [19], [20]. In 2011 the Ministry of Energy conducted a study to identify the difficulties experienced by electricity projects in progressing to commissioning. In total, 13 projects (predominantly hydropower dams and thermal power plants) were identified that had received 117 administrative or legal objections [21], demonstrating high social opposition. This is in part explained by Mundaca [9] who stated that Chile’s environmental framework law permits private companies to choose the information to be presented in the Environmental Impact Assessment (EIA) system, and, therefore, allows manipulation, lessens transparency and suppresses opportunities for public discussion in the assessment process. Similarly, Berdegue [22] stated that society’s continuous opposition to new power projects is due to the lack of legitimacy of the evaluation process which does not provide an effective space for discussion; additionally, the distribution of costs and benefits for affected communities is inadequate.

1.2.3. Environmental impacts

As a member of UN, Chile has committed to creating a new international climate agreement to be presented in the U.N. Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP21) that will be held in Paris in December 2015. For that reason, in December 2014 the Chilean government presented a public consultation to decide national strategy for reduction of greenhouse gas (GHG) emissions. The reduction will vary from 25% in 2025 up to 45% in 2030 in relation to 2007 emissions. Considering that the main contributor to GHG emission is the energy sector (75% in 2010), the mitigation plan will focus in the reduction of emissions generated by the electricity system.

Chile will face important challenges in the coming years associated with economic, social and environmental aspects, where the electricity sector will play a relevant role. All the issues mentioned in previous sections justify the development of a study that assesses sustainable future scenarios for the electricity system in Chile through the application of a specific methodology.

II. SELECTED METHODOLOGY

Santoyo-Castelazo and Azapagic [23] developed recently a methodology to assess the sustainability of energy systems. These authors developed a generic framework that can be applied to a variety of energy systems and enables the integration of sustainability assessment with future scenarios using a life cycle approach. This methodology has been selected to be applied to the Chilean electricity system.

2.1. Sustainability assessment methodology

As can be observed in Figure 1. this methodology consists of several consecutive steps: i) selection of sustainability indicators, ii) selection and specification of technologies, iii) definition of scenarios, iv) environmental, economic and social assessments and v) multi-criteria decision analysis.

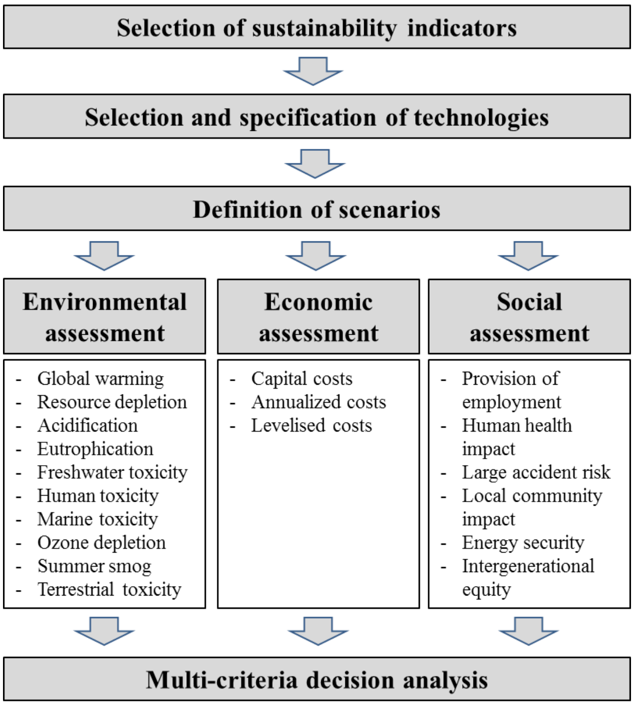

Figure 1. Sustainability assessment methodology [23].

2.1.1. Selection of sustainability indicators

Several environmental, social and economic indicators can be chosen to assess the sustainability under a life cycle approach [23]. For environmental issues, Life Cycle Assessment (LCA) is a methodology that explores the potential environmental impacts caused by a product during its whole life cycle (raw material extraction and production, infrastructure commissioning, products or services production, use and final disposal). It has been used for more than 35 years and has become a well-known tool which has been useful in several sectors, including energy generation [24]. The life cycle assessment (LCA) methodology is regulated by the International Standards Organization (ISO) through the ISO 14040 standards. Based on LCA, the following environmental impacts can be considered in the mentioned sustainability methodology: global warming, abiotic depletion, acidification, eutrophication, freshwater aquatic ecotoxicity, human toxicity, marine aquatic ecotoxicity, ozone depletion, photochemical ozone creation and terrestrial ecotoxicity [23].

Social life cycle assessment focuses in the social effects of the life cycle of a product or process. This methodology shares similarities with environmental LCA, including the following challenges: acquiring site-specific data; addressing location- or scale-specific information; and achieving standardised techniques [25]. Social indicators can be considered in the assessment methodology according to their relevance to the sector, such as provision of employment, human health impact, large accident risk, local community impacts, energy security and intergenerational equity [23], [26].

For the economic evaluation, life cycle costing (LCC) will be applied. LCC is defined as "an economic evaluation of different design options taking into account every significant cost to obtain assets along the economic life of each option expressed in present currency". For energy systems, LCC is used to estimate and compare all costs associated with the production of electricity in different scenarios. The economic indicators that may be considered are: capital costs, total annualized costs, and levelised costs, where the latter represents total costs per unit of energy [23].

2.1.2. Selection and specification of technologies

The aim of this step is to identify all technologies that could be included in the analysis according to availability in the present or future and territorial conditions [23]. For example, renewable, nuclear or conventional technologies may be considered in this analysis.

2.1.3. Definition of scenarios

Scenario analysis is included to find alternative energy situations and assess their sustainability implications. Several factors can be considered for the development of scenarios, such as economic growth, security of supply, mitigation of climate change and future technological development [23].

2.1.4. Environmental, social and economic assessment

Each scenario must be assessed with the purpose of estimating its potential impacts. The indicators selected previously are applied in this step [23].

2.1.5. Multi-criteria decision analysis (MCDA)

Robust decisions involving a range of options must consider a range of environmental, economic and social criteria. Often, there is no single best option in relation to all criteria: decisions may lead to an improvement in some criteria and a decline in others. In order to support improvements and solve these problems, MCDA provides various structured techniques for decision makers [27].

MCDA methods address problems that involve multiple criteria based on preferences or weights for each criterion. This is particularly useful in energy systems because of the various sustainability issues that have to be considered and a diverse range of stakeholder perspectives [14]. For that reason, MCDA had been used extensively in relation to sustainable energy [27].

Generally, the first step in MCDA involves identification of options or scenarios to be considered and sustainability indicators which will be used as decision criteria [27]. This is followed up by decision makers expressing their preferences for different decision criteria by assigning weights of importance. Various methods can be used for this, including the analytical hierarchy process or utility function [28]. This could be carried out by consultation with decision makers [27] in which they are asked to compare different indicators, or in a wider consultation with other stakeholders, such as the public [28]. The indicators are then aggregated into a single score based on the weights of importance so that the alternatives or scenario can be compared more easily, thus facilitating identification of the most sustainable option [28], [29].

III. CONCLUSIONS

Electricity systems are highly complex involving many environmental, social and economic aspects. The case of Chile is not an exception and the results of implementation of the proposed sustainability methodology will give support to decision and policy makers. One of the major challenges will be to find, select and develop information that is correct and appropriate in the context of Chile's characteristics.

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The effect of foreign direct investments and of different offshoring models on the upgrading of the local IT-Industry in emerging economies.

Searching for "inter-firm knowledge transfer flows" based on case studies in Chile and Uruguay.

M.Sc. Carla Gutiérrez Basso[1]

ABSTRACT

The offshoring of knowledge services has become increasingly important for firms and their competitiveness as well as for countries wishing to enter the global market. Previous studies have considered the effects of offshoring and the forms of knowledge transfer mainly within multinational corporations (MNCs) and their subsidiaries abroad. This paper focuses on the effects of offshoring in the host market and their supply firms, and is based on a dynamic of "mutuality of interest" in a balanced organization in the global market. The main argument of this paper is that knowledge creation should be supported by both sides. Due to the "digital revolution" many emerging countries have the chance to position themselves in the global market through offshoring and therefore to upgrade the local economy. This is a theoretical and empirical approach based on the case studies of Montevideo (Uruguay) and Santiago and Valparaíso (Chile), and indicates that each offshoring model has different effects on the knowledge transfer between firms. Moreover, proximity between foreign direct investments (FDI) and domestic firms can play an important role in interactive learning processes. Through the classification of companies in the information technology sector, the identification of "*inter-firm knowledge transfer flows*" between FDI and domestic firms, and the identification of cases of offshoring, a structure emerges which shows how domestic and foreign firms transfer knowledge, and to what extent this can benefit the host economy.

Keywords: offshoring, knowledge transfer, foreign direct investments.

I. INTRODUCTION

The current global market of services represents a chance for emerging economies, as new information and communication technologies (ICT) allow them to compete on a global scale. Looking at the effects of globalization, this paper aims to suggest a balanced international cooperation between firms in the service industry. This international cooperation should not only serve the interests of the multinational corporations (MNCs), but also those of the host market. In this context, Bartlett and Ghoshal [2] outline the concept of "*mutuality of interest*" between MNCs and the global supply firms, and they argue that mutual cooperation pushes both sides forward. Though previous studies have considered the forms of knowledge transfer mainly within MNCs and their subsidiaries abroad, the effects on the host markets have not been studied in depth.

Some publications list such effects of globalization as inequality, changes in the labor market (substitution effects and employment creation) and strain caused by cultural differences between countries [6][7].

The literature surveyed so far pays little or no attention to the effects of outward FDI and MNCs' activities in foreign markets, the only exception being the limited set of studies on production transfer within MNCs [6].

Nevertheless, the number of studies and publications that focus on the host market and their R&D activities is increasing. The most relevant issues and discussions are: The characteristics of the host market and the reasons MNCs choose to internationalize operations in subsidiaries abroad [8]; The assignment of responsibilities to subsidiaries and their level of autonomy [5]; the impact of the globalization of R&D activities and the innovation expertise of MNCs [2]; and the internationalization of innovation through "Global Innovation Networks" [9].

The current paper focuses on FDI and offshoring cases and their effects on the host markets. It specifically analyses the spread of MNCs through their subsidiaries abroad and their effects on the development of domestic firms. The MNCs use subsidiaries is mainly to reduce the cost of production. Moreover, they are looking for a knowledge source to generate new knowledge. This knowledge source depends on cooperation with local partners and the nearness to the domestic technologies and markets. In addition, the offshoring cases also offer a way for firms to analyze and extend their scope to the global market.

This paper presents a theoretical and an empirical approach based on the context of knowledge transfer and learning organization theory. The empirical analysis was performed in 2013 in Uruguay (Montevideo) and Chile (Santiago).

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II. KNOWLEDGE TRANSFER AND GEOGRAPHICAL PROXIMITY

„*The knowledge transfer is a process in which an organization recreates and maintains a complex, causally ambiguous set of routines in a new setting*“[10]. In this theoretical analysis the knowledge transfer is organized according to three properties of the knowledge management context defined by Argote, Mcevily and Reagans [1]: properties of the knowledge itself (knowledge concept and knowledge base), properties of units (e.g., an individual, a group or an organization), and properties of the relationships between units (networks). The theoretical approach is based on the definition and main discussions of these properties for the performance of the knowledge transfer processes.

In the context of the MNCs theory there are also knowledge flows to and from a subsidiary [3][8]. Firms need to search for knowledge on a global scale, and collaborate with partners located outside their home countries and regions. These knowledge flows are: “primary knowledge transfer” from headquarters to the subsidiary, “secondary knowledge transfer” between subsidiaries, and “reverse knowledge transfer” from subsidiary to headquarters. Subsidiary autonomy is hence an important issue, because it is likely to have important implications for an MNC’s knowledge flows. The innovation performance of MNCs increasingly depends on offshore subsidiaries, and thereby implicitly on efficient knowledge transfer between headquarters and offshore subsidiaries.

The strategy of an MNC in the host market is also related to the knowledge flows and the subsidiary autonomy, informing the decisions on how to internationalize operation in subsidiaries abroad. Kuemmerle [9] defines the strategy of the MNC subsidiary in two types, in terms of geographical dispersion of R&D activities abroad: the home-based augmenting site is established in order to tap knowledge from competitors and universities around the globe; in this type of site, information flows from the foreign laboratory to the central lab at home. The home-based exploiting site is established to support manufacturing facilities in foreign countries or to adapt standard products to the demand there; in this type of site, information flows to the foreign laboratory from the central lab at home.

Furthermore the organizational learning theory is considered as well for the analysis between subsidiaries and domestic firms. Buckley, Glaister, Klijn, und Tan [4] define modes of knowledge transfer and use the form of strategic alliances as a case of inter-organizational learning between firms (see figure 1). In this research, however, offshoring is the favored form for analyzing inter-organizational learning.

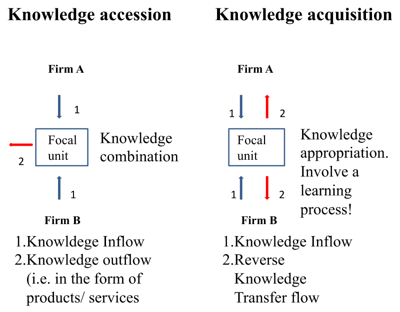

Figure 1: Modes of knowledge transfer: „knowledge accession“ and „knowledge acquisition“ in strategic alliances. Source: [4]

Offshoring means getting work done in a different country. Outsourcing is the contracting out of a business process to another party but in the same country. In the twentieth century, it became increasingly efficient to have certain tasks performed in other geographical locations. Offshoring projects are composed of a demand part (firms which relocate business process) and a supply part (firms which offer the business process from foreign countries). There are two main forms of offshoring. One is Offshoring Outsourcing, and refers to the practice of hiring a vendor to do the work offshore. The second form is the Captive Offshoring, in which MNCs establish subsidiaries in several countries to do different types of work. Moreover, Vashistha and Vashistha [11] have defined six offshoring models: Captive Offshoring, Supplier Direct, Dedicated Center, Joint Venture, Third Party Transparent, and Build-Operate-Transparent (BOT) (see figure 2).

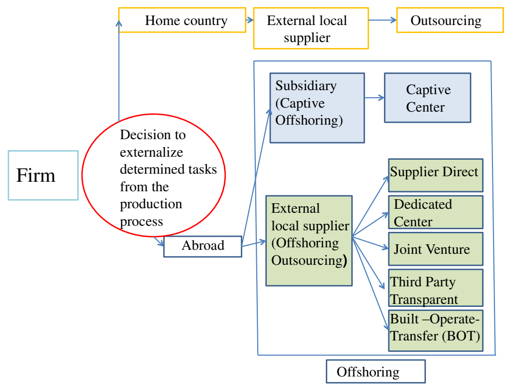

Figure 2: Offshoring and Outsourcing

III. EMPIRICAL ANALYSIS

The empirical analysis is based on a collection of qualitative data obtained through 69 expert interviews (see table 1) in the IT-sector in Montevideo (Uruguay), and Santiago and Valparaíso (Chile) in 2013. The examination groups are IT subsidiaries**,** domestic IT firms**,** and private and public organizations. Some of the horizontal services of the selected firms are IT services (BPO as back office and financial services), corporate and professional services, engineering and industrial services, consulting, etc. And some examples of the vertical services they offer are health insurance, global logistics services, electronic design automation, engineering in risk prevention management (mining industry), business services (e.g. retail, banks), public sector, traceability and asset management, video games, and more.

Table 1: Local and foreign actors in Chile and Uruguay

Groups	Chile (39)	Uruguay (30)
IT Subsidiaries (20)	Evalueserve, Unisys,Accenture, TCS, Everis,Soaint Gestion, Terra Remote, Oracle, Prevsis (Appear Networks), Synopsis, Nimbic Chile, Fraunhofer Chile, Inria Chile	Globant, Katon Natie, TCS, Indra, Microsoft, IBM, Hexacta
IT Domestic firms (26)	SONDA, Adexus, Ki-Teknology/Nisum Chile, COASIN, Wanaco Games /Behavior, Atakama Labs/DeNA, Kibernum, Blue Company, Ciclo2, Bissen, Isercon, Humboldt Consulting, Gonzalo Gandia, Juan Carlos Muñoz	Intermedia, K2B, Dvelop Genexus Consulting, UruIT , Ingenous Softworks, Infocorp, Memory, Quanam, Arkano, Manentia, MVD Consulting
Public and private organisations (23)	ProChile Santiago, ProChile Valparaíso CORFO (TI), CORFO (Start-up Chile), CIE, CEPAL, Duke University, Universidad de Chile, Foro innovación, CCS (CES), ACEC, FEDIT Chile	Uruguay XXI, LATU (Inkubator: Ingenio), ANII, BID, Universidad ORT, CUTI, CZFUY, ALES, Zonamerica, Aguada Park, WTC

The hypothesis presents a correlation between local cooperation of subsidiaries with domestic firms and local offshoring supply development. The hypothetical basis of my argumentation is that the geographical and social proximity of firms is a requirement for knowledge appropriation through local and international inter-firm-relations. If the local network consists of local cooperation of subsidiaries and domestic firms, the knowledge transfer works in both directions. Specifically, the domestic firms can benefit from their experience with international companies and use what they've learned to compete in the global market. In this learning economy, emerging economies could be part of the global services industry, developing and supplying intensive and specialized knowledge services. Therefore, the main questions are: can we identify knowledge transfer flows between subsidiaries and domestic firms? To what extent can offshoring improve the local IT industry? This hypothesis will be corroborated through the empirical analysis of these factors in Chile and Uruguay:

1. *Strategic and Subsidiary autonomy:* Main strategy of the subsidiary in the host market and distinction between home-based augmenting or exploiting site. Subsidiary autonomy analysis with consideration of the function of the subsidiary abroad and the intra-organizational level (division of work) and inter-organizational level (collective learning, interdependencies between companies).
2. *Local cooperation of IT subsidiaries with domestic IT firms:* Cooperation description between subsidiaries and domestic firms. Search of "knowledge transfer flows" between subsidiaries and domestic firms.
3. *Identification of knowledge base and learning processes of domestic firms*: Ability to cooperate with foreign firms and to acquire new knowledge.
4. *Local cooperation of domestic IT firms with IT subsidiaries*: Categorization of a firm´s development as a result of its cooperation with a subsidiary.
5. *Offshoring cases and models:* Identification of offshoring cases and models.
6. *Public policies in Chile and Uruguay:* promotion of offshoring. Qualitative analysis of both countries.

IV. RESULTS

The results are presented based on the factors under examination. First, the strategy and autonomy of the subsidiaries have a direct correlation with the capacity to communicate and absorb knowledge in the host country. In this research, the subsidiaries were first classified in terms of the products and services that they offer. After that we evaluated the linkage between subsidiary autonomy and strategy. The most autonomous subsidiaries are working with R&D and need to involve local partners to acquire new knowledge and ideas. In contrast, the less autonomous subsidiaries are selling products or standard services and do not have any cooperation with local partners, only with clients. The strategy of lower autonomy is always associated with the home-based exploiting site, while the home-based augmenting side shows higher autonomy. Specially, R&D research institutes and technology developers of products and services stand out, with the more interactive and embedded network in the host country.

The second result of the empirical analysis offers evidence of forms of cooperation between 20 IT subsidiaries and 26 domestic IT firms in Chile and Uruguay. This cooperation differentiates between the local demands of partners and the offer of or request for specific knowledge. This is a qualitative analysis of „*knowledge transfer flows*" between subsidiaries and domestic firms, and it is based on the evaluation of these indicators within MNCs by Gupta A. K. and Govindarajan, V. [8]: Value of knowledge stock, motivation to share knowledge, existence and richness of transmission channels, motivation to acquire knowledge, and capacity to absorb knowledge.

Five main forms of cooperation with subsidiaries are described here: The most common form is the subsidiary as supplier of manufacturing facilities and services to a direct local client or through local partners. These subsidiaries are traditional, selling their product in the host market and principally trying to expand the sales market abroad. A second form is the subsidiary as R&D center or "knowledge center", with and without contact with local actors. Some of this R&D occurs in the host market, with the collaboration of local universities and start-ups. There are also foreign research institutes in this category, which also work closely with local universities, research institutes and specialized firms in the development of new technologies and solutions of new problems. Some of them even belong to a government promotion program to support local knowledge transfer, so they also work closely with the local government policies.

Another form of R&D subsidiary is one located in the host market with internal standards processes, which do not incorporate cooperation with other actors. These are normally suppliers of manufacturing facilities and services like the first form, but also include R&D activities to respond to demand from headquarters. The last form is the subsidiary as captive center, to exclusively support foreign clients. They do not collaborate with other firms in the host market (with some exceptions in social work, like TCS in Uruguay, e.g. the implementation of the Maitree-Enable program in “El Molino” woman´s prison), but contract mainly local employees. There are also some exceptions to the traditional model of subsidiaries that develop technologies. These are developing knowledge centers and moving to more interactive work with local partners to develop R&D activities. Three of these subsidiary forms show cooperation in “knowledge transfer flows” with local actors: subsidiaries as R&D centers (or “knowledge centers”), the foreign research institutes, and the traditional subsidiaries, which are developing technologies. These subsidiaries are working in two directions through the transmission channel. They send knowledge from the subsidiary to the headquarter (inflows, *reverse knowledge transfer*), and they also transfer knowledge from the subsidiary to the domestic firms (outflows). See the Conclusion for a complete description and definition of these, referred to here as *“inter-firms knowledge flows”*.

The third result, on the knowledge quality of domestic IT-firms, can help us evaluate the ability of local firms to cooperate with foreign firms and acquire new knowledge. In other words, it is necessary to evaluate whether the domestic firms are able to benefit from the presence of foreign subsidiaries. In fact, the domestic firms should have an adequate level and quality of knowledge to be able to capture new knowledge from foreign MNCs. The empirical work shows specific findings about the link between the learning processes and the knowledge base of the firms. Understanding the knowledge base of firms enables us to assess their chances for growth and survival. Four knowledge bases are categorized by Lundvall and Johnson [10]. These are: *know-what* (knowledge of facts and information), *know-how* (skills), *know-who* (specific social relations), *know-why* (scientific knowledge). The domestic IT firms are working mainly with *know-how*, using special skills to do technical tasks. They get this technical capacity using entrepreneurial learning processes such as *learning by doing*, training workshops, and courses of specialization abroad. *Know-who* is likewise present in all firms and they actively work to develop their local network. They participate in events and government business initiatives, and some of them build strategic alliances with local or foreign partners. In most of the IT firms engaged in software development and software implementation, *know-how* and *know-who* are the main categories of knowledge. *Know-what* has been found principally in video game and consulting firms. They have an ability to use and learn specialized information to work on complex areas. Finally, *know-why* is present in firms which develop technology. They have access to knowledge in a specific field such as electronics and often make advances in technology. The firms which need access to this kind of knowledge interact with specialized organizations like universities and research institutes.

Fourth, regarding the cooperation of domestic IT firms with IT subsidiaries, these are the same cooperation forms as the subsidiaries, but it is important to distinguish the results of this cooperation. The domestic firms also show different paths as result of cooperation with a subsidiary. In this manner it is possible to categorize the development results of a firm’s cooperation with a subsidiary (see figure 3).

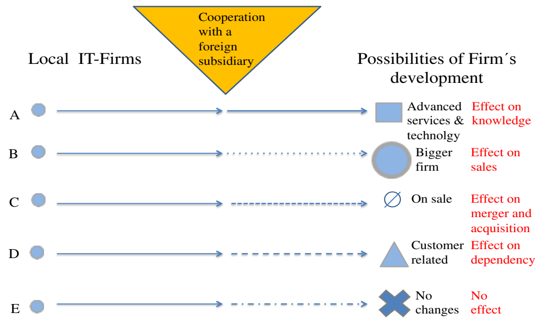

Figure 3: Domestic firms’ evolution after a cooperation with a subsidiary in the host market

These figures show us five different possibilities for a firm´s development and effects as a result of its cooperation with a subsidiary, which have been found in Chile and Uruguay. The form of cooperation will affect the firm’s evolution. In some cases there is no knowledge or information flow between them but the purchase of products or transfer of personnel (human capital). This results in customer-related development or growth due to an increase in demand and sales or a local dependency. There are other cases in which the domestic firms sell a product or a service only one time to a subsidiary. This does not affect the domestic firms because this is only a one-time buyer-seller cooperation. Acquisition is a phenomenon which takes place especially in emerging economies. The domestic firm is sold to a foreign firm that is looking to enter or, in case of a subsidiary, to expand that market. The first development possibility in figure 3 shows the case of the appropriation of knowledge and results in an offer of advanced services and technological development. In some cases, the domestic firm is offering outsourcing to a foreign partner, who is localized in the host market. In this instance the outsourcing partners have a long-term contract, which gives them at least the basic requirements and conditions to transfer knowledge to each other.

Fifth, we found a total of 15 offshoring cases from international and domestic firms. At this stage, it is important to mention that the concept of "offshoring" is not always well-understood by the domestic firms. Due to this problem, it was difficult to find firms who offer offshoring effectively. Some firms confuse the export of a one-time service with offshoring, or they do not clearly distinguish offshoring from another international form of cooperation such as a strategic alliance. Ten such cases were identified in Chile, and five in Uruguay, and these are classified for each model (see table 2). Some of these offshoring cases are described in detail in the final doctoral publication, with the intent to identify and analyze the intensity of the knowledge transfer between the offshoring partner in each case of the offshoring model. In this way it is possible to exemplify the models and explain why each case has been chosen for each model.

Table 2: Identification of models for each offshoring case

Offshoring models	Offshoring cases
Supplier Direct	Adexus, COASIN, Intermedia
Joint Venture	Ki-Teknology/Nisum Chile, Genexus Consulting
Dedicated Center	Wanaco Games /Behavior Atakama Labs/DeNA Topsystems/Stefanini*
Build-Operate-Transparent	Capgemini Chile*
Third Party Transparent	Accenture, Everis, Unisys, TCS Chile
Captive Center	Globant, Katon Natie, Evalueserve, TCS Uruguay

But how intensive is the knowledge transfer by each model? We use the mentioned theory of the modes of knowledge in strategic alliances by Buckley, Glaister, Klijn, und Tan [4] and we adapt and apply it in offshoring. We create four new modes of knowledge for each offshoring model specifically (see the Conclusion).

Sixth and finally, the empirical fieldwork offers a brief country comparison analysis and diagnostic concerning the policies for cooperation between the subsidiaries and the local firms and for the development and promotion of offshoring. Chile and Uruguay offer similar advantages for attracting FDI, in terms of political and legal stability as well low corruption levels. In fact, they have the same rank (21/175) and score (73/100) in Transparency International's 2014 Corruption Perceptions Index. Chile and Uruguay are seen from abroad as stable, trustworthy and growing markets. The location of both countries in a common time zone with USA is another advantage, and they boast good insfrastructure and digital connectivity. Both countries are traditionally exporters of commodities and their governments are working actively in the implementation of public policies to attract FDI in global services. The comparative costs of their services are not especially low, but they focus on the offer of specialized value-added services.

Some weaknesses are also identified in both countries. The English level must be enhanced in the early stages of the respective education systems. Industry and the academy (university and research institutes) should be more connected. It is generally necessary to improve the job training to create more qualified human capital. E.g. In Uruguay, the BID is financing the program "Finishing Schools", where IT and logistic firms as well as contact/call centers offer diverse technical training for employees and external persons. In Chile the government program "start-up Chile" promotes the development of local start-ups and accelerates international networking. Chile and Uruguay are small emerging economies that need to increase their labor pool of qualified human capital and above all look for investments in R&D. The agencies Uruguay XXI and ProChile are offering promotion programs for the export of global services. Specially organized is the case of Uruguay under the Free Zone Law nr. 15.921. Free Zones can be private or state. The greater part of global services is provided from free zones exclusive for services. Some of these services free zones are: Aguada Park, Zonamerica and World Trade Center. Finally, both countries offer more incentives for global export services and count on international agreements.

IV. CONCLUSIONS

The augmenting innovation strategy of an autonomous subsidiary abroad benefits as much to the MNCs as to the host market. A comparison of traditional subsidiaries with foreign research institutes (R&D activities) in terms of knowledge transfer into the host market shows that R&D firms and research institutes have a stronger impact in the knowledge spread to domestic firms than traditional subsidiaries. Traditional subsidiaries and specially the model of captive center have in contrast a low impact of knowledge in the host market.

"Inter-firms knowledge transfer flows" between subsidiaries and domestic firms were identified in Chile and in Uruguay when the subsidiaries have high autonomy, produce reverse knowledge transfer flows to the headquarter, and the domestic firms work with them through a strong knowledge intensive cooperation form as outsourcing or strategic alliances, then domestic firms are able to become offshoring supplier (see figure 4)

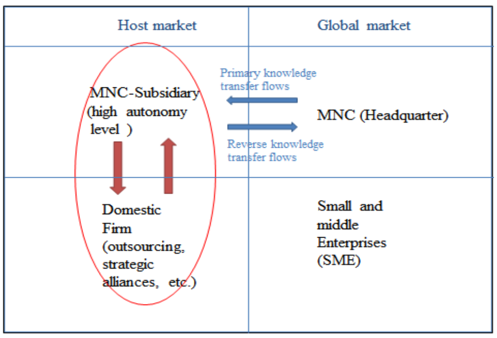

Figure 4: Identifying *"inter-firms knowledge transfer flows"*

Regarding the domestic IT firms, the knowledge bases categories *know-what* and *know-why* should be more present in the software development firms to achieve innovation processes and develop new technologies. It is important to outline that this kind of knowledge is easy to reproduce. Data bases can be precisely described and copied by others. These categories should be more demanded taking cooperation in specialized teams and frequent confrontations with many different situations to develop and keep up with the knowledge.

The determination of the intensity of knowledge transfers for the different offshoring models is defined by the categorization of modes of knowledge transfer. The knowledge modes "knowledge acquisition" and "knowledge accession" by strategic alliances coincide as knowledge modes for the offshoring models "Supplier Direct" and "Joint Venture" respectively. For the other four offshoring models we define four new modes of knowledge transfer based on the identified offshoring cases in Chile and Uruguay. In the next table we can see the categorization of modes of knowledge for each offshoring model with their identified cases (see table 3):

Table 3: Modes of knowledge transfer for offshoring

Offshoring Model	Mode of knowledge transfer	Identified offshoring case
Supplier Direct	Knowledge acquisition	Adexus, COASIN, Intermedia
Joint Venture	Knowledge accession	Ki-Teknology/Nisum Chile, Genexus Consulting
Dedicated Center	*Knowledge absorption*	Wanaco Games /Behavior, Atakama Labs/DeNA, Topsystems/Stefanini*
Build-Operate-Transparent	*Knowledge appropriation*	Capgemini Chile*
Third Party Transparent	*Knowledge transmission*	Accenture, Everis, Unisys Tata Consultancy Services
Captive Center	*Knowledge imitation*	Globant, Katon Natie, Evalueserve, TCS

The most advisable offshoring models for the upgrading of the local economy in Chile and Uruguay are "Supplier Direct", "Joint Venture", "Build-Operate-Transfer" and "Third Party Transparent". The intensity of knowledge transfer by the modes of knowledge "knowledge acquisition", "knowledge accession", "knowledge appropriation" and "knowledge transmission" is higher than the modes "knowledge imitation" by "Captive Centers" or "knowledge absorption" by "Dedicated Centers". In these last cases there are indirect effects for the upgrading of the local industry such as promotion of the host country as good location for offshoring or as example to imitate by domestic firms. These effects are also positive for the local IT industry, but they do not have a relevant knowledge impact. Therefore, there is a need to develop a public policy model for Chile and Uruguay, which support domestic IT firms to work on these recommendable and analyzed offshoring models for the upgrading of the local IT industry. Foreign direct investment in the service industry should recognize a given structure from the government policy to support a knowledge-based cooperation with local actors.

ACKNOWLEDGEMENT

We thank all IT subsidiaries, IT domestic firm and organization in Chile and Uruguay for their collaboration in this research and whish all of them a successfully performance in the global services industry.

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Small Photovoltaic Plants as an Alternative Electricity Source for Chilean Households

Alejandro Harbach[1]

ABSTRACT

This paper deals with an analysis if the implemented conditions of the new law 20.571 (Net-Metering-Law) that constitutes an economic benefit to the average household (concerning the electricity consumption) in Chile after having installed a small photovoltaic (PV) system. For this purpose, a PV system installation for every regional major city in Chile has been simulated for an average household. The analysis is based on three of the **classic** methods of investment analysis; the Net Present Value, the Internal Rate of Return and the Payback Period [1]. These were basically applied to the annual savings that were achieved due to the installation of a PV system in a household. In order to determine the most important factors from which the economic efficiency depends, a sensitivity analysis has been carried out. The findings of this study reveal that the newly implemented framework conditions do not constitute an economic advantage for the average Chilean household. The main reasons for this are a lack of loans that offer particular financing terms for the installation of PV systems and high investment costs. The results could serve for a possible reform of the law and for the development of (attractive) financing terms for such kind of investments.

Keywords: Net-Metering, Small Photovoltaic Plants, Analysis of Profitability**.**

I. INTRODUCTION

In October 2014, the 20.517 law (also known as the Net-Metering law) was passed. This law establishes the connection framework conditions of small power systems (up to 100 kWP) to the distribution grid. The bill is particularly of interest for small photovoltaic (PV) systems in Chile regarding its high solar radiation. Since the economic advantages for households have not been evaluated yet under these framework conditions, this paper deals with the central issue: Are small photovoltaic plants economically profitable for the Chilean household regarding the framework conditions of the Net-Metering-Law?

To answer this, a small PV system installation has been simulated for every regional major city in Chile for an average (concerning the electricity consumption) household. The installation of a PV system in a household aims to decrease the electricity consumption from the grid and even in periods, where the electricity production of the PV system is higher than the consumption of the household, electricity can be fed into the distribution grid, where a remuneration is earned. All this causes a reduction in a household electricity bill, and in some cases money can be earned. However, to purchase and install a PV system, a household has to invest money. The level of electricity remuneration is regulated by the Net-Metering-Law. The main aspects of the law in order to determine the economic efficiency of a small PV system are listed as follows [2]:

- In Chile, the electricity price of the grid consists of an energy node price, a power node price and a distribution cost. The electricity remuneration for fed power into the distribution grid is equivalent to the energy node price that a household has to pay if electricity from the grid is obtained.
- In addition to the energy node price, the decrease of distribution loses are considered in the electricity remuneration by multiplying the factor of the average distribution loses by the energy node price.

Both, the energy node price and the factor of average distribution loses are calculated by the National Energy Commission (CNE, Comisión Nacional de Energía) [3].

In order to determine if a small PV system is economically efficient for an average household or not, three methods of investment analysis are applied; the Net Present Value method (NPV), the method of the Internal Rate of Return (IRR) and of the Payback Period method (PBP) [1]

The Net Present Value method determines if the reduction in the electricity bill, that the installation of the PV system causes, covers the investment during the 25 year life-time of the power plant. The Internal Rate of Return method calculates the discount interest rate that such kind of investments can cope with. The Payback Period method gives the information in which period the reduction in the electricity bill will cover the investment. This is the main target of this study: The determination of *NPV, IRR* and *PBP* for the investment in a small PV system for an average Chilean household in the 15 major cities of the country.

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In addition, in order to determinate the key factors of the economic efficiency of small PV systems, a sensitivity analysis will take place in this study.

II. METHODOLOGY

The following formulas were used to calculate the three target figures:

Net Present Value and Internal Rate of Return [2]:

$$NPV = \sum_{t=0}^{25} \frac{Savings_t}{(1+i)^t} \qquad (1)$$

NPV: Net Present Value
t: Period t (the period is equivalent to 1 year)
i: Discount interest rate
Saving$_t$: Household savings in year t

Payback Period:

$$PBP = min\left\{25\,; I_0 + \sum_{t=0}^{25} REB_t \geq 0\right\} \qquad (2)$$

PBP: Payback Period
I$_0$: Initial Investment
REB$_t$: Reduction in the household Electricity Bill in year t

The method used to determinate the target figures is the same for all the cities.

A) Determination of the target figures

The variable ***Savings$_t$*** in formula (1) is equivalent to the difference between the reduction in the electricity bill *REB$_t$* and the costs of reduction in the electricity bill *CREB$_t$* that a household achieves if a PV small plant (PV system) is installed on the rooftop:

$$Savings_t = REB_t - CREB_t \qquad (3)$$

Saving$_t$: Household savings in year t
REB$_t$: Reduction in the Electricity Bill in year t
CREB$_t$: Costs of Reduction in the Electricity Bill in year t

The variable *REB$_t$* in formula (2) is the same as in equation (3). This means that the calculation of this variable is the same for both equations. Formula (4) indicates how *REB$_t$* is determined:

$$REB_t = E\_Bill_{nonPV,t} - E\_Bill_{PV,t} \qquad (4)$$

E_Bill$_{nonPV,t}$: Electricity bill without a PV system in year t
E_Bill$_{PV,t}$: Electricity bill with a PV system in year t

E_Bill$_{nonPV,t}$ depends on two variables, the electricity demand of the household and the development of electricity price for the 25 year life-time of the PV system. For this study, it was assumed that the annual electricity demand of the household for the next 25 years remains constant. The forecast of the electricity price development is explained in the next section. *E_Bill$_{PV,t}$* depends on the same variables as *E_Bill$_{nonPV,t}$* plus the electricity yield of a PV system. In this variable, the remuneration of electricity injection to the distribution grid is also included.

The variable costs of reduction in the electricity bill *CREP$_t$* in equation (3) corresponds to the costs that a household must incur to achieve the electricity yield in year t.

$$CREB_t = Y_{Elec,t} \cdot LCOE \qquad \textbf{(5)}$$

Y$_{Elec,t}$: Electricity yield in year t
LCOE: Levelized Cost of Electricity

To calculate *LCOE* the following formula was used [4]:

$$LCOE = \frac{I_0 + \sum_{t=0}^{25} \frac{Y_{Elec,t} \cdot oc}{(1+i)^t}}{\sum_{t=1}^{25} \frac{Y_{Elec,t} \cdot (1-d)^{t-1}}{(1+i)^T}} \qquad \textbf{(6)}$$

oc: Operation Costs
d: Degradation factor of the PV system

In order to determinate the *Y$_{Elec,t}$* in formula (5) and (6), the method presented in the book „Photovoltaic: Strom aus Sonnenlicht für Verbundnetz und Inselanlagen“ [5] was used. A database was created to define the necessary data for this method with the aid of an online research. This database relies primarily on the online-database „Cartografía Interactiva de los climas de Chile“ [6] of the Pontificia Universidad Católoca de Chile and on „Irradiancia Solar en Territorios de la República de Chile“ [7] from the Universidad Técnica Federico Santa María.

There were two methods used to determine the initial investment “*I$_0$”* in formula (6) of installing a PV system. For the first one, the prices for PV Modules and inverters were researched online. For the second one, a quotation to local providers was requested to determine the remaining costs for installing a PV system.

Furthermore, according to the *LCOE* calculation, the in Chile applicable financing terms, thus the discount interest rate “*i*” were estimated. The main reason for this is that in Chile there are no special financing terms to fund a PV system. For a household means to get a consumer credit with unfavourable terms to fund a PV system. The adopted discount interest rate is 10% p.a. The adopted degradation factor “*d*” in formula (6) is 0,89% p.a. The last assumption is based upon the specifications of the PV modules producer, that the power of the modules decreased by 80% after a 25 year use.

[2] The same formula was used to calculate *NPV* and *IRR*. To determine *IRR*, the *“i”* must be found, so that *NPV=0.*

B) Electricity price development

The electricity price development for the next 25 years is relevant for this study because the higher the electricity price for a household, the bigger the reduction in the electricity bill is (REB_t) generated by the PV system. That has a positive impact on the profitability of an investment in a PV system. It also generates an increase in the remuneration on injected electricity to the distribution grid because the price for injected electricity to this grid, depends on the electricity price of the grid, according to the Net-Metering-Law,. This way, the higher the development of the electricity price is, the higher the remuneration for injected electricity for a household will be, which also has a positive impact on the profitability of an investment on a PV system.

In order to determine the forecast of the electricity price development for the next 25 years, „AEO2014 Early Release Overview“ [8] of the U.S. Energy Information Administration was used. This overview is a forecast for oil price development for the next 25 years. To prove if it can be applied to determine the forecast for the Chilean electricity price development, the correlation between the oil price of „AEO2014 Early Release Overview“ and the energy node price and also the power node price was calculated[3]. The overview has also three scenarios for the oil price development. These were adopted by this study. They are: "Low", for a low price increase (20% related to the electricity price of May 2013), "Moderately", for a moderately price increase (68% related to the electricity price of May 2013) and "High" for a high price increase (114% elated to the electricity price of May 2013).

C) Sensitivity analysis

A sensitivity analysis for all target figures was carried out. The analyzed variables were the initial investment I_0, the electricity yield $Y_{elec,t}$, the discount interest rate i and the PV system power (P_{G0}).

The method used to carry out the sensitivity analysis is the same for all the target figures and variables. How to carry out the sensitivity analysis of the target figure *NPV* for the variable I_0 will be shown as follows:

First, the value of NPV is determined for the unchanged I_0, "$NPV(I_0)$". After that, I_0 is increased by 1% ($I_{1\%}$) and *NPV* is calculated again "$NPV(I_{1\%})$". Finally, $NPV(I_{1\%})$ *is* subtracted from $NPV(I_0)$ and this difference is divided by $NPV(I_0)$. The result is the percentage change in *NPV* by an increase of I_0 of 1%.

III. RESULTS AND DISCUSSION

In this section all the monetary values are converted from Chilean pesos ($) to Euros (€). The used exchange rate is the average rate of May 2014 (1€=762$).

The calculated electricity Yield of the PV system for each city was divided by the corresponding capacity of the PV system. The results are the final yield (Y_F) for each city. This value is equivalent to the full load hours of the PV system. Y_F is used to compare power systems relating to installed capacity and location.

The results for Y_F and *LCOE* for all examined cities are shown in table 1.

City	LCOE [€/kWh]	Y_F [h/a]
Arica	0.20	1359
Iquique	0.19	1440
Antofagasta	0.19	1543
Copiapó	0.18	1629
La Serena	0.21	1318
Valparaiso	0.22	1213
Santiago	0.20	1306
Rancagua	0.20	1274
Talca	0.20	1359
Concepción	0.20	1364
Temuco	0.27	947
Valdivia	0.27	984
Pto. Montt	0.28	906
Coihaique	0.23	1106
Punta Arenas	0.27	944

Table 1: Results for Y_F and LCEO for all examined cities

In this table it is shown, that according to the geographical location, the full load hours is higher in the northern cities than in the southern ones. The reason is that in northern Chile the solar radiation is higher then in the south of the country. At the same time, it can be recognized that in the cities were the Y_F values are high, the *LCOE* are correspondingly low. Consequently, it can be confirmed that PV systems in the north are more worthwhile than in the south.

According to literature, full load hour of 1000 h/a is possible in sunny regions. In Germany, depending on location and commissioning, full load hours values of 900 h/a and 950 h/a can be achieved [9]. These values can be compared with the ones between Valdivia and Punta Arenas because the latitude of these cities corresponds to the latitude of Germany. It can be seen, that the values of Chile (between Valdivia and Pta. Arenas) and Germany, with the exception of Coihaique, are consistent. This fact validates the method used to calculate the electricity yield and LCOE. The unusual high Y_F value of Coihaique can be explained by high measured solar radiation of the city.

In Germany, the *LCOE* value varies for small rooftop PV systems (up to 10 kW_P), between 0.098 €/kWh and 0.142 €/kWh [10]. These can be compared with the values on table 1 between Valdivia and Pta. Arenas. This way is clear that the *LCOE* in Chile can be about three times higher than in Germany. The reasons could be the electricity yield, the investment costs of the plant and/or the financing terms. Because of the fact that the calculated final yield in Chile with the of Germany are consistent, this difference can not be explained through this value. The specific investment costs for small rooftop PV systems (up to 10 kW_P, relating to 2013) in Germany,

[3] The calculated correlation with the energy node price is 0.92 and 0.97 for the power node price. The calculation is based on the historic price development from 1987 to 2013 of all prices. For distribution costs, it is assumed that they will increase only in the inflation rate (3.58% p.a.).

varies between 1.3 €/W_P and 1.8 €/ W_P [10]. In this study, the determined specific investment costs are 1.89€/ W_P. This value is slightly higher than in Germany and can be understood as a part explanation to the high *LCOE* values in Chile. An important part of the specific investment costs are the ones for the PV module. In Germany, these are 40% to 50% of the total costs [10]. This means, that the specific costs for PV module is between 0.52 €/ W_P and 0.9 €/ W_P. The researched Module price in this study is 0.78 €/ W_P. Thus, it becomes clear that the module price in Chile is located in the German price range, which does not explain the high specific investment costs. But it means, that the higher specific investments costs in Chile have to be explained through the specific costs for the inverter and/or the specific remaining costs. The third possible reason for the high *LCOE* values in Chile is the financing terms. The German market has special financing terms to fund a small rooftop PV system. For example, the KfW-Bank financing terms will be shown. The offered effective interest rate to fund small rooftop PV systems is 2.32% to 7.56% p.a. with a grace period of three years and a 20 year credit period [11]. The adopted interest rate in comparison is 10% p.a. less beneficial than the one offered by the KfW-Bank. Furthermore, no grace period is adopted. The impact of the (discount) interest rate in the *LCOE* value is handled in the sensitivity analysis.

Table 2 shows the results of the *NPV* for all examined cities and scenarios.

Target figure	NPV [€]		
City	High	Mod.	Low
Arica	-105	-823	-1295
Iquique	-93	-819	-1295
Antofagasta	-139	-751	-1153
Copiapó	-84	-708	-1119
La Serena	-198	-885	-1337
Valparaiso	-501	-1203	-1665
Santiago	-859	-1560	-2020
Rancagua	-731	-1466	-1949
Talca	-309	-967	-1400
Concepción	-456	-1075	-1481
Temuco	-1084	-1718	-2135
Valdivia	-1037	-1589	-1952
Pto. Montt	-1406	-2276	-2853
Coihaique	218	-775	-1430
Punta Arenas	-1709	-2359	-2787

Table 2: Results of the *NPV* for all cities and scenarios

Based on these values, it can be determined that with the evaluated conditions, a small rooftop PV system for all cities and scenarios is not profitable for an household in Chile. Based on the findings so far, it can be determined that in the cities where the Y_F values are high and the *LCOE* values are low, PV systems are more profitable (but not economically efficient). The exceptions are the cities of Santiago, Rancagua and Coihaique. The reason for this is the electricity price level. An example can be made with the capital city, Santiago. The full load hours in this city is the highest of the country and the *LCOE* is not as high as in other cities. Nevertheless, the economic efficiency of a PV system is one of the worst in the country. The reason is that in Santiago, the electricity price level is the lowest of Chile. The higher the electricity price is, the more profitable a PV system is. The opposite case can be found in Coihaique. In this city, the full load hours are in the lowest and the LCOE is of the highest in the country. But the economic efficiency is one of the highest in Chile, because the electricity price level in Coihaique is the highest. It can be concluded that Y_F and *LCOE* are important figures in the economic efficiency of small PV systems, nevertheless the exclusive consideration of these figures is not enough to determinate if a small PV system is profitable or not. The electricity price level and its development in the future plays a key role in this determination.

Table 3 shows the calculated Internal Rate of return for all examined cities and scenarios.

Target figure	IRR		
City	High	Mod.	Low
Arica	9.5%	6.0%	3.0%
Iquique	9.6%	6.0%	3.0%
Antofagasta	9.2%	5.7%	2.8%
Copiapó	9.5%	6.0%	3.1%
La Serena	9.1%	5.6%	2.8%
Valparaiso	7.9%	4.6%	1.9%
Santiago	6.7%	3.6%	0.9%
Rancagua	7.2%	4.1%	1.4%
Talca	8.5%	5.2%	2.4%
Concepción	7.8%	4.6%	1.8%
Temuco	5.7%	2.9%	0.3%
Valdivia	5.4%	2.5%	0.0%
Pto. Montt	5.4%	1.8%	-1.9%
Coihaique	10.8%	7.1%	4.1%
Punta Arenas	4.2%	1.6%	-0.8%

Table 3: Results of *IRR* for all cities and scenarios

The analysis of the economic efficiency of small PV systems based on *IRR* is identical to the analysis based on *NPV*. Nevertheless, different information can be taken from this table. *IRR* is the maximal discount rate that an investment can cope with, which means that with this figure, the maximal interest rate can be determined for a special credit to fund a PV system in Chile. For example, to make an investment profitable in a small PV system in Santiago (therefore, for ca. 42% of the inhabitants Chile) for the scenario “Moderately”, the interest rate for a credit cannot be higher than 3.6% p.a. and the credit period cannot be lower than 25 years (in this case, a grace period is not necessary).

Table 4 shows the values of the Payback Period of an investment in a small PV system for all examined cities and scenarios.

Target figure	PBP [a]		
City	High	Mod.	Low
Arica	10	14	18
Iquique	10	14	18
Antofagasta	10	14	19
Copiapó	10	14	18
La Serena	11	14	19
Valparaiso	12	16	21
Santiago	13	17	23
Rancagua	12	17	22
Talca	11	15	20
Concepción	12	16	21
Temuco	14	19	25
Valdivia	15	19	>25
Pto. Montt	15	21	>25
Coihaique	9	13	16
Punta Arenas	16	21	>25

Table 4: Results of *PBP* for all cities and scenarios

According to this method, in all cities and scenarios (with the exception of a few cases) a small PV system would be profitable for a household because the Payback Period is lower than the life-time of the installed system. Nevertheless, it is to consider, that this method does not take the time value of money into account. This is the reason of the different conclusion between this method and the *NPV* and *IRR*.
Table 5 shows the results of the sensitivity analysis. It should be noted that these results are the average variation of all examined cities, wherein the determination of the variation of *IRR* and *NPV* where some values were disregarded because they varied disproportionately high compared to the variation of other cities, which would artificially increase the average variation of the target figure.

		$Y_{Elec,t}$	i	I_0	P_{G0}
NPV	High	9.8%	-8.3%	-11.1%	-1.0%
	Mod.	1.8%	-1.3%	-2.6%	-0.6%
	Low	1.2%	-0.6%	-1.8%	-0.4%
IRR	High	1.2%	0.0%	-1.5%	-0.1%
	Mod.	1.6%	0.0%	-2.4%	-0.3%
	Low	4.1%	0.0%	-6.0%	-0.7%
PBP	High	-0.4%	0.0%	1.2%	0.0%
	Mod.	-0.6%	0.0%	1.5%	-0.6%
	Low	-1.0%	0.0%	0.4%	0.0%
LCOE		-1.1%	-0.7%	1.0%	-0.2%

Table 5: Results of the sensitivity analysis

The negative or positive sign of the values in the table, means that by a 1% increase of a variable (Y_{Elec}, *i*, I_0 and P_{G0}), the target figure (*NPV*, *IRR* or *PBP*, and *LCOE*) decreases or increases. Depending on the target figure, it can mean that the economic efficiency improves or aggravates. For example, if Y_{Elec} has an increase of 1%, the *NPV* in scenario "High" improves by 9.8%. This means that the economic efficiency of a small PV system improves. On the other hand, if I_0 increases by 1% in scenario "High", NPV would decrease by 11.1% meaning that the economic efficiency of a small PV system would aggravate.
The variables with the greatest impact on the target figures are the initial investment I_0, and the electricity yield as well as the discount interest rate. This realization can be used to improve the economic efficiency of small PV systems in Chile.

IV. CONCLUSIONS

The results of the target figures *NPV* and *IRR* show, that with the new market conditions from the Net-Metering-Law in Chile, a small PV system for all examined cities and scenarios for an average household is not profitable. The main reasons are, as the sensitivity analysis shows, the absence of special financing terms to fund such kind of investments and the high investment costs. According to *NPV* and *IRR,* a small PV system is not an advantageous alternative electricity source for Chilean households. On the other hand, according to *PBP,* a small PV system is an advantageous alternative electricity source, because the payback period in all the cities and scenarios (with few exceptions) is shorter than the life-time of the system. Hence, there is no contradiction because the *PBP* does not consider the time value of money, which is a decisive consideration for such kinds of investments.
Another important contribution of this study is the determination of reference figures for the Chilean electricity market. The most important calculated figures (excluding *NPV* and *IRR*) are *LCOE*, Y_F and specific I_0 for small PV systems. They can contribute to answer following research questions:

- What changes should be implemented in the Net-Metering-Law so that the installation of small PV systems for an average household can be profitable?
- For what kind of households would the conditions of the Net-Metering-Law be PV system profitable?
- At what point could a small PV system be profitable, considering the gradual decrease in the cost of PV technologies?

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The effect of energy efficiency policies on air pollution in south-central Chile

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ABSTRACT

We have investigated technical, economical and policy aspects in the use of fuel wood in households of south-central Chile. Low efficiency in buildings' envelopes was found, which leads to very high consumption of firewood and hence to high emissions of particulate matter (PM). In addition, user practices that systematically choke the air inlet of fuel wood stoves were found to further increase PM emissions. Around 95% of households in Valdivia use firewood for heating and 80% of households were found to spend more than 10% of their income in residential energy. Present policies promote energy efficiency through subsidies for retrofitting and to replace old stoves and their effects on emissions reductions, comfort standards and energy poverty were studied. Different techniques and materials to retrofit existing houses and the replacement of old stoves for newer technologies were studied for a sample of 2025 households in Valdivia. It was found that retrofits have high potential to lower fuel consumption and thus reduce air pollution and energy costs; while replacing stoves could have a limited effect on lowering emissions but would not alleviate energy poverty. In the economic analysis we have calculated the total cost for private and public sector. From private households' point of view, the options with retrofit led to much lower cost as the savings in fuel wood are significant, and subsidies reduce the cost of retrofits. For the public sector, the savings are in healthcare services and the main investment is in the subsidies, thus the option replacing only stoves has lowest cost for the public sector. However, this option is not sustainable due to persisting high consumption of firewood and vulnerability to air choking practices.

Keywords: Air pollution, fuel wood, house thermal efficiency.

I. INTRODUCTION

Major cities in south-central Chile face a serious problem of air pollution, which has worsened the last ten years. Particulate matter (PM) in air has been increasing steadily in the last decade, and measurements and chemical analysis found that the main contribution is combustion of wood fuel in household stoves. For instance, data was clear in attributing major air pollution to wood stove emissions in the city of Temuco, where 93% of the $PM_{2.5}$ fraction originated from firewood burning [1].

Firewood is extensively used for heating due to its low price compared to other fuels and the cold climate in the region, which extends the need for heating between six to eight months in the year. When making a comparative analysis of fuel prices for consumers for the year 2013, the cost for obtaining 1 GigaJoule relative to firewood price is, 3.6 for diesel, 5.2 for gas and 6.6 for electricity. According to these price ratios, the only accessible fuel for medium and low income households is wood fuel (INFOR, 2012).

Despite the lower price of firewood, in a study conducted in the winter of 2007 and summer of 2008 for the determination of baseline energy consumption for heating and indoor temperature in households it was found that the average heating time per day for households varies between 7 and 14 hours in the cities of south-central Chile. As for indoor temperature in households, the average air temperature was between 14.3°C and 16.5°C [2]. Hence, it can be seen that the temperature conditions of households are under comfort levels most of the time in winter days, what is probably more critical in the low-income population. Comfort temperature is assumed between 18°C and 19°C [3].

At present, two government programs promote thermal efficiency to control contamination: 1) subsidies for replacing old stoves with new models; and 2) subsidies for thermal refurbishment of dwellings for low-income sectors. In 1) a program for replacing old stoves and steel cook stoves used as heaters intended to incorporate new models which improve combustion due to secondary burners. In 2), thermal improvement of houses for the lowest income sector intends to refurbish dwellings to achieve a minimum thermal efficiency as stated in the Chilean Norm from 2007. In previous works, a very large potential for reducing firewood consumption through improved dwellings' efficiency was found [4-5].

The aim of the present work is to identify major causes of air pollution and discuss possible reasons explaining the failure of current policies to reduce hazardous emissions. Once identified and their potential for improvement assessed quantitatively, the cost of the measures to reduce air pollution will be used to perform a cost-benefit analysis including their health consequences. Based on the observation of households' mechanisms to ensure the satisfaction of heating demands, and given the current low thermal efficiency, we argue that the current programs

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have very limited potential for reducing air pollution. With this information, policy makers can focus on measures that could have greater impact for reducing wood fuel consumption and thereby toxic emissions.

II. Methods

Data from a survey of 2025 households in Valdivia were used for the study. The survey was performed during 2011 by Certificación e Investigación de la Vivienda Austral (CIVA), Universidad Austral de Chile. Dwellings in the urban area built before the enactment of the 2007 building codes were considered. In a first stage of the project the most typical typologies were identified [6], and in the second stage a random selection of one-family dwellings of the most common typologies located throughout the city were surveyed [7]. The survey included 42 questions, of which 12 were considered for the present work, related to: house value; information on fuels used for heating and amount yearly consumed; types of stoves and age; air-mode of operation of combustion stoves; period in which firewood is acquired; whether certified or informal commercialized firewood is preferred, and amount; house thermal quality; and level of consumer awareness on topics like wood moisture and subsidy options. Since income levels were not included in the survey, we assumed here that the house value is an indication of income, whenever needed for the analysis. Due to the house-value range criteria, the sample is associated with low to middle income sectors.

Income levels were identified as C2, C3, D and E and represent the typical socio-economical classification according to income, place of residence and consumer habits. C2 corresponds to the highest income group and E to the lowest. There are also higher income groups (ABC1) that were not included in the analysis because they are not represented in the survey, and account for only 6% of the population in Valdivia.

Levels of energy poverty for Valdivia were studied, which in this case is directly related to the high consumption of firewood by households. The definition of energy poverty first appeared in England at the beginning of the 1990s as the inability of a household to obtain an adequate amount of energy services with 10% of their income. When energy for heating or cooling is included, the amount of energy to maintain an indoor temperature between 18ºC and 21ºC must be considered, with heating being available for 9 h on weekdays and 16 h at weekends. Households in fuel poverty do not meet this thermal standard and it has been found to be associated with excess winter mortality and morbidity [8].

Fuel poverty due to high levels of energy consumption was studied for the 5 income groups. Energy expenditure was Official data for income levels, gas and electricity consumption were used, and the consumption of firewood assess from the survey of 2025 households in Valdivia, adjusted to ensure an indoor temperature of 18ºC to provide minimum comfort level.

The costs and emissions reduction of thermal improvements for dwellings were studied for four different levels of efficiency: (1) the base house as it is but replacing existing fuel wood stoves by low-emissions fuel wood new models; (2) house retrofit complying with the 2007 Norm (NT2007); (3) the 2007 norm improved with double-glazed windows, sealing of doors and active ventilation systems (NT2007 I); and (4) an energy efficient option complying with European standards (EE). Options 2, 3 and 4 also include the replacement of the heating devices and cooking stoves for new models. A retrofit cost per m^2 was obtained for the different levels of efficiency and different typologies of walls and roofs.

Technical aspects and costs for different retrofit proposals where studied and technical solutions where developed with construction materials regularly found in the market, and requiring simple labor. All the retrofit proposals where designed to be performed in inhabited dwellings and the utility for the construction firms that perform retrofits was calculated assuming a large-scale intervention.

We have calculated the net present value (NPV) for private (household) spending on refurbish dwellings, stoves, firewood and healthcare. Different income levels were considered as explained before, and the sample of houses surveyed in Valdivia analyzed. NPV is defined as the sum of the net cash flow for each year divided by the discount factor for the period of years considered (http://www.financeformulas.net/Net_Present_Value.html). In the present case the value at time zero is negative as it represents the spending in improvements. The interest rate used was 5.18%, which is the past-10-year average for no-risk savings published by the Central Bank of Chile. The four options of efficiency improvements were considered as defined in previous sections. Private cash out-flows include spending in retrofit, and cash in-flows are savings in healthcare and in purchase of fuel wood.

The modelling of the energy demand for the different retrofit levels was performed according to ASHRAE methodology with degree-days method for the heating requirements. Official climatic data from Dirección Metereológica de Chile [9] averaged over the period 1971-2000 was used. Since the official station is in Pichoy Airport, 30 km north from Valdivia, we adjusted average temperatures by using available official data for Valdivia from 1994 to 2002 [9]. Our calculations where performed for an indoor temperature of 18ºC, as internationally recommended [3].

To calculate de emissions reduction for the stove replacement the current stove was considered with emissions of 13gPM/kg of firewood burnt and an efficient new stove with 6.5 gPM/kg firewood. The values for the emissions were obtained from experimental studies done in New Zealand with similar fuel wood stoves [10-11] and were explained in a recent article [5].

Operation with air inlet choked is a frequently used mode (68% according to survey Ref. 7). Emissions in choking mode vary according to users´ behavior and there is no precise data about the air inlet or testing for this option. As a reference of the magnitude in variations we have the study of Jordan and Seen [12] in Australia that compared very low emissions for a modern stove with older equipment. These authors found that the modern stove have indeed low emissions (2.6 gPM/kg) when the air inlet is open, but produces 35 gPM/kg with air inlet closed, which are even larger emissions than older stoves in the same choking mode (33 gPM/kg), while these older models with air inlet open showed emissions of 13.5 gPM/kg. This large increase of emissions with air inlet closed was also measured in Chilean-made stoves tested in Switzerland [13]. It is relevant to note that when operating with the air inlet choked, modern and older stoves arise to similar emissions, blurring the advantages that new modern equipment could certainly introduce. This is due to low temperature in the combustion chamber when lacking proper air inlet, and thus secondary combustion, which is the advantage in the design of modern stoves, does not work properly. Choking air inlet is a practice done by the large majority in Chile to let fuel burnt slowly and last longer; however, the practice dramatically increases emissions.

In order to include possible (and very likely in the present case study) rebound effect, we have estimated income-dependent current indoor temperatures. According to previous works, indoor winter temperatures in social housing average 14.5ºC [2]. Based on house typologies, we have assumed 15ºC as for present housing in incomes E and 18ºC present indoor temperatures for incomes C2, the highest considered here, which is reasonable due to housing quality and fuel wood consumed. For intermediate incomes, D and C3, we have assumed 16ºC and 17ºC winter average. The difference in firewood consumption by rebound effect was thus obtained by comparing the heating degree-days (from meteorological data averaged over 30 years) needed with the present winter temperatures and with a desirable level of 18ºC for all income groups.

As mentioned, we have considered three levels of efficiency improvements; however, for each there are also options of two different stove emissions (the present ones and the best low emissions possible). Rebound effect was considered for all cases. To assess the lowering of firewood consumed due to better new stoves, we have used data from the Ministry of New Zealand that experimentally studied "real-life" efficiency of commercial stoves [14]. The average efficiency for current stove is 61.4%, 51% for cooking stoves and 66.7% for new ones. It is important to note that, due to different proportion of older heating stoves and fuel wood cooking stoves, the various income groups experience different efficiency improvements when replacing stoves. The range is between 8% and 20% reductions, from C2 to E, respectively.

To study the increase in emissions by air choking, even allowed in new stoves, we have analyzed the effectiveness in PM-saved emissions for the sample in Valdivia assuming different scenarios of choking. PM saved per cost unit and the effectiveness were compared between retrofitted houses at levels NT2007, NT2007 improved and EE provided with new and old stoves, and for houses without retrofit but new stoves having choking in their operation achieving one-half and one-quarter the reduction in emissions when changing stoves.

To assess the relationship between the costs of thermal improvements and stove replacement and the reduction in PM emissions we have defined effectiveness, as the cost in Chilean pesos ($cl) per kg of PM saved annually.

III. RESULTS AND ANALYSIS

A. Fuel poverty

In Valdivia, 95% of households use fuel wood for heating [6-7], so this option was considered in all cases. Income groups D and E spend in energy were 15% and 31% of their total household income, respectively; and thus they are classified as fuel poor. These two groups account for 52% of households. Group C3, accounting for 27% of households, spent in energy 9.8% of their income, and then they are at the boundary level of fuel poverty. Incomes higher than C2 were not at risk, being only 21% of households. It is to note that relative to house size and to income, lower income groups have much higher firewood consumption than higher incomes. This is due to lower house quality and lack of thermal insulation. Hence, government programs prioritize lower incomes to access subsidies; however, the number of subsidies per year is small compared to the need.

B. Cost Analysis

Figure 1 shows the result of the net present value (NPV) for household spending. The graph reflects a play between private spending in retrofits (moderated by subsidies), firewood costs and health insurance. The option that changes only stoves but does not improve the house envelope efficiency has negative slope due to the fact that more firewood than at present is needed to achieve the comfort condition of 18ºC [3] (rebound effect). Emissions of PM cause health problems and costs. NPV for private spending is very little sensitive to PM emissions, because most households in the sample rely on public healthcare. However, NPV for private spending is very sensitive to fuel wood consumed, and it demonstrates that option 1) that changes only stoves is not sustainable for households, more so in view of the large fuel poverty percentage discussed in the previous section.

After two years, all retrofit options showed better NPV than option 1), and after six years, the highest efficiency option EE showed the best NPV results. Not shown in Figure 1, the EE option has also the less sensitive response to air choking practices. This is due to large reductions in space heating needs when dwellings are provided with high efficiency thermal envelopes.

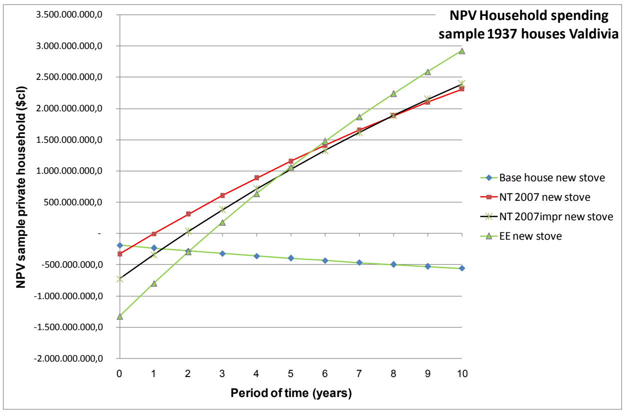

Figure 1. Net present value (NPV) of private household spending to improve 1937 houses in Valdivia

In Figure 2 we have plotted the effectiveness cost per kg of PM saved including the total cost private and public, in which we have included public spending in subsidies for retrofits and stoves and the cost of health care in public hospitals for PM-related diseases. (For simplicity option 3, NT2007I, is not depicted in Figure 2 because the results lay between EE and NT2007).

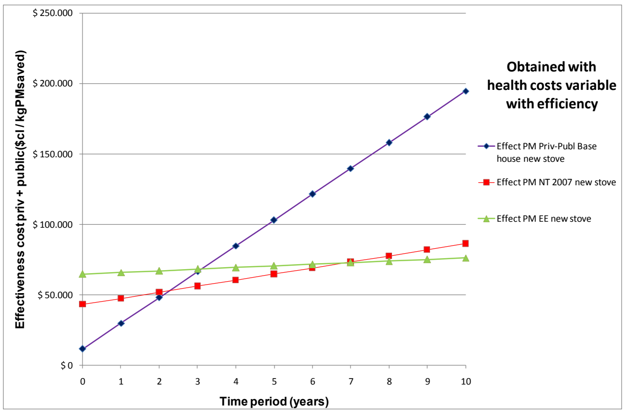

Figure 2. Total private and public effectiveness cost of each kg of PM emissions saved on the sample of 1937 houses studied in Valdivia.

The intersection of the various graphs in Figure 2 is most interesting. Due to higher costs needed for retrofits NT2007 and EE at the starting date, the option for replacing only stoves has lower initial effectiveness cost; however, beyond 2 and 3 years lower fuel wood consumption in retrofitted NT2007 and EE houses leads to lower effectiveness costs, respectively. After 7 years we obtained that the option of EE is most effective, followed by NT 2007.

IV. POLICY DISCUSSION

House retrofitting, in spite of having by far the highest potential for reducing firewood consumption, improving air quality, improving indoor comfort, and slow forest degradation, is not yet recognized as a priority. According to the study conducted here, the two current main strategies will have limited potential for improving air quality: i) acceptance of certificated firewood is very low; and ii) stove replacement has low impact if wood-heaters with an option of air-choking are still provided. Further acknowledgement on households' realities and further public-private interaction could speed the process needed to combine successfully the three strategies studied.

Given the air pollution emergency that is occurring in all regions of south-central Chile, and the fact that the measures so far could neither reduce air pollution nor create incentives to massively improve thermal quality, we propose here a set of improvements for existing policies based on the above analysis:

a) Establish an agenda on priority tasks and involve universities to create national and regional laboratories for research on equipment and techniques, and design a method to measure the real level of moisture in firewood currently in the market. It is urgent to have reliable empirical data on users' practices regarding firewood, equipment, houses, and social receptiveness of proposed changes.

b) Implement continuing education and assistance programs in every city. The creation of technical offices for every city sector could assist and train neighbors, and coordinate requirements and suggestions. This is a way to encourage social participation in the process of improving energy efficiency and communitarian and associative initiatives in neighborhoods. Social sectors able to afford improvements could be also encouraged by the continuing assistance and education initiative.

c) The emphasis on policy should shift from firewood certification and wood-stove quality to thermal refurbishments, which has the largest potential for lowering air pollution by dramatically reducing heating needs. In addition, improving sealing by implementing vapor barriers should be acknowledge as an effective mean to both reduce consumption of wood fuel and to avoid indoors pollution by incoming outdoor smoke.

d) It is urgent to investigate the effects of air-choked equipment on PM emissions and work on it together with industry and commerce. This will lower chimney smoke significantly but, given the low thermal efficiency of current households, proper air inlet would increase wood-fuel consumption. Besides, heaters are located in one room of the house, so even with a replacement for a better technology, indoor temperatures and associated health problems will not improve considerably if the house does not have proper thermal insulation. Therefore changes towards better stoves and house retrofits cannot be separate initiatives, along with changing in practices on the use of stoves. A further step would be to ban devices that allow complete air choking.

e) The premises and goals of the wood certification program should be critically revisited. Feasible future goals may merge with a more practical and simple starting strategy focusing in moisture and quality of firewood.

f) There is no systematic measurement of wood moisture. It is urgent to help both householders and the informal firewood market to regularly monitor moisture and achieve proper moisture content. This will also help households to improve their current practice on firewood purchase.

g) The current thermal efficiency subsidy for low incomes should include those that already have been beneficiaries of non-thermal house improvements; and should be extended to all social vulnerable sectors disregarding social housing plans.

h) The limitations on income levels to be eligible for the thermal insulation subsidy should be more lenient so as to include assistance of mid-level income social sectors. It is more likely for medium-income sectors to invest in thermal refurbishment, since low-income sectors are not able to afford it and high-income sectors have less incentive to do so.

i) Monitoring and verification protocols should be implemented so results can be verified, not only the number of subsidies have to increase, but also their correct execution. Surveys of households after the retrofit show improvements in condensation, mold reduction, and lifetime of materials, but other problems as infiltrations and thermal bridges were not solved with the thermal refurbishment. The same studies show that sometimes the subsidy is used for other improvements in the dwellings that are not related with the thermal performance.

j) Prioritize the elements of the envelope to be retrofitted: nowadays it is common to see investments with the subsidy financing double glass in dwellings that do not even have insulation in the roof. Prioritization of items in retrofits could ensure users are receiving an intervention that will be efficient in reducing their energy consumption.

k) In social housing the building extensions made by the owners are not considered in the subsidy; thus, only the original social house is retrofitted. If this extension is not thermally insulated, the overall effectiveness decreases considerably, in some cases even invalidating the effect of the retrofit.

l) Householders with no income capacity to afford replacement of old cook stoves should be provided with alternative cooking and water heating devices.

V. CONCLUSIONS

We have investigated technical and economical aspects of the characteristics in the use of fuel wood in households of south-central Chile. High consumption of firewood was found, correlated with low efficiency in the envelope of buildings and very high particulate matter (PM) emissions.

Different techniques and materials to retrofit existing houses to comply with current regulations and to achieve even better standards were studied. It was found that retrofits have high potential to lower fuel consumption and thus reduce air pollution.

There are presently government programs subsidizing retrofits and stove replacement. We have thus studied different options for stoves and considered emissions as measured in real-life operation, which differ from ideal laboratory measurements. In Chile, wood stoves in the market have the possibility to choke the air inlet. This mode is much used because wood can burn for longer time; however this practice increases PM emissions dramatically due to bad combustion.

In the economical analysis we have consider the cost of retrofits and the savings on firewood in the operation of retrofitted houses with new stoves. The percentage of improvements cost that the subsidies cover depends on income level, as houses in higher incomes are larger and require more spending in retrofit. Technical solutions and economical implications are income sensitive and care was taken to consider the differences.

We have calculated the total cost for private and public sectors, which include the initial investment and the yearly spent in fuel wood and healthcare. From private households' point of view, the options with retrofit led to much lower cost as the savings in fuel wood spent are larger, and subsidies reduce the cost of retrofits. From the public sector, the savings are in healthcare services and the main investment is in the subsidies, thus the option replacing only stoves appears as having lowest cost for the public sector. We have calculated the net present value (NPV) of the various efficiency options throughout a 10-year time period. For private households, the option that improves efficiency with new stoves but keeps the house without retrofit led to a decreasing NPV, resulting in more fuel poverty and thus unsustainable. All retrofitting options increase NPV. We have also calculated an effectiveness to save PM emissions (units $cl/kgPM-saved). For the sample in Valdivia, and considering all total private and public cost, between the second and third year the retrofit options have better effectiveness than changing only stoves, and after the sixth year the EE option has the best effectiveness of all, i.e., the cost is smallest for each kg of PM saved.

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Evaluation of a net billing incentive mechanism for distributed generation in Northern Chile

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ABSTRACT

Chile is committed to the development of non-conventional renewable energies. In order to achieve this goal, several laws have been approved creating the necessary incentives. One of the most recent instruments, the net billing law, promotes the integration of renewable technologies in the distribution area. Since in Chile subsidies have not been used, only cost-efficient technologies are incorporated. The net billing law has not shown much impact so far, therefore further incentive mechanisms are under discussion. This paper reports on the integration scheme for residential photovoltaic generation within the net billing context. Different options of photovoltaic plants are analyzed: a) self-consumption, b) self-consumption and feeding into the grid, c) self-consumption and storage. Discrimination of the best options has been determined based on the economic benefits of each alternative, which are determined by performing calculation of VAN. Growth rates for each of sizing options have been also determined and compared with the price of energy for the residential segment (BT1) in order to find the optimal choice. The results obtained show that for the existing market conditions in Chile and the net billing scheme the size of the photovoltaic plant in northern Chile should be about 1 kW. Furthermore, the option of using storage is not yet economically feasible.

Keywords: Energy Photovoltaics, Energy Storage, Net Billing,

I. INTRODUCTION

Energy is essential for society since the access and supply of it directly influences social and economic growth, and consequently, in reducing poverty. The lack of access to resources and reliable energy networks certainly constitutes a dangerous limitation for sustainable social progress, economic growth and the welfare of the population [1].

The Chilean electrical system consists of four parts: The Northern Interconnected System (SING), Central Interconnected System (SIC), Electrical Systems of Aysen and Magallanes. By 2015 the Chilean system reached a total installed capacity of 19,027 MW, from which 78.4% corresponds to the SIC, 20.7to SING and 0.9% to Aysen and Magallanes [2]. Additionally, the electricity consumption for 2020 should grow at a rate of 6 to 7 %.

On the other hand, in Chile the import of energy resources and the dependence on fossil fuels dominate, due to the high levels of scarcity in recent years. Price variability considerably influences the marginal costs of power generation and consequently the price of electricity [1]. It is therefore important to develop new forms of power generation sources that complement current generation, and gradually achieve greater autonomy of energy resources.

The Chilean electricity market consists of three segments: generation, transmission and distribution. Law regulates services and prices within the transmission and distribution segments. Regarding customers, there are those who are regulated and unregulated. In the case of regulated customers, on which this research focuses, the authority through the Ministry of Energy defines the fee. This value has associated a generation-transport component (marginal costs of generation and transmission) and a distribution (investment and losses) component.

Concerning Non-Conventional Renewable Energy (NCRE) in the Chilean electricity market, the state of Chile has undertaken measures in order to reduce barriers that limit the development of these technologies. One of them is the enactment of law 20257, which establishes participation percentages of NCRE in the energy production [3]. Subsequently, law 20571 established mechanisms to allow distributed generation for the residential sector. Recently, an "energy agenda" that defines a roadmap on issues of energy development for the period 2014-2030 [4] was also appointed.

Among the measures set out in the renewable law tagged that from 2010 the electrical system must meet NCRE injection amounts. This participation was increased in 2013 by law 20689, which requires that by 2025, 20% of the electricity must be generated from NCRE, for the contracts affected by this law [4].

According to the preceding paragraphs, law 20571 will be addressed, also called “net billing” since the payment for the energy injected into the grid will not be paid at the purchase price. This law regulates the payment of injected energy from unconventional sources of generation or efficient cogeneration facilities for clients subject to determinate prices, for regulated customers and for

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customers with renewable energy installations not exceeding 100 kW [5]. This law was created in order to promote self-consumption and distributed generation, in addition to boosting efficient and environmentally friendly generation.

In the manner the law is constituted, net billing promotes the design of photovoltaic (PV) systems only for self-consumption, because the selling price is lower than the purchase price. The estimated selling price for the energy to be injected into the grid is close to 60% of the purchase price for the energy from the grid. Moreover, considering the prices of the technologies and that of energy in Chile, only middle and upper socioeconomic groups may invest in such initiatives [6].

Considering the facts presented above, to find the best investment in PV systems for the residential sector in northern Chile, this research has been focused on analysing more deeply some incentive mechanisms for distributed generation net metering and net billing type. Furthermore, the option of including battery energy storage was scanned in order to determine whether this improves the incentive for FV installations sources under a net billing scheme.

II. METHODOLOGY

The methodology used in this work consists of the following steps. First, a description of the solar resource in the coastal area in the Antofagasta city is performed. Subsequently, an energy demand profile for typical residential users is given. Afterwards, the maximum economic benefit by installing PV plants with and without storage for different scenarios is determined. In the following sections, the details of each stages are explained.

A. Solar resource and electricity demand

Solar resource information comes from the existing database of the Antofagasta Center for Energetic Development of the University of Antofagasta. The data consists of recorded values of the Global Horizontal Irradiance (GHI) at the coastal area in the region in the year 2013. Fig. 1 shows the monthly average profile of the GHI for three sectors of the Antofagasta city.

The demand by the consumers was modelled from records of the hourly consumption at different feeders of the system, which combined with consumption patterns, allowed to obtain a profile of annual hourly consumption for three socioeconomic groups in the city. Fig. 2 shows the annual average consumption profile per hour of each socioeconomic group [7].

The purpose of segmenting the population into socioeconomic group (GSE) is to understand the differences in lifestyles, consumption patterns and differences in purchasing power. In 1986, Chilean Association of Market Research Companies (AIM) performed the first study of socioeconomic distribution, which has been evolving and updating. To date GSEs have been classified as follows; D = low, C2 = medium and ABC1= high

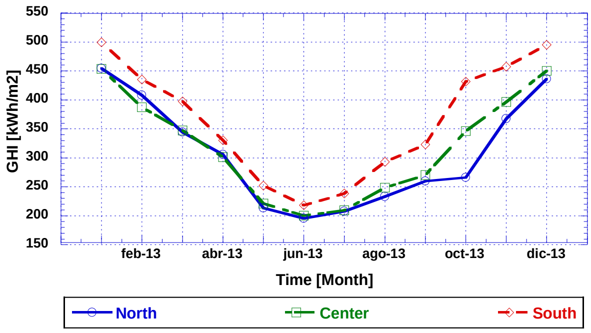

Fig.1 Monthly GHI for the three stations in Antofagasta City

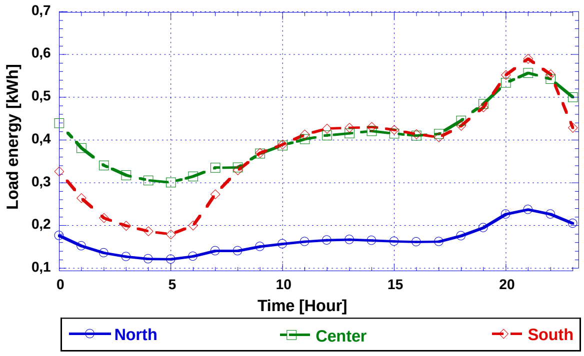

Fig. 2 Annual average consumption profile per hour of each socioeconomic group.

B. Projection of energy prices

The energy generated by photovoltaic systems will be evaluated at the BT1 price. In this rate, there is only energy charge for energy consumed, and only low voltage consumers with a connected capacity less than 10 kW apply for it. [8]. Since the evaluation is performed with horizons reaching 10 years, it is necessary to project the prices in order to carry out the respective economic evaluation. The projection of BT1 energy prices is obtained based on a linear prediction of the long-term base marginal prices from the supplied by the distributor. Prices are those paid by distribution companies to generators.

C. Design of the photovoltaic plant

The size of a photovoltaic plant will depends on the type of business that it is proposed: Therefore, two methodologies of design are discussed. Self-consumption (AUT) and Net Billing (NBIL).

C.1. Plant size AUT

An estimation of the size of the PV plant is pursued in such a way that the plant is not overstated or under-sized. This problem can be solved by considering the following optimization problem.

$$Min\{err = \sum_{i\in\Omega}(E_d^t - E_{GPV}^t(P_P))^2\} \qquad (1)$$

Where:

E_d^t: Energy demanded in each hour in kWh

E_{GPV}^t: Energy generated in each hour by the PV plant [kWh]

P_P: Nominal capacity of the plant in kWp at STC.

Ω: Effective sun hours

The model proposed in (1) seeks to minimize the deviation between the generated power and demand at any time when the sun is available.

To find a solution to the problem defined in (1) it is important to consider the relationship that link the production of a PV system with the required irradiance. This relationship can be obtained from a coefficient of performance defined by the standard IEC 61724, called Performance Ratio (PR). This coefficient has been defined as follows

$$PR = \frac{E_{GPV}/P_P}{H_{POA}/G_{STC}}\ (\%), \qquad (2)$$

Where:

H_{POA}: Irradiation at the plane of array (POA) in kWh/m^2.

G_{STC}: Irradiance at STC, i. e. 1 kW/m^2.

Substituting (2) in (1) and applying first order optimality conditions, the size of the PV plant is defined by the following relationship:

$$P_P = \frac{\sum_{t\in\Omega} E_d^t}{PR \cdot \sum_{t\in\Omega} HSE^t} \qquad (3)$$

Where $\sum_{t\in\Omega} HSE^t$ are the equivalent sun hours obtained from $HSE = H_{POA}/G_{STC}$.

The model proposed in (1) is equivalent to net metering (NMET) business model where it must be paid for the energy sold and generated by the PV plant at the same price as that of the power purchase rate. In this case, the best solution is selling the same amount of energy purchased, while investment is paid with the savings achieved by generating power when the sun is available.

C.2. Plant size NBIL

Under a net billing (NBIL) incentive scheme, the price of energy to be sold is lower than the rate of purchase. In particular, in the Chilean case, the price to pay is the marginal cost of energy at the point where the company purchases energy. In addition, the effect of the transmission losses in the distribution system must be added.

To determine the optimal size of the photovoltaic plant (PV), the cost reduction that would introduce an investment in a PV plant is required. This variation of charge is determined as explained in the following equations.

Before establishing the project, costs are determined by customer residences as:

$$C_1 = E_{Ant} \cdot p_{BT1}, \qquad (4)$$

Where E_{Ant} is the energy purchased from the network before the project and $p_{BT1}$is the price of the residence rate called BT1.

The cost incurred after the project is completed:

$$C_2 = AVI + E_{COM} \cdot p_{BT1} - E_{VEN} \cdot k \cdot p_{BT1}, \qquad (5)$$

Where AVI is the annual cost of investment in the PV plant, E_{COM} the annual energy that is purchased to the system, E_{VEN} the annual energy sold to the system, *k* is the factor that weighs the price of BT1 rate for determining the price sales, k ∈ [0.4, 0.6].

Cost variation is then defined without and with project as $\Delta C = C_1 - C_2$, which is presented more explicitly in (6).

$$\Delta C = E_{TA} \cdot p_{BT1} - (AVI \cdot P_P + E_{COM} \cdot p_{BT1} - PR \cdot HSE \cdot P_P \cdot k \cdot p_{BT1}) \qquad (6)$$

The optimal size of the plant is obtained by performing a searching of P_P values that maximize the Net Present Value (NPV). This value is presented in (7):

$$P_P = \max\{\sum_t \frac{\Delta C_t}{(1+r)^t}\} \qquad (7)$$

C.3. Rate of development

Considering (6), more information about the problem can be extracted. To make the project attractive, it is necessary that the cost variation must be positive, i.e., $\Delta C \geq 0$. This means that the costs after the realization of the project should be less than the existing before its begin. From (6) we can obtain the rate price of electricity, in which case, it holds:

$$p_{BT1} \geq \frac{AVI \cdot P_P}{E_{TA} - E_{COM} + PR \cdot HSE \cdot P_P \cdot k} \qquad (8)$$

This price corresponds to an approximation of the rate value at which the project becomes profitable. It is equivalent to the Levelized Cost of Energy (LCOE).

Moreover, from (6) it is possible to obtain the lower bound of the plant capacity for which the project is profitable. This value is defined by (9).

$$P_P \geq \frac{E_{COM} \cdot p_{BT1} - E_{TA} \cdot p_{BT1}}{PR \cdot HSE \cdot k \cdot p_{BT1} - AVI} \quad (9)$$

D. Self-consumption factor

Self-Consumption factor is an index that permits distinguishing energy facilities according to distributed generation level that they have [9].

The self-consumption represents the electrical energy consumed that is supplied by local generation sources. Therefore, the self-consumption factor (ξ) is calculated as:

$$\xi = \frac{E_{PV,Carga} + E_{Bat,Carga}}{E_{Carga}} \quad (10)$$

Where, ξ is the self-consumption factor, $E_{PV,Carga}$ is the FV energy that feeds the consumption in kWh, $E_{Bat,Carga}$ is the stored energy from the batteries in kWh and E_{Carga} is the energy consumed by the load in kWh.

Note that ξ may be used in different periods. Because ξ is normalized between 0 and 1, systems with different sizes and load can be compared. Thus, if ξ=0 corresponds to the case when no local generation exists, and ξ=1, when all demand is supplied with local power.

III. RESULTS

In this section, the results of evaluating the incentives to introduce distributed generation in Chile are presented. The analyses presented have been limited to the city of Antofagasta-Chile, which is representative of northern Chile. This city can be considered an optimistic case because of the high abundance of solar resource in the area. Considering a year of solar radiation measurements , it was determined that the equivalent sun hours HSE was 1916.4 h for the north, 2001.9 h for the centre and 2261.4h for the south sector.

The first case analysed is the self-consumption. Table 1 shows the sizes of the PV plant in kWp for different socioeconomic groups (GSE) and for each city sectors; North, Centre and South. The GSE are classified as low (D) with an annual monthly average consumption of 120 kWh, medium (C2) with an annual monthly average consumption of 271 kWh and high (ABC1) with an annual monthly average consumption of 286 kWh.

Table 1. Powers optimal consumption in kW

GSE	NORTH	CENTER	SOUTH
D	0.98	0.94	0.83
C2	2.22	2.12	1.88
ABC1	2.33	2.23	1.98

The results shown in the Table 1 indicate that when a plant for self-consumption has been designed, sizes tend to the following values: for a low socioeconomic sector, the plant size is around 1 kWp, while for GSE medium and high, the plant size is around 2 kWp. It is also seen that the plants located at the northern sector are larger than those located at the south of the city. This is explained by the fact that in the southern sector the solar resource is higher, so smaller plants are needed. Moreover, in Table 2 it can be observed the percentage of self-consumed energy and injected energy into the network.

Table 2. Self-consumed and injected energy into the network

	Self-consumed Energy			Injected Energy		
Sector	Norte	Centro	Sur	Norte	Centro	Sur
D	39.78%	40.39%	40.17%	60.22%	59.61%	59.83%
C2	44.57%	45.36%	45.07%	55.43%	54.64%	54.93%
BC1	40.28%	40.83%	40.17%	59.72%	59.17%	59.68%

From Table 2, it can be determined that the injected energy is equal to the energy purchased, since it is the complement of the self-consumed energy. Thus, it follows that the size defined by (3) perfectly equalizes the energy that must be purchased with which it is sold to the grid. This result confirms the hypothesis that this design operates as a net metering scheme, because when the purchase price and sell price are the same, the best decision is to inject the same amount of energy that is purchased. In this way, the savings obtained from the self-consumed energy will pay the project.

Considering now a sizing of PV plant for a net billing scheme. As it was presented in (7) the capacity of the plant can be obtained by searching the power value that produces a positive NPV. The values used to calculate the NPV are: the BT1 energy price of 0.195 US$/kWh, useful life of 25 years, rate of return of 6.17%, O&M costs of 1.5% of investment and k = 0.6. Two cases of investment costs have been analysed. The first one takes 1900 USD/kWp and the second one considers 2000 USD/kWp. These values are the most optimistic that have been observed in the industrial sector of the Chilean PV market. Table 3 shows the results obtained for the first case of investment cost, and Table 4 presents the results for an investment cost of 2000 USD/kWp.

Table 3. Size of NBIL plant for 1900 USD/kW

GSE	NORTH	CENTER	SOUTH
D	1.0	1.0	1.0
C2	1.5	1.3	1,2
ABC1	1.7	1.6	1.4

Table 4. Size of NBIL plant for 2000 USD/kW

GSE	NORTH	CENTER	SOUTH
D	0.93	0.92	0.80
C2	1,30	1.20	1.10
ABC1	1.50	1.40	1.10

Tables 3 and 4 show that the sizes of the plants are below those of net metering. This is reasonable, because only 60% of the power purchase rate is paid by the injected energy to the grid.

In the following, the development rates of the NMET and NBIL schemes are analysed. The results was determined by supposing a useful life of 25 years and the same investment costs as for the case NBIL. Fig. 3 shows the costs for NBIL scheme, which is compared with the current rate system whose value is 0.195USD kWh.

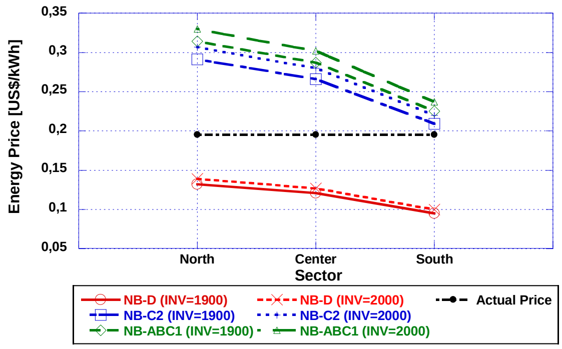

Fig. 3. Rates of development for Net Billing.

In Fig. 3, it is observed that only systems with 1 kWp capacity are viable from an economic point of view.

Now, if in Chile the Net Metering incentive was developed, would exist more interest to install PV plants. In this case, a PV plant capacity of 2 kWp would be economically profitable as shown in Fig. 4.

The investment cost is one of the factors determining the selling price of energy, as shown in Fig. 5, the current costs in Chile are very high, which means that the energy cost should be much higher than the current BT1 rate value.

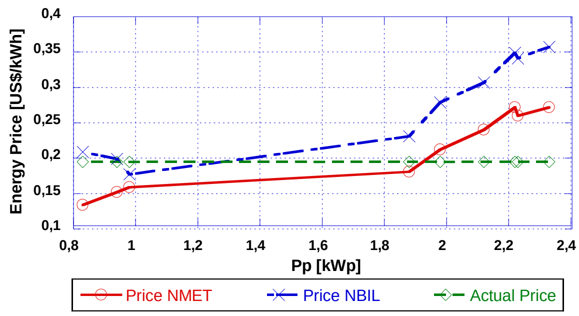

Fig. 4. Price development for Net Net Metering and Billing.

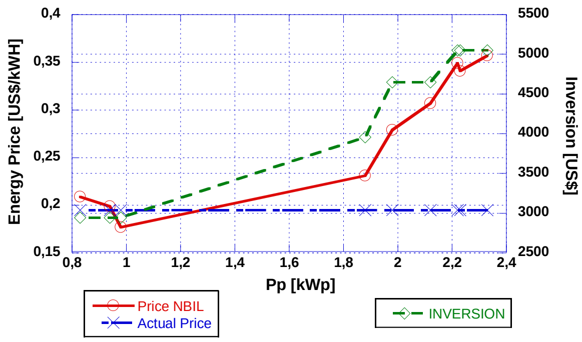

Fig. 5. Comparison of current energy prices and Net Billing

Finally, the development rate for battery storage system has been evaluated. For this analysis, the same procedure described in Section C.2 using equation (8) was considered. In this situation, the system is designed so that the stored energy E_{ComAut} is consumed during the time when there is no sun, so it is not required to purchase energy from the network, or this purchase is considerably lower. On the other hand, also the possibility of selling energy, E_{VenAut}, to the system has been considered. In this case, the value for the sold energy should be 60% of BT1 current rate.

To calculate this rate, investment costs of lead acid battery have been considered. The battery size was calculated using a depth of discharge factor of 60%. The results are presented in Table 6. In addition, in Fig. 6 shows calculated prices for NBIL scheme versus prices calculated with storage at Table 5.

Table 5. Development rate for system with storage

[US$/kWh]	NORTE	CENTRO	SUR
D	0.32	0.32	0.28
C2	0.44	0.40	0.32
ABC1	0.53	0.50	0.26

For this case, the development rate is higher than the BT1current rate, so that the storage is not a commercially profitable option.

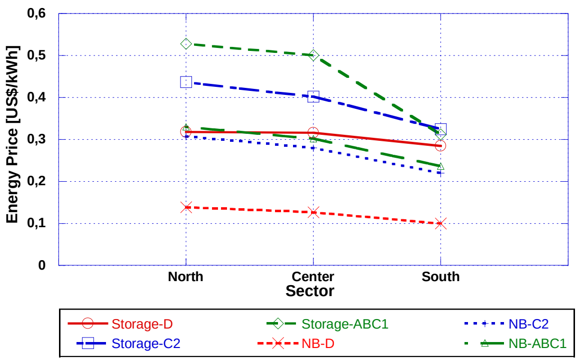

Fig. 6. Comparison of prices modal NBIL versus storage

Finally, the self-consumption factor is analysed. Despite that the development rate are so high compared with the previously analysed cases, the self-consumption factor (ξ), presented in (10), exceeds the 60% for the most unfavourable case, such as shown in Table 6.

Table 6. Factor of self-consumption for the system with storage energetic

ξ	NORTH	CENTER	SOUTH
D	0.76	0.74	0.73
C2	0.67	0.66	0.64
ABC1	0.91	0.89	0.88

IV. CONCLUSIONS

In this work, a comparison of the incentive mechanisms for distributed generation applied in Chile has been done. One of the main findings in this investigation is that under the marketplace condition existing in Chile, the net billing scheme is profitable for installations of size around 1 kWp. Furthermore, the dissimilar availability of solar resource in the north, centre and south part of the city does not affect significantly this result. On the contrary, if the incentive mechanism was net metering, the size of the PV plant should be close to 2 kWp.

Finally, at the residential level, the use of storage is not yet a viable alternative in Chile.

It is important to consider that the results shown in this research represent the most optimistic case, because the investment cost vary in the range 2000 to 3000 USD/ kWp.

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