PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE

ESCUELA DE INGENIERIA

EVALUATING HOUSEHOLD AND COMMUNITY RENEWABLE MICRO GRIDS IN CHILE: ENERGY MANAGEMENT AND OPTIMAL SIZING FOR DIFFERENT BUSINESS MODELS

CAMILO MAXIMILIANO AVILÉS ARIAS

Thesis submitted to the Office of Research and Graduate Studies in partial fulfillment of the requirements for the Degree of Master of Science in Engineering

Advisor:

DAVID EDUARDO WATTS CASIMIS

Santiago de Chile, (May, 2017)

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A María Paz y a mi familia, quienes me apoyaron en los momentos más difíciles.

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RESUMEN

Esta investigación propone la evaluación de micro redes renovables que incorporan el dimensionamiento y operación óptimos para reducir los costos de abastecimiento bajo diferentes modelos de negocio a lo largo de Chile.

Con este objetivo se calcula y se dimensiona una micro red residencial o comunitaria que puede estar conectada o desconectada de la red, a través de un mix de recursos energéticos distribuidos, los que incluyen fuentes renovables como generación solar y eólica, generación diésel a través de un generador económico y un generador flexible, sistemas de almacenamiento de energía con baterías y gestión eficiente de la demanda. Para micro redes conectadas a la red, se evalúan tarifas reguladas que incluyen cargos por energía y potencia a nivel comunitario, y tarifas con cargo único por energía a nivel residencial. Los esquemas de Net-Billing y Net-Metering son evaluados tanto en micro redes residenciales como comunitarias, pero en estas últimas también se comparan los esquemas Norma-4, PMGD y desconectado de la red.

Para evaluar la viabilidad económica de esta propuesta se levantó el recurso renovable de cada zona, los precios de tarifas residenciales y comunitarias, los precios de combustible diesel y la demanda para 24 días del año tanto para comunidades como residencias a lo largo de Chile, junto con los costos de inversión de cada una de las tecnologías que componen las micro redes.

Es posible clasificar la operación de micro redes comunitarias y residenciales conectadas a la red en tres familias a lo largo de Chile: abastecen gran parte de la demanda con generación renovable, reducen demanda de punta en horarios de mayor consumo y minimizan la compra de energía a la red en lugares con tarifas altas. El autoabastecimiento es económicamente factible con fuentes renovables, principalmente solar fotovoltaica, tanto a nivel comunitario como residencial en cada uno de los modelos de negocio a lo largo de Chile. Esto permite reducir el costo medio de abastecimiento al desplazar suministro más caro proveniente de la red por energía renovable barata.

Palabras Claves: Micro redes, generación distribuida, Modelos de negocio en distribución, Desarrollo solar fotovoltaico, autoconsumo, generación renovable, cargos por demanda

ABSTRACT

This research examines renewable micro grids that incorporate optimal sizing and energy management to reduce supply costs for different Chilean and international business models. From that perspective, household or community micro grids, either connected or unconnected to an upstream network, can be measured through a mix of distributed energy resources, including renewable sources such as solar and wind generation, diesel generators, battery storage systems and efficient demand management. Regulated rates are assessed for grid-connected micro grids, which include community demand and energy charges as well as single-dwelling charges. Net-Billing and Net-Metering schemes are evaluated for both household and community micro grids. In the latter, small-distributed generation (which cannot sell back energy surpluses to the upstream network), large-distributed generation and unconnected network schemes are also evaluated.

Seventeen sites in Chile were analyzed with a focus on renewable energy, retail rates, seasonal variation, and weekend versus weekday demand. Technology investment and economic viability were fundamental concerns. Our findings show that self-sufficiency is economically viable through micro-grid deployment in Chile with net-zero consumption, while using the upstream network as a back-up supply. Furthermore, large-scale generation and purchases from the grid can be substituted with distributed generation, reducing grid utilization. Therefore, solar photovoltaic generation at both household and community levels and other forms of distributed energy resources can significantly enhance power supply, creating a trading platform between prosumers, distributed generation and conventional sources.

Keywords: Micro grids, distributed generation, distributed energy resources, distribution business models, Solar PV deployment, self-supply, renewable energy, demand charges

1. INTRODUCTION: POTENTIAL DEVELOPMENT OF RENEWABLE RESIDENTIAL AND COMMERCIAL MICRO GRIDS BOTH CONNECTED TO THE GRID OR ISOLATED

With the fast enhancement of energy demand and fossil fuel dependency, countries all over the world are facing essential challenges on security, reliability and low emission issues (Zeng, Zhao, Yang, & Tang, 2014). This has led to increased clean energy production and pressure to push forward energy efficiency improvements. In the last years, massive renewable energy systems have been deployed over the world on the networks both at the transmission and distribution levels. Hence, there is a need of adapting the existing electricity transmission and overall distribution infrastructure in order to facilitate a more diverse portfolio of renewable energy sources (RES) and greater levels of demand side participation (Bolton & Foxon, 2011).

1.1 The transition from traditional to future smart distribution networks

Future distribution networks must be prepared to allow massive solar photovoltaic (PV) deployment, large amount of distributed generation (DG) sources, massive integration of battery energy storage systems (BESS) or electrical vehicles (EV), high component of combined heat and power (CHP) and demand response programs, which are all part of the components of what is often referred as distributed energy resources (DERs). The main components of DERs are presented in Fig. 1-1.

DERs can be used to actively enhance power quality an reliability of delivered electricity end-uses, increased energy efficiency, reduced carbon emissions and many other benefits such as reduces line losses and grid expansion deferral. However, controlling a potentially huge number of DERs creates a daunting new challenge for operating and controlling the network safely and efficiently. This challenge can be partially addressed by Micro Grids (MGs) (Hatziargyriou, Asano, Iravani, & Marnay, 2007).

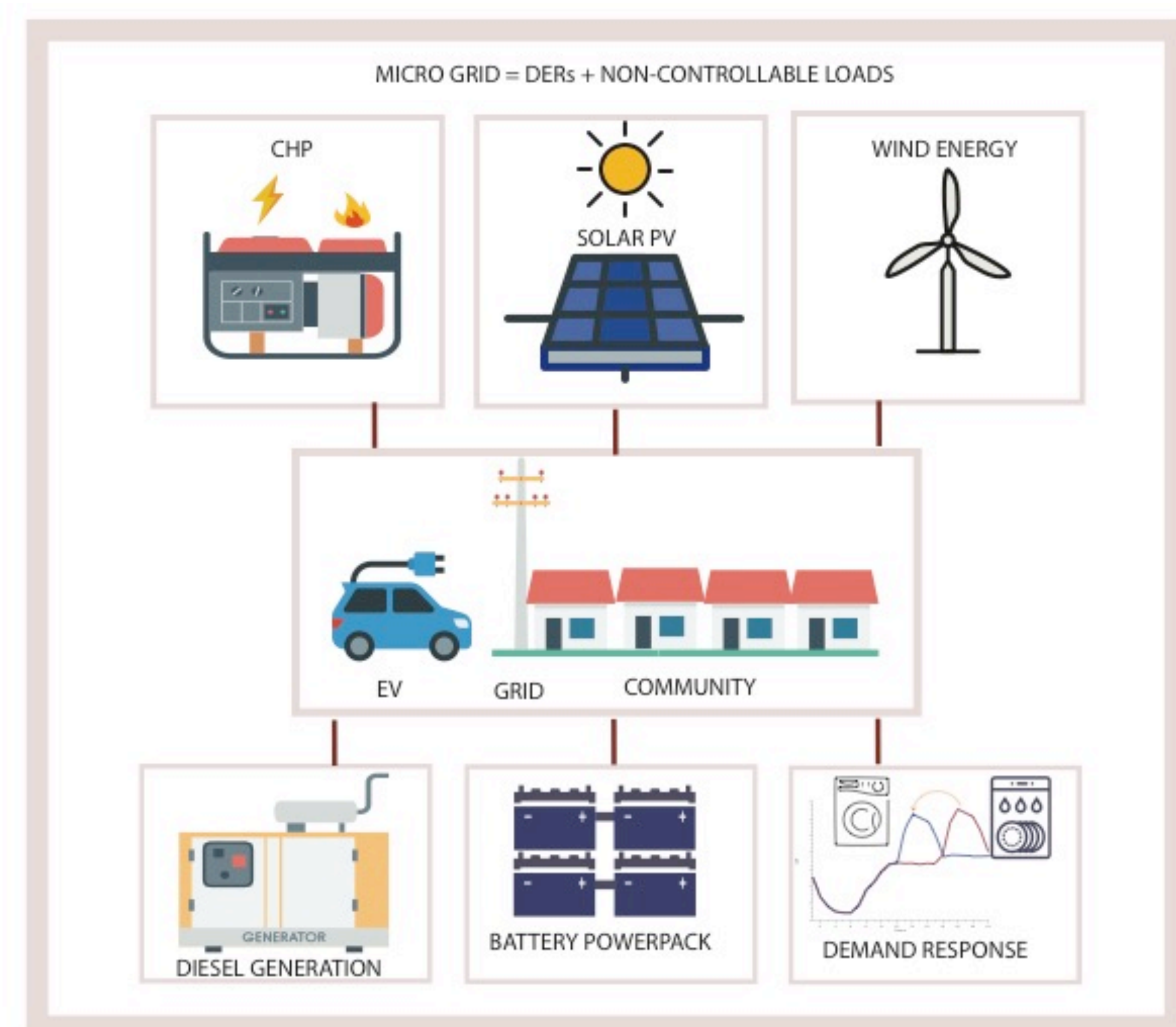


Figure 1-1: DER components in a micro grid connected to distribution network

1.1.1 Changes in distribution networks to enhance MGs deployment: ¿Why do we need MGs?

MGs are perfectly suited to meet the challenges of the future distribution networks. In literature, several drivers are mentioned for their deployment as the following:

- *A more reliable and sustainable service grid that can reduce the risk of outages*: Distribution networks are usually the prime source that causes outages in the power system (Yin & Lu, 2009). According to literature, 80% of customer interruption happens because of problems in the distribution system (Billinton & Allan, 1996),(Sultana, Mustafa, Sultana, & Bhatti, 2016).

- *A more participatory household that can be able to manage the electrical consumption*: With the fast development of science, technology and demand side participation, an evolution in costumer behavior is expected who will become an active energy producer or **prosumer**. Also, customers will be able to participate in energy scheduling and generate savings from reducing or shifting their electricity consumption by moving flexible loads (Zakariazadeh, Jadid, & Siano, 2014).

- *A lower energy rate cost and peak power charge:* On-site production can deliver power directly to its internal loads without utilizing the upstream network. This could result in savings in transmission and distribution costs of about 30% of electricity costs (Pepermans, Driesen, Haeseldonckx, Belmans, & D'haeseleer, 2005), (IEA, 2002).

- *A lower operational cost for utilities:* Due to higher penetration of RES in distribution networks, utilities could benefit from investment deferral

(Hatziargyriou et al., 2007), congestion relief and ancillary services such as voltage droop and frequency control.

- *A more flexible grid that can support the intermittency and volatility of* renewables: local network must be adapted to support the penetration of small-scale distributed energy sources, thus, allowing more penetration of RES.

1.1.2 Enhancing consumer independence with micro grid: distributed generation

MGs are often comprised of solar PV, wind, EV or BESS, DR programs, DG units and consumers, which comprises DERs. This is presented in Fig. 1.2. DG describes small-scale electricity generation technology connected directly to the upstream network or on the customer site of the meter (Ackermann, Andersson, & Söder, 2001). DG is a broad term and can refer to units producing from a few kW of electricity up to the MW scale (Touretzky, McGuffin, Ziesmer, & Baldea, 2016).

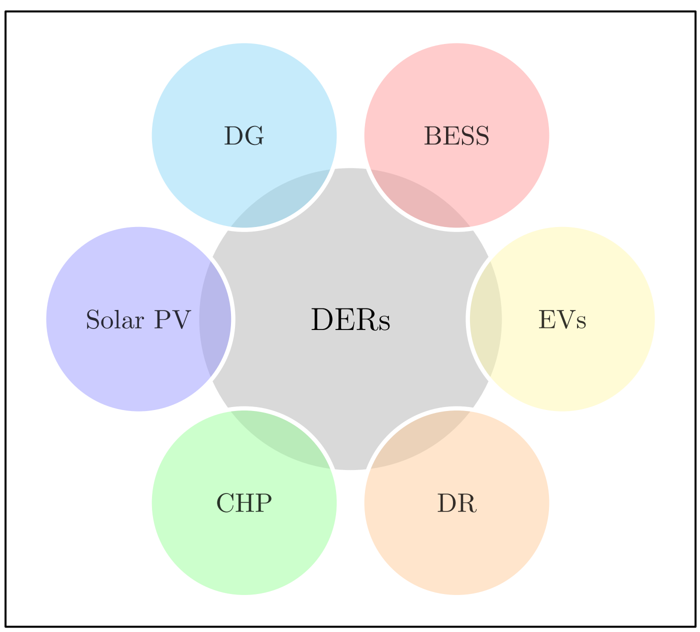


Figure 1-2: Technologies that comprise DERs

MGs are small scale distribution systems containing non-controllable loads and DERs, that can be operated in a controlled, coordinated way both connected to the upstream network or isolated (Marnay et al., 2015), (Romankiewicz, Marnay, Zhou, & Qu, 2014). DERs have several applications included residential and commercial ones.

1.1.3 Purposes of MGs: functions and properties

Three types of MGs can be defined based on performance analysis (Paquette & Divan, 2012):

1. Reliability, by providing backup during outages and shortages (Lee, Soto, & Modi, 2014; Mirsaeidi, Mat, & Wazir, 2016; Y. Wang, Ravishankar, & Phung, 2016).
2. Energy arbitrage, by providing revenue in grid-connected operation through peak-shaving
3. Improve power quality by rapidly islanding during utility disturbances. If the power of distributed generators is high enough to feed the loads of a certain area, this area could be disconnected from the main grid and operate in islanded mode. (Hassan, Niknam, & Blaabjerg, 2017; Moradi, Bahrami, & Abedini, 2017; Romo & Micheloud, 2015).

MGs have the potential to provide value for all three dimensions simultaneously. Most research, however, tends to focus on only one of these three value qualities. In recent years, with the cost reduction of DG options (particularly solar PV), self-supply is slowly becoming a more feasible economic alternative, adding a fourth purpose for MG development. MGs are deployed to provide revenues by moving flexible loads to hours of the day when there is low-cost generation and by providing peak demand power when energy prices are high. Moreover, when local supply is economically sufficient, MGs are deployed to reduce grid purchases and produce economic savings.

1.1.4 Economic benefits and usage advantages of energy arbitrage

Besides producing energy locally, MGs can be designed to purchase energy from a grid when prices are lower and export energy to the grid when prices are higher. Additionally, reducing demand during peak periods decreases the amount of power purchased from the upstream network, which is especially valuable in countries using demand charges or some form of peak-load pricing. Reduced peak demand can be achieved with MGs by managing the operation of shiftable or controllable loads in DR programs, along with the optimized operation of BESS (Jaramillo & Weidlich, 2016). MGs can also benefit from less expensive generation during times of congestion in the utility grid (Morris, Abbey, Wong, & Joos, 2012). Moreover, reduced energy purchases from the utility grid translate into lower distribution charges, insuring economic benefits (Parhizi, Lotfi, Khodaei, & Bahramirad, 2015). MGs are usually comprised of DG based on fossil fuels (mostly diesel). Such technology can be used to mitigate supply uncertainty, often associated with RES. This is due to the flexibility diesel provides for production, ramped up or down quickly to satisfy short term load balancing needs (Touretzky et al., 2016).

1.2 Transition in Chile: the need for a more secure and reliable network

Chile, along with many other countries, is in transition from traditional outdated networks to newer, more reliable and flexible grids, supporting high penetration of renewables. In August of 2016, Chile achieved the lowest solar power cost in the world (USD 27/MWh). It now has the second lowest cost in energy auctions, showing that unsubsidized solar PV is competitive and even cheaper than conventional sources. Furthermore, Chile is the world's fourth projected top market for solar PV exports, according to the International Trade Administration (International Trade Administration, 2016). In fact, the Atacama Desert in Northern Chile is widely considered the world's best solar resource. In Latin America, Chile is the largest solar PV market and the second largest wind-energy market (Kristin Seyboth, 2016), (GTM Research, 2016). Sustantial geothermal and hydropower resources also exist across the country.

1.2.1 Chilean and International Standards: the need for more security and new regulation in distribution networks

Chile aims to generate at least seventy percent of its electricity from renewable sources by 2050, with particular emphasis on solar and wind (Coquelet, 2016). The International Energy Agency has reported that in Chile electricity generation is fairly resilient, but transmission and distribution networks are more fragile. In the Chilean electricity supply, the system average interruption duration index (SAIDI) reaches 16 hours per connection per year (MaRS Advanced Energy Centre, 2015). This is quite distant from European members of the Organization for Economic and Cooperative Development, where SAIDI is below eight hours, and in countries like Denmark, Germany and Switzerland where SAIDI is less than one hour (CEER, 2015). Hence, new regulation in distribution networks must be addressed and encouraged in Chile if MG deployment is to be successfully implemented. The Inter-American Development Bank is financing an energy distribution reform in Chile to tackle these challenges, and our research team is in the vanguard of the move to deliver this reform. Several impediments stand in the way of such necessary MG deployment, however.

1.3 Financial, regulatory and technical barriers facing MGs

MGs barriers can be classified into three categories (Soshinskaya, Graus, Guerrero, & Vasquez, 2014):

- *Technical*, which comprise mainly dual mode operation, power and frequency control and protection and safety
- *Regulatory*, which comprise interconnection rules and lack of market support mechanisms which could allow DG to access the electricity market freely and to reward DG according to its service to the network (Pudjianto et al., 2005) and

- *Financial*: which comprise a relatively high capital cost for renewables technology and electrical storage systems and relatively low selling electricity prices, which discourage new investment.

Due to financial barriers, it is often necessary to provide incentives or new business models for MG development.

1.4 Encouraging MG deployment: unlocking and exploiting distributed energy resources

Several policies have been addressed in countries to create incentives for DG:

- *Net-Metering:* allows utility customers to offset home energy consumption with RES. Also, excess energy sent to the utility can be sold back at retail price (Comello & Reichelstein, 2017; Darghouth, Barbose, & Wiser, 2014; Poullikkas, 2013; Yamamoto, 2012).
- *Net-Billing:* allow consumers to produce their own energy, consume it, and generally sell the surplus at almost half the retail price, thereby avoiding the utility generation cost.
- *Feed-in tariff*: in which excess energy sent to the utility is sold back at a higher price than retail (Poullikkas, 2013).

Forty-four US states have Net-Metering schemes (Chandra, 2014) which are differentiated by capacity limits in residential and non-residential locations. Net-Metering is also employed in Belgium, The Netherlands, Denmark and UK (Knaack, 2015).

1.4.1 Net-Billing experiences in Chile

Net-Billing (or Net-Metering) policies are used in forty-eight countries, and some form of financial incentive for renewables exists in 126 countries (REN21, 2015). Chile has had Net-Billing since 2014, although changes to this law were approved in 2017:

- Lower response times and fewer steps in processing, especially for residential projects.
- Simpler connection request documentation.
- Allowing joint processing of real estate projects.

Moreover, a Net-Metering scheme has been suggested for consumers with capacities up to 10 kW, or even more (Watts, Valdés, Jara, & Watson, 2015).

1.4.2 Development of several business model to enhance MG deployment

In addition, several business models have been proposed with the aim of finding feasible financial solutions for MGs deployment:

- *Loans model:* purchase of the plant with financing (loans) or without financing.
- *Owner-ship models:* Comprise build-own-operate-transfer (BOOT) and leasing models
- *Energy service company (ESCO) models:* which comprise energy performance contracting (EPC) and energy supply contracting (ESC) models

In ESC, client and ESCO sign a power purchase agreement (PPA) in order to reduce the price of the energy bill. This is usually called Chauffage contract (Bertoldi, Boza-Kiss, Panev, & Labanca, 2013), whereas in EPC two different models are addressed:

- Shared savings: where ESCO finances the whole project
- Guaranteed savings: where client finances the whole project (ANESCO Chile, 2016), (Bank, 2015), (GIZ, 2014).

Figure 1-3 summarizes the MG business models.

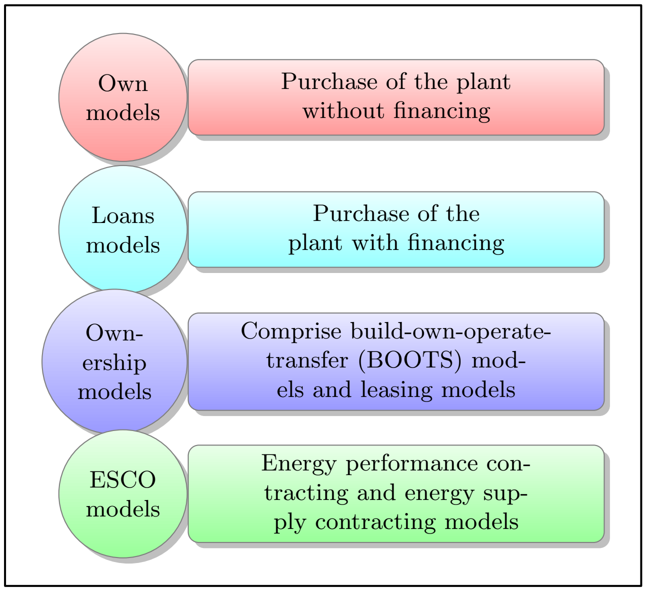


Figure 1-3: Micro Grid Business Models

1.5 Development of a bilevel optimization model for the MG optimal design and operation

In order to evaluate the feasibility of deploying community and residential MGs, an optimization model must be addressed to obtain the optimal sizing and operation of MGs. A bi-level optimization model is used, which methodology is similar to the models developed by (Khodaei, Member, Bahramirad, & Member, 2015), (Quashie & Joos, 2016), (H. Wang & Huang, 2015) , (J. Zhang et al., 2016) and (Bahramara, Parsa Moghaddam, & Haghifam, 2016) in that they decompose the planning problem into an upper problem (investment) and lower problem (operation). In terms of operation optimization model this paper is based on (D. T. Nguyen & Le, 2014). However, none of these works evaluate the deployment of several MGs business models with electricity rates that incorporate peak demand charges in more than one place.

1.6 Hipothesis of the investigation

General hipothesis of this thesis is the following:

It is feasible to implement cost-effective and economically sustainable MG models in northern, central and southern Chile that allow greater flexibility in the system by incorporating energy storage systems and technologies to manage electrical demand, given the high volatile and intermittent nature component of non-conventional renewable energies. Also, RES self-sufficiency is feasible in most places where renewable resources are available.

Considering the elements mentioned above, this document is developed around multiple questions and more specific hypotheses:

- The conditions under which a micro-network is feasible depends on the geographic location, the availability of renewable resources, the remoteness with the network and the electricity supply rates that exist in the area.
- MGs with a high solar photovoltaic component are easier to implement from Santiago to the north of the country.
- Demand management is a technology economically feasible to implement in MGs, which allows greater flexibility in the system to manage electrical charges.
- Having storage batteries allows greater flexibility and greater penetration of non-conventional renewable energy into the system.
- Electric generation ramps generated by the penetration of non-conventional renewable energies can be met by generation based on fossil fuels such as diesel oil, energy storage systems such as electric batteries and technologies to manage demand

1.7 Objectives of the investigation

In agreement with the proposed hypothesis, the general objective of this thesis is the elaboration of a proposal of MG development throughout Chile considering the levels of rates and renewable resource availability for different business models: Net-Billing, Net-Metering, Small Distributed Generation, Large Distributed generation and Isolated MG. For this, a bilevel optimization model is presented which considers the sizing and operation of the MG. Specific objectives are the following:

1. Development of a conceptual framework for the deployment of MGs throughout Chile that justifies the need of evaluating the consequences of distributed generation penetration and how this could positively affect the savings of regulated clients.

2. Development of a bi-level optimization model. The following output is obtained from the model:

- Optimum dispatch and operation that minimizes the costs of supplying the MG and
- Optimal capacity installed for each technology that comprise each MG throughout Chile

3. Evaluation of regulated electrical rates for communities and residential micro grids under Chilean regulation rates: BT1 (THR) and BT2.

4. Evaluation of several business models for MGs based on current regulations and technical standards.

5. Facilitate the enactment of public policies that consider the design and implementation of MGs, by quantifying the solar and wind resources throughout the national territory, and then evaluating the technical - economic feasibility of implementing MGs in urban communities throughout Chile.

6. Model and design a one-year self-consumption generation system, with solar, wind, backup generation based on diesel oil, energy storage systems and demand management programs, along with the possibility of selling energy to the grid.

To address the proposed objectives, a bibliographical review of the state of the art was carried out on the most important topics. These have fomented discussion at the international level in the field of DG and MGs, both connected and disconnected from the main network. This review of the literature mainly includes the drivers of MG development, and the benefits of operating with MGs, among other things. The latter are presented in Table 1-1.

Table 1-1:
Why Micro Grids?
Author elaboration based on (Bialek, 2013) & (Dohn, 2011)

Reduce demand and enhance reliability	Enhance the integration of DG & RES	Advanced controls	Enhance independency	Supports the Macrogrid
Promotes demand-side management and load leveling Usage Transparency Improve reliability and power quality. Potential to reduce peak load	Gas turbines <50 MW Diesel generators Integration of storage Integration of renewables	Demand response programs Balance system supply and demand Optimization of power system based on performance metrics. Smart metering.	Automatic connect and disconnect from main grid to meet specific performance outcomes. Support emergency operations Promotes community energy independence and allows for community involvement in electricity supply.	Enables a more flexible macrogrid by handling sensitive loads and the variability of renewables locally. Potential to resolve voltage regulation

1.8 Relevance of the investigation

The importance of this research is that the proposed model of MGs deployment is developed by the own community/residence with a third party that is responsible for building and maintaining the equipment, which allows a participatory-community and cooperative operation of the MG. This MG model proposes:

- Characterize different business models for the development of electricity distribution in urbanized communities from a participatory and multidisciplinary approach by promoting a decrease in electricity bills

- Evaluate electricity rates, whose peak demand component at peak hours punishes users by charging them a higher rate
- Reduce peak-demand either through DG, including generation based on diesel oil, batteries or self-managed demand programs.
- In addition, it seeks to incorporate the particular behaviors and interests of families living in urbanized neighborhoods, by motivating the self-management of demand against high electricity tariffs.
- It allows to know the places of Chile that have technical-economic feasibility for the development of MGs which depends on the availability of resources of the selected zone.
- In addition, it shows the importance of developing MGs with high solar photovoltaic component. This allow taking advantage of the high levels of solar radiation from Santiago to the North
- Also, it shows the importance of developing wind energy in the south, especially in places near the coast
- It allows to characterize the benefits of having energy storage systems, which can provide flexibility to the system and reducing peak-demand in peak-hours
- It allows to characterize the benefits of self-managed demand programs together with the local development of photovoltaic solar energy. These can provide flexibility to the system by moving flexible loads from peak hours to hours where there is greater solar generation.
- It quantifies potential sites with good solar radiation for the development of solar PV, which allows a greater sustainable local development in the communities of Chile.
- It promotes technological changes at the electricity distribution network level, showing the economic viability of the development of MGs throughout the country. This can lead to a greater prominence to the residential user, who can control and manage their electricity consumption.

1.9 Highlights of the research

- MGs focused on energy arbitrage are developed to enhance solar PV, Battery energy storage systems and demand response development in distribution networks
- The effect of peak demand charges on community rates is evaluated and modeled throughout Chile
- A bilevel optimization model is developed to evaluate the micro grid planning problem: optimum sizing, dispatch and operation
- The deployment of 17 potential MGs composed by DERs is modeled across Chile for different business models.
- Regional evaluation of several micro grid business models to assess cost-effective MG zones comprised of wind + PV + diesel + BESS + DR
- Net-Billing and Net-Metering schemes are compared in order to incentivize MGs deployment
- Chilean current distribution network regulation and electricity rates + diesel price + hourly production profiles of regional potential solar PV + wind farms are presented.

1.10 Scope of Research

The research is part of the regulatory context of the new changes that are looming in the electricity distribution segment, since there is a prevailing need to move towards more intelligent and reliable electrical systems. Needs have emerged by an increase in non-conventional renewable technologies, especially for the development and increased knowledge of solar PV energy around the world. With this, the penetration of DG has been promoted, which in Chile has consisted in the installation of solar panels at commercial, industrial and residential level. This research has an exploratory scope, in that the technical-economic feasibility of installing MGs in different localities with their renewable resources, diesel fuel prices and different electrical rate prices, is evaluated. In this sense, this is the first work based on MGs that studies their operation in more than one place. In addition, it has a descriptive scope, in that it provides detailed information of MG energy schedule behavior. Finally, it has an explanatory scope in that it exposes the causes of the behavior of the MG with the unique sizing in every place.

1.11 Assumptions of the work

Few assumptions are considered in this work, which are explained next:

1. Distribution network operators (DNOs) are not neutral. If the micro grid is developed DNOs receive a lower income from micro grid clients. Hence, other clients have to subsidy the cost recovery. However, this effect is not considered in the optimization model.
2. Micro grid returns are considered in this work as if only community and people were organized and developed micro grids. Hence, all profits are pursuited by community and single-dwelling ratepayers. Other stakeholders such as banks and energy service companies are not considered for business opportunities.
3. The cost function used for modeling investment and operational costs in the bilevel optimization model does not take into account the incremental savings of massive technology investment. Hence, investment costs are flat during the time horizon.
4. Project evaluation is measured through economic indices such as internal rate of return, net present value, payback and annualized costs. Depreciation, amortization, debt, taxes and other types of financial variables are not considered.
5. The focus of this work is based on people, capable of organized themselves, and hence, develop micro grids thoughout Chile. The entrance of others stakeholders is not considered.
6. In Net-Metering business model, the injection rate takes into account the energy and power. Hence, the injection rate is the same as purchase rate.

1.12 Thesis structure

This research is structured as follows: Section 1 highlights the main drivers of change in distribution networks and the development of MGs to meet that challenge. Section 2 examines research with specific reference to the most relevant and enlightening work on related topics. Section 3 provides an MG energy production analysis that describes arrangements and business models for MG evaluation and implementation. Section 4 presents a community/residential (for the purpose of this paper, the term *residential* refers to single-dwelling households) MG system based on the bilevel optimization model, designed to obtain optimal sizing and energy management (EM) for each MG. Section 5 is a case study featuring available renewable resources, latitude and longitude of evaluated sites, and prices for purchase/sale of energy from and to the grid. Sections 6 and 7 present the results and conclusions for this research. whereas section 8 presents the future work.

2. LITERATURE REVIEW IN MGS OPERATION AND INVESTMENT OPTIMIZATION MODELS

To deploy cost effective and sustainable MGs an adequate component sizing and optimal operation are needed to reduce the investment requirement, consumption of fuel and variable operational costs of the micro grid. The latter is done through the planning problem next.

2.1 The micro grid planning problem: definition and key features

MG planning problem comprises two temporal stages, investment and operation as explained next:

- *Investment problem*: which is a long-term optimization problem to find the optimal combination, design and sizing of DERs to meet the future electrical demand at a minimum lifecycle cost (Liang & Zhuang, 2014) and
- *Operation problem,* also known as energy management (EM) problem which mainly deals with optimal micro grid planning over the short term and it is determined by unit commitment (UC) and economic dispatch (ED).

UC is performed from one day to one week ahead providing the start-up and shut-down schedule for each generation and storage unit such that the micro grid operation cost can be minimized. ED is performed from few minutes to one hour in advance and makes short-term decisions to economically allocate the demand to the on-line units, while considering the load demand and system constraints (T. A. Nguyen & Crow, 2016).

2.1.1 Dimensions comprising the MG planning problem

According to the literature review, there are six different dimensions that can comprise micro grid planning problem. Figure 2-1 summarizes the dimensions.

1. Objective: objective function of the micro grid operation, sizing and planning
2. Temporal: Time horizon of the problem and time granularity of the model
3. Demand and customer model: Demand growth and variability analysis
4. Economic: Cost and benefits accounted for in analysis
5. Optimization: Solution approach for the micro grid problem
6. Technology: Range of alternative technologies included in the micro grid problem

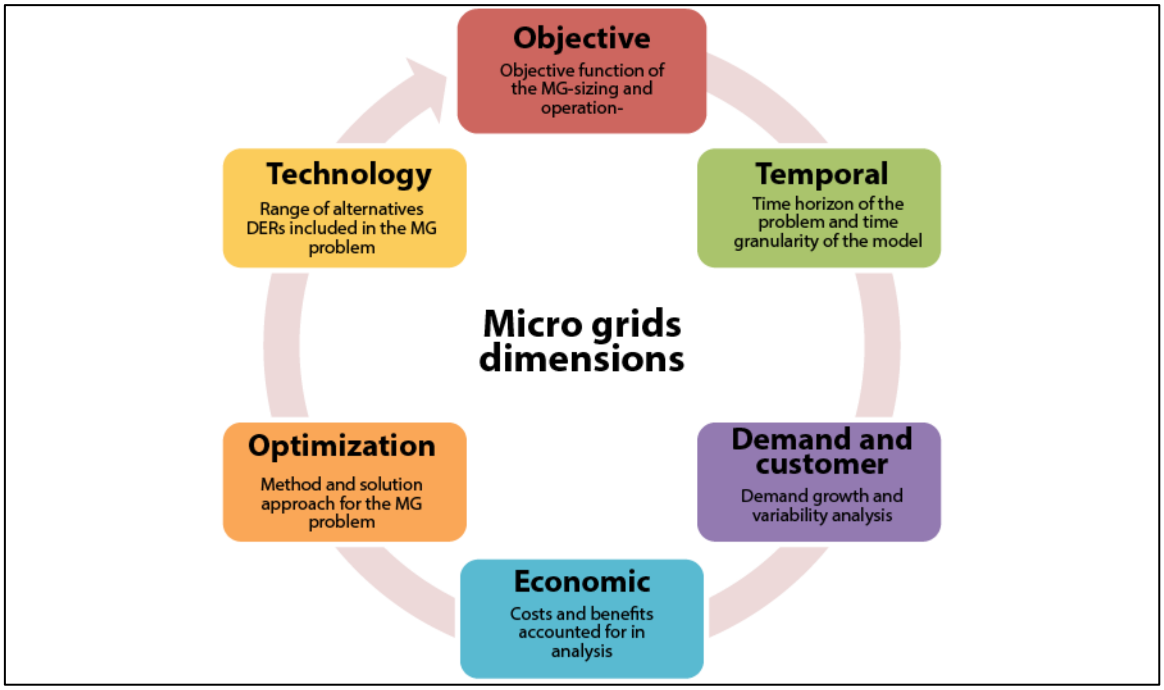


Figure 2-1: Six dimensions based on micro grid planning problem: operation and investment

Objective dimension's aim is to determine what type of micro grid problem is solved: the entire MG planning problem (investment + operation) or partial planning problem (EM). The EM in MGs can have different objective functions which are influenced by user preferences, geographical area, equipment installed in MG, capacity of MG, government regulations, types of tariff, energy storage and generation (Ahmad Khan, Naeem, Iqbal, Qaisar, & Anpalagan, 2016).

Most are focused on the MG operation, with a given and fixed portfolio of technologies (no investment). Publications focused on MG operation usually have more sophisticated models than those focused on sizing and operation, due to covering one single theme. However, in several papers, a simplified operation theme is accounted for where UC is not committed but a sequence of economic dispatches without considering technical constraints of generators (ramping up-down, min time up-down). Objective dimension of several publications is summarized in Table 2-1.

Table 2-1: Objective dimension

	Operation (UC + ED)	Operation simplified (ED)	Operation (UC + ED) + Investment	Operation (ED) + Investment
Publications	(Kriett & Salani, 2012),(Holjevac, Capuder, & Kuzle, 2015),(Jaramillo & Weidlich, 2016), (Alharbi & Bhattacharya, 2013) (D. T. Nguyen & Le, n.d.)	(Microgrid, PvMicrogrid, P., Moshi, G. G., Bovo, C., Berizzi, A., & Milano, Moshi, Bovo, Berizzi, & Milano, 2015),(Hoke, Brissette, Chandler, Pratt, & Maksimović, 2013), (Morais, Kádár, Faria, Vale, & Khodr, 2010)	(J. Zhang et al., 2016), (H. Wang & Huang, 2015)	(Quashie & Joos, 2016)

Temporal dimension's aim is to determine the horizon and the window time resolution that most of the works use to simulate micro grid operation problem and the amount of data that they have.

Most works focused on the optimization of the micro grid operation have been done in a time horizon of one day with average window scales of one hour. This means a lack of temporal and seasonal measurement of resources variability. However, a few articles include reserve requirements in window time scales of one hour to deal with intra hourly variations. Also, in terms of data used, it is very uncommon to find articles that use on-site measures. Most invent and extrapolate a profile from other site or develop a simple estimation of consumption and available resource evolution.

The methodology to model MG resources (i.e solar irradiance and wind speed) depends on the window time resolution and time horizon that are chosen. Section 2.3 shows the different methodologies to model the said above and Table 2-2 summarizes the information found in the literature related to this topic.

Table 2-2: Temporal and data dimension from several publications

Publications	Window time resolution	Horizon time	Seasons	Data measured
(Tenfen & Finardi, 2015)	1 min	1 day	No	Zero data/ Estimation off site
(Olivares, Canizares, & Kazerani, 2014)	5 min	1 day	No	Measured off site /test bus system
(Microgrid, PvMicrogrid, P., Moshi, G. G., Bovo, C., Berizzi, A., & Milano et al., 2015)	1 hour	1 day	No	Unknown
(Wouters, Fraga, & James, 2015)	1 hour	1 day	Yes (3)	Unknown
(Yazdani, Bhuiyan, & Primak, 2015)	1 hour	1 year	No	Measured off site/ test bus system
(Kriett & Salani, 2012)	15 min	1 year	Yes	Measured on site
(Alharbi & Bhattacharya, 2013)	1 hour	1 day	No	Measured off site
(D. T. Nguyen & Le, n.d.)	1 hour	1 day	Yes	Measured off site
(Holjevac et al., 2015)	30 min	1 year	Yes	Estimation off site
(Hoke et al., 2013)	1 hour	3 days	Yes	Measured on site
(Morais et al., 2010)	1 hour	1 day	No	Unknown
(R. Palma-Behnke, Benavides, Aranda, Llanos, & Sáez, 2011)	15 min	2 days	No	Measured on site

Demand and customer model dimension's aim is to determine how demand growths in MGs are modeled through the time horizon. In general, demand growth in electricity markets is modeled with a vegetative increase, however, in MGs, demand growth has more uncertainty and lumpiness. Thus, peaks are generated (e.g. due to the addition of a new customer house, a new community, among others). Hence, growths are zero until new units are added. It is common to find that demand increases with power capacity. Also, in terms of demand consumption, it is very uncommon to model appliances consumption. Instead, most common is to aggregate demand consumption. Moreover, only few articles model the interaction between the demand and market prices, and the response of consumers against rates. We found this dimension concept to be underexplored in micro grid literature. Table 2-3 presents publications related to this topic.

Table 2-3: Demand and customer model dimension

Publications	Demand evolution	Demand Consumption modeling	Demand interaction
(Tenfen & Finardi, 2015)	Lumpy	Aggregated Critical, non-controllabe, reschedulable demand.	Peak price match critical load demand
(Tasdighi, Ghasemi, & Rahimi-Kian, 2013)	Flat	Aggregated appliances demand	Peak price match peak demand
(Baziar & Kavousi-Fard, 2013)	Flat	Aggregated demand (residential, commercial and industrial)	-
(Wouters et al., 2015)	Flat	Aggregated electrical cooling and heating demand	-
(Kriett & Salani, 2012)	Lumpy	Aggregated electrical Appliances and heat demand	Real Time prices match with demand
(Ravindra & Iyer, 2014)	Flat	Aggregated demand	Demand –supply matching using DR
(Najibi & Niknam, 2015)	Flat	Aggregated demand (residential, commercial and industrial)	-
(D. T. Nguyen & Le, 2013)	Flat	Aggregated electrical demand	-
(Holjevac et al., 2015)	Flat	Aggregated electrical demand	-
(Atia & Yamada, 2016)	Lumpy	Aggregated electrical appliances, heating and non-controllable load demand	Time-of-Use prices match with load demand

Economic dimension's aim is to determine what costs or variables are minimized in the ED problem to obtain the optimal micro grid operation. According to (Ahmad Khan et al., 2016) costs can be classified as:

- Operational costs that include production costs, fuel costs, maintenance costs, start-up and shutdown costs, degradation costs and purchase costs from the utility grid, among others
- Miscellaneous costs such as penalty factors, load shedding and demand response, among others.
- Storage costs and

- Carbon emissions costs

From articles reviewed, none maximize the social welfare; conversely they are generally focused in minimizing the costs previously mentioned. Regarding benefits, most articles consider only the cost savings regarding grid connection. Mostly, operational costs are minimized which comprise start-up/shut-down costs and exchange costs with grid. A few accounted for CO2 emissions and demand response programs. Minors are those who minimize peak power costs. We found this latter to be underexplored in micro grid literature. Table 2-4 summarizes the information found in the literature related to this topic.

Table 2-4: Economic dimension

Publications	Economic cost dimension
(Wouters et al., 2015)	Investment valorization + Min OM, fuel, grid exchange & carbon tax costs
(M. Q. Wang & Gooi, 2010)	Max profit (reserve, lost load, operational costs)
(Morais et al., 2010)	Min battery, PV, WT, fuel, undelivered energy costs
(Yazdani et al., 2015)	Min capital, replenishment, operation, maintenance, fuel and salvage costs
(Jaramillo & Weidlich, 2016)	Min peak power purchase, start-up costs for electrolyzer and FC & grid exchange costs
(Holjevac et al., 2015)	Min fuel & grid exchange costs
(Hoke et al., 2013)	Min fuel, DR, battery conversion losses and grid exchange costs
(Tenfen & Finardi, 2015)	Min fuel, maintenance, start-up, shut down, CLD and grid exchange costs
(Tsikalakis, Member, Hatziargyriou, & Member, 2011)	Min fuel, start-up, power bought cost & curtailment costs
(Alharbi & Bhattacharya, 2013)	Min fuel, start-up, renewable curtailment & shift demand costs
(Kriett & Salani, 2012)	Min fuel, start-up, shut-down, grid exchange costs
(R. Palma-Behnke et al., 2011)	Min fuel, start-up, unserved power & unserved water cost
(D. T. Nguyen & Le, 2014)	Min grid exchange, startup, shutdown, fuel, shift demand, penalty factors costs, load shedding
(Quashie & Joos, 2016)	Min investment + Min emission, fuel, maintenance, grid power purchase & CHP costs
(H. Wang & Huang, 2015)	Min investment + Min fuel cost
(J. Zhang et al., 2016)	Min investment + Min start-up + reserve

Optimization dimension's aim is to determine what optimization types are proposed to solve the micro grid-scheduling problem and the approach used.
Optimization types include: integer models such as mixed integer programming (MIP) where several types are used such as linear (MILP), quadratic (MIQP) and non-linear (MINLP), robust models, stochastic models and dynamic models.

In integer programming, decisions are discrete and involve integer or binary variables. Hence, the problem is integer go-no go where some decision variables are 1's or 0's and a few decisions are committed (e.g. invest or not invest, turn-on or turn-off the machine, among others) (Bradley, Hax, & Magnanti, 1977). Moreover, in this decision-making there is no uncertainty, thus, initial conditions and parameters determine the output.

Optimization problems that involve uncertainty are often modeled with stochastic programming (Shapiro & Philpott, 2007). In this latter, a type of knowledge or characterization of uncertainty is known from probability distribution functions (PDFs) that are commonly known or can be estimated from historical data. Then, most optimize the expected value of the objective function, given the uncertain nature of some variables (Shapiro, Dentcheva, & Ruszczynski, 2009). Thus, the solution that truly optimizes the expected value of the objective function is called the stochastic solution (Kall & Wallace, 2003). Also, stochastic programming is often applied when decisions are taken under same circumstances and the objective is to obtain a decision that behave well with the expected value (Shapiro & Philpott, 2007).

For example, stochastic programming can be applied in a two-state problem, where in first state the decision is to know how much solar PV is needed to satisfy the yearly electrical demand and then, once solar PV generation is known, more or less solar PV investment is needed due to surplus or lack of solar generation. Finally, decisions must be taken before knowing the behavior of uncertain variables.

While in stochastic optimization variables are modeled as random variables with known or estimated distribution function and expected value is optimized (Boyd & Vandenberghe, 2004). In Robust methods, instead of protecting the solution in a probabilistic way against stochastic uncertainty, the solution is optimized by the decision-maker who models uncertainty by sets and not individual realizations (Dimitris Bertsimas, Brown, & Caramanis, 2010)(D. Bertsimas & Thiele, 2006). In this context, robust programming is accounted for random variables whose PDF is hard to predict (Velásquez, Watts, Rudnick, & Bustos, 2016). Furthermore, there are several decisions by variables and the objective of this type of programming is preventing wrong decisions within a range of actions (e.g. minimize the maximum regret of investing or not investing in a certain technology). It is focused on managing unexpected actions with bounded parameters previously known. Finally, the decision-maker avoids the system worst-case within convex uncertainty sets that contain random variables (Dimitris Bertsimas & Sim, 2004).

Dynamic programming is similar in terms of the amount of decisions that are accounted for but these are taken in each stage based on the previous system state. Moreover, uncertainty of variables is not necessary taken into account. Given the initial state of the system, a given function of the returns of all states and stages that the system goes through given our decisions is optimized (Kall & Wallace, 2003). The optimal decision at each stage is made after the result of the uncertain process at the previous stage (Bradley et al., 1977). Hence, optimal level decisions determine the output.

The difference in the way deterministic, robust, stochastic and dynamic models make decisions depends on MGs configuration and the variability of its resources (Farzan et al., 2013), (Parhizi et al., 2015).

Optimization approaches include Heuristics, Model predictive control (MPC), exact methods, agent based (AB) and evolutionary strategy among others. In the latter, genetic algorithm (GA), swarm and ant colony optimizations are the most common. Table 2-5 and figure 2-3 summarizes the optimization types and approaches that are often used in MG literature.

Table 2-5: Optimization dimension

Reference	Optimization type/approach
(Jaramillo & Weidlich, 2016)	Deterministic - Integer programming (MILP)/Exact
(Alharbi & Bhattacharya, 2013)	Deterministic - Integer programming (MILP)/Exact
(Wouters et al., 2015)	Deterministic – Integer programming (MILP)/Exact
(D. T. Nguyen & Le, 2014)	Deterministic/Heuristic
(Jha et al., 2015)	Dynamic programming/Heuristic
(Ping, Zuoxiao, Shuncun, Chenxi, & Qiaoyong, 2016)	Dynamic programming/Swarm optimization
(T. A. Nguyen, Crow, & Fellow, 2012)	Dynamic programming/Simplex method
(Cheng, Shan, LongZhao, Long, YU Jiang, 2016)	Dynamic programming/Swarm optimization
(Tenfen & Finardi, 2015)	Integer programming (MILP)/Exact
(Tsikalakis et al., 2011)	Integer programming (MILP)/Exact
(D. Zhang, Evangelisti, Lettieri, & Papageorgiou, 2016)	Integer programming (MILP)/GA
(Chen, Gooi, & Wang, 2012)	Integer programming (MILP)/Heuristic
(Parisio, Rikos, & Glielmo, 2014)	Integer programming (MILP)/MPC
(Morais et al., 2010)	Integer programming (MILP//Exact
(Hooshmand, Poursaeidi, Mohammadpour, Malki, & Grigoriads, 2012)	Integer programming (MINLP)/MPC
(Holjevac et al., 2015)	Integer programming (MILP)/MPC
(Quashie & Joos, 2016)	Integer programming (MILP)/Exact
(Kriett & Salani, 2012)	Integer programming (MILP)/MPC
(Rodrigo Palma-Behnke et al., 2013)	Integer programming (MIP)/MPC
(Hoke et al., 2013)	Linear programming/Dual Simplex
(Yu Zhang, Gatsis, & Giannakis, 2013)	Robust/Heuristic
(R. Wang, Wang, & Xiao, 2015)	Robust/MILP- exact method
(Kuznetsova, Ruiz, Li, & Zio, 2015)	Robust/AB
(M. Q. Wang & Gooi, 2010)	Stochastic/Heuristic
(Alharbi & Raahemifar, 2015)	Stochastic/Heuristic
(Arnold & Andersson, 2011)	Stochastic/MPC
(H. Wang & Huang, 2015)	Stochastic/Two level
(Su, Wang, Member, & Roh, 2013)	Stochastic/Two level

Technological dimension's aim is to determine the composition of MGs and what kind of DER is considered in the MG planning problem. Part of the technologies portfolio are usually Solar PV, CHP (fuel cells, Micro turbines), Wind turbines (WTs), diesel generators (DGs), Mini Hydro, storage, EV and DR, among others.

Most, if not all, focused on renewable plants such as solar PV and wind energy. Furthermore, and given the current global trends of the importance of using storage systems, batteries including EV are simulated in the micro grid operation. Also, due to intermittency and volatility nature of RES, back-up generators such as DG based on fuels, micro turbines and fuel cells based on natural gas are used. Table 2-6 summarizes the technological dimension in the literature.

Table 2-6: Technological dimension

Publications	Technologies
(Jaramillo & Weidlich, 2016)	PV + FC + EV + ELECTROLYZER
(Tsikalakis et al., 2011)	WT + PV + FC, MT + GRID
(Quashie & Joos, 2016)	WT + ESS + MT
(R. Palma-Behnke et al., 2011)	WT + PV + BESS + DIESEL GEN + WATER SUPPLY
(J. Zhang et al., 2016)	WT + PV + COMPRESSED ENERGY STORAGE (CAES) + DIESEL GEN.
(Kriett & Salani, 2012)	WT + PV + ELECTRICAL AND THERMAL LOADS + GRID
(H. Wang & Huang, 2015)	WT + PV + ESS + DIESEL GEN. + DR + GRID
(Yazdani et al., 2015)	WT + PV + ESS + DIESEL GEN. + GRID
(D. T. Nguyen & Le, n.d.)	WT + PV + ESS + DR + DIESEL GEN + GRID
(Alharbi & Bhattacharya, 2013)	WT + PV + ESS + DR + DIESEL GEN.
(Morais et al., 2010)	WT + PV + ESS + FC + GRID
(M. Q. Wang & Gooi, 2010)	WT + PV + ESS + MT + FC + GRID
(Hoke et al., 2013)	WT + PV + ESS+ DIESEL GEN. + DR + GRID
(Holjevac et al., 2015)	WT + PV + UCHP + HEAT AND ELECTRICAL DEMAND, FLEXIBLE DEMAND + GRID
(Wouters et al., 2015)	WT + PV + UCHP + SPACE HEATING AND COOLING + THERMAL DEMAND
(Tenfen & Finardi, 2015)	WT + PV+ ESS+ FC+ GAS MT+ CRITICAL, CURTAILABLE AND RESCHEDULABLE LOAD DEMAND

2.2 Optimization methods in micro grid planning problem

2.2.1 Integer, stochastic, robust and dynamic micro grid optimization model

a) Integer programming models for MG optimization

Within integer programming models, several works have been proposed and can be classified in terms of optimization difficulty from frequent application (e.g. optimize the operation of the micro grid) to less frequent (e.g. sizing of the units) and if the MG is connected or isolated from the main grid, as explained next: (Hoke et al., 2013) present a Linear programming model for minimizing the operation costs of the micro grid while meeting various resources constraints. DERs included are conventional generators;

BESS, DR and RES. (Morais et al., 2010) seek for the optimal operation of a micro grid by developing a MILP approach. (Tenfen & Finardi, 2015) present a mathematical model for the EM problem of a MG by means of a MILP approach, which DER portfolio is shown in table 6. (Wouters et al., 2015) propose a MILP model to identify the optimal micro grid design with a combined use of DG technologies, thermal units and energy storage with an optional interconnection with the central grid. (Malheiro, Castro, Lima, & Estanqueiro, 2015) propose a MILP model to obtain the optimal sizing and scheduling of the micro grid, which is comprised of RES, BESS and DGs, based on oil. (Bahramirad, Reder, & Khodaei, 2012) propose a MIP model to obtain the optimal size of an ESS in a micro grid considering reliability criterion. (Ravindra & Iyer, 2014) propose a scenario analysis by using a MILP approach to identify and assess the impact of different decentralized energy options at a community level while in (Parisio, Rikos, Tzamalis, & Glielmo, 2014) a MPC approach is applied for achieving economic efficiency in MG operation management based on a MILP model. (Ma, Member, Yang, Li, & Qin, 2012) propose a MINLP and investigate the application of MPC method in a Micro Grid with (DERs), including DGs, energy storage and DR to achieve higher penetration of RES.

Regarding isolated MGs, (Alharbi & Raahemifar, 2015) develop a mathematical model for the islanded mode operation of a MG. The optimization is formulated as a MILP problem, which includes DR and BESS and (Malheiro et al., 2015) optimize the micro grid planning problem of an islanded MG comprised of WTs, Solar PV, BESS and DGs over a time horizon of one year and hourly changes in resource availability.

b) Stochastic programming models for MG optimization

To deal with uncertainty in micro grid, most papers have focused on uncertainty resource such as wind, solar irradiance and electrical demand. Hence, stochastic models have been proposed and can be classified in terms of optimization difficulty from frequent applications to less frequent as explained next. Due to wind volatility and intermittency, (Wu & Guan, 2014) present a scenario analysis to obtain the optimal look-ahead dispatch of the micro grid comprised of wind generation, storage and loads. In the same way, (Safamehr & Rahimi-Kian, 2015) present a stochastic scenario analysis to obtain a cost-efficient and reliable EM of the micro grid using intelligent DR.

Moreover, (Alharbi & Raahemifar, 2015) develop probabilistic scenarios for the uncertainty of loads and DERs and additional reserve requirements to obtain the optimal operation of a micro grid. (Chen et al., 2012) present a new method based on the cost-benefit analysis for optimal sizing of an energy storage system including reserve requirements. Time series and feed- forward neural network techniques are used for forecasting the wind speed and solar radiations. (Arnold & Andersson, 2011) propose a stochastic MPC strategy to keep the consequences of forecast uncertainties at acceptable level; hence, a two-level control scheme is applied, which is divided into day-ahead planning and on-line dispatch. (Hooshmand et al., 2012) present a stochastic MPC method for managing a MG. In order to reliably provide the required power for costumers, the proposed method enables the MG to use the renewable energy sources as much as possible while keeping the storage device to its maximum state of charge and minimizing the power generated by the micro gas turbine.

c) Robust programming models for MG optimization

Several works have focused on sets of uncertainty resource due to unavailability of probability distribution functions such as wind, solar irradiance, electrical demand and market prices by considering robust models. Thus, works can be classified in terms of optimization difficulty from frequent applications (e.g. worst case approach) to less frequent (minmax regret). Hence, (Yu Zhang et al., 2013) propose a novel power scheduling approach considering the uncertainty of RES by modeling worst-case transaction cost stemming from RES harvested. (Yu, Kang, Chang, Lee, & Lee, 2016) develop a multi-objective optimization model for robust MG planning, on the basis of an economic robustness measure, i.e. the worst-case cost among possible scenarios, to reduce the variability among scenario costs caused by uncertainties. (Kuznetsova et al., 2015) propose an extended analysis of a MG EM framework based on Robust Optimization (RO). Wind and Solar PV energy consumption uncertainties are modeled in the form of prediction intervals (PIs) under the worst realization of the uncertainty conditions. The system is described by Agent-Based Modelling (ABM). (R. Wang et al., 2015) propose a robust optimization based energy generation scheduling problem in a CHP-MG scenario considering robust optimization to model heat and net demand uncertainty, price uncertainty and non-linear constraints. (Alavi, Ahmadian, & Aliakbar-Golkar, 2015) propose an optimal micro grid EM and combines stochastic and robust programming by modeling wind and solar uncertainties according to Weibull and Beta PDFs, respectively and robust optimization is used to model load demand uncertainty. Finally, (Christian, 2014) propose an optimal micro grid operation by considering a minimax MPC, where a limitation of the RES is accounted for.

d) Dynamic programming models for MG optimization

In the case of dynamic programming, several works have focused on the micro grid dynamic behavior. Most of them model BESS dynamic models without considering uncertainty of resources. Hence, works can be classified in terms of optimization difficulty from frequent application (e.g. model BESS dynamics) to less frequent (e.g. maximize micro grid profit) as explained next: (Xiaoping, Ming, Jianghong, Pingping, & Yali, 2010) propose a dynamic programming model to obtain the optimal economic dispatch of the micro grid which include BESS. (Ping et al., 2016) propose a dynamic multi-objective optimal micro grid operation which comprise diesel generators, wind power, solar PV and BESS. (Prodan & Zio, 2014) propose a dynamic optimization model to obtain the optimal operation of a BESS. Thus, an MPC is proposed, where uncertainty due to variations in the generator model parameters is accounted for. (Jha et al., 2015) present a grid dynamic pricing based on dynamic economic load dispatch problem comprising different scheduling strategies for WT, PV, and FC. A new powerful meta- heuristic optimization algorithm known as Harmony Search Algorithm (HSA) is used to solve this problem. Finally (M. Y. Nguyen, Choi, & Yoon, 2009) propose a dynamic UC to maximize profit for a micro grid, which consider RES as negative loads and batteries as load-flattened device.

2.3 Methodologies for modeling the resources (including uncertainty)

While demand in a small micro grid is quiet variable and uncertain most articles deployed limited efforts to this issue. Uncertain loads add even more uncertainty to the one coming from the integration of renewable energy sources (RES) (Alharbi & Raahemifar, 2015). Due to that reason, resource uncertainty can greatly affect the MG planning problem by oversizing the capacity of this and hence, resulting in increased system costs. Also, the micro grid operation, including UC and ED can be altered because of a lack of RES in a certain time. Also, volatility of electrical demand can produce a great impact in the design of the micro grid. However, in several works uncertainty is not considered and deterministic approaches are often used. In that cases, the micro grid is comprised of peak generators -that can provide flexible generation when needed-, energy storage systems and load shedding.

Solar PV and wind technologies are increasingly important elements in MGs due to their reduction in costs. Efficiency will continue to increase and prices will continue to fall as time goes on and in the case of Solar PV even more. Moreover, wind energy and solar PV are technologies, not fuel. As such, they have a very low maintenance and operation cost compared to fossil fuels energy based.

2.3.1 Solar irradiance modeling in MG literature

System production based on solar PV depends on both the resources (i.e. irradiance, ambient temperature and wind speed) and technology (Ryan, Dillon, Monaca, Byrne, & O'Malley, 2016). Given the uncertainty of the resource, forecasting models are addressed to assure stable performance of solar PV systems. Hence, solar resource forecasting is the basis of the power prediction of PV generation. With the fast growth of solar PV deployment, more precise and accurate modeling, forecasting and prediction of solar resources are needed (Tang, Yang, He, & Qin, 2010; F. Wang, Mi, Su, & Zhao, 2012). Moreover, prediction models complexity will increase by combining most of the solar PV resources such as temperature, wind speed, irradiance, clouds covering and seasonal changes (Raza, Nadarajah, & Ekanayake, 2016).

Forecasting of irradiance is the first and an essential step in most PV power prediction systems. By the way, irradiance is often classified as Global Horizontal Irradiance (GHI), which is the total amount of shortwave radiation received from above by a surface horizontal to the ground used in solar energy analysis for a specific location. However, its different components such as Diffuse Horizontal Irradiance (DHI) and Direct Normal Irradiance (DNI) are often not considered in the analysis (Reno, Hansen, & Stein, 2012).

GHI varies in different time scales, including short time scales (i.e minutes) in which irradiance can be well forecasted with enough accuracy to maintain the control of the plant and longer time scales (i.e hours or days). The variation of irradiance is important for the optimal operation and prediction of solar PV plants energy.

GHI forecasting approaches in MGs may be categorized according to the input data used which also determine the forecast horizon (Diagne, David, Lauret, & Boland, 2013). For hourly time scales, the following approaches are considered: statistical methods (PDFs, Time series (AR, ARMA, ARIMA), Persistence method (PM) and Artificial neural networks (ANN)), and non-statistical methods, in which the use of typical values (i.e. hourly average and hourly or minutal measures or estimations) is mainly used. Irradiance in micro grid solar PV system is often modeled using historical hourly measurements or the hourly average of measurements in a determined horizon usually one day. Table 2-8 summarizes the solar irradiance models used in MG literature.

Table 2-7: Solar irradiance modeling

References	Solar irradiance model
(Holjevac et al., 2015)	Measurement of hourly irradiance
(Wouters et al., 2015)	Average of hourly irradiance
(Tenfen & Finardi, 2015)	Forecast not mentioned
(Tsikalakis et al., 2011)	Persistence Method (for next 10 minutes)
(Hoke et al., 2013)	Measurement of hourly irradiance
(Alharbi & Bhattacharya, 2013)	Average of hourly irradiance
(Zakariazadeh et al., 2014)	Hourly PDF (Bimodal) fit of solar radiation (unknown amount of data) to obtain hourly profile
(Nikmehr & Najafi Ravadanegh, 2016)	Daily PDF (Beta) fit of solar radiation (historical data for 1 year) to obtain hourly average profile for 1 year. It implicitly takes into account the seasonality of the resource.
(D. T. Nguyen & Le, 2013)	Hourly PDF (zero-mean Normal) fit of solar radiation error considering the hourly average profile of August.
(Su et al., 2013)	Hourly PDF (Normal) fit of solar radiation error (historical data for 1 year) to obtain hourly profile
(Bustos, Watts, & Ren, 2012)	TS (ARMA)
(Pereira, Muñoz de la Peña, & Limon, 2016)	Measurement of hourly irradiance
(H. Wang & Huang, 2015)	Measurement of hourly irradiance
(Su et al., 2013)	TS/Monte Carlo
(Alabedin, Member, Member, & Salama, 2012)	Hourly Discretized PDF (Normal) fit of solar radiation error (unknown amount of data) to obtain hourly profile
(Saber & Venayagamoorthy, 2012)	
(Alharbi & Raahemifar, 2015)	Five state discrete PDF (Normal) fit of solar radiation error
(H. Wang & Huang, 2015)	Measurement of data of solar radiation for 365 days from historical data

Sun path is often not used, thus, most use statistical methods that introduce bias or errors that are often limited by a bounded time horizon (e.g. one month) to estimate the appropriated PDF or the different model used.

a) Equations used in micro grid models to convert irradiance to solar PV power

Consistent and accurate evaluations for the PV system performance are critical for the development of this type of technology. Most if not all model hourly energy production through estimation or measurement irradiance, commonly GHI, multiplied by a series of efficiency factors along the energy production chain. Despite the differences in sight, all models are very similar.
Thus, several publications model explicitly the PV solar losses through Performance Ratio (PR), which represent inverter efficiency by comparing the produced energy with measured site irradiance with the energy that would produce in case of having reference system irradiance (Marion et al., 2005), (Watts et al., 2015). Also, PR depends on several factors such as system size, location and orientation of the PV array. Finally, PR can be expressed in terms of all losses on the rated solar PV output as the following expression:

$$PR = \eta_{sh} \cdot \eta_{IAM} \cdot \eta_{deg} \cdot \eta_{tem} \cdot \eta_{soil} \cdot \eta_{mis} \cdot \eta_{net} \cdot \eta_{mpp} \cdot \eta_{inv} \tag{1}$$

Where each of these terms represent the power losses of nearby shadows (η_{sh}), inverter losses (η_{inv}), maximum power point tracking (η_{mpp}), wiring (η_{net}), mismatch (η_{mis}), soiling (η_{soil}), temperature (η_{tem}), module degradation (η_{deg}), incident angle modifier (η_{IAM}) (Watts et al., 2015).

Whilst others model implicitly solar losses by considering the comparison between standard test conditions and real measured conditions such as equations (3) and (4), where temperature of the cell and maximum power point of the system are quite relevant. For example, (Bustos et al., 2012) present an hourly analysis of PV production and find that same expressions can be represented with the same relation by changing the proportional constant. Table 2-9 summarizes solar PV power equations found the micro grid literature.

Table 2-8: Solar PV power equations in micro grid literature

Authors	Hourly energy production		Analysis
(M. Q. Wang & Gooi, 2010), (D. T. Nguyen & Le, 2013),(R. Palma-Behnke et al., 2011), (Zakariazadeh et al., 2014)	$E = G \cdot A_{pv} \cdot \eta \cdot PR$	(2)	G is the hourly irradiance, n is module efficiency, PR is the performance ratio coffiecent for losses and A is the area of the panel
(J. Zhang et al., 2016), (Bustos et al., 2012) (Mao, Jin, Chang, & Xu, 2014), (Mao et al., 2014), (Yazdani et al., 2015)	$E = P^{STC} \cdot \frac{G_t^C}{G^{STC}}\left(1 - 0.0045(T_t^C - T^{STC})\right)$	(3)	Tstc is the temperature of the cell at standard conditions, Tct is the hourly cell temperature, Pstc is the out power measured at the standard test condition and 0.0045 is the temperature coffiecient of power
(Logenthiran, 2009)	$E = \frac{G_t^C}{G^{STC}}\left(P_{max}^M + \mu_{P_{max}} \cdot (T_a + G_a(\frac{NOCT - 20}{800} - T_M)\right)$	(4)	NOCT is the normal operating cell temperature of PV. Ga is the hourly GHI, Pmax, 0 is the maximum power, TM,0 is the module temperature at the standard condition, and Ta is the hourly temperature of the ambient.

2.3.2 Wind speed modeling

Wind energy based production depends on both the resources (e.g. air density, altitude, and wind speed) and technology (e.g. aero generators, rotors, gearbox, among others). Hence, the total amount of energy that can be produced in a certain location depends on the local wind features (European Wind Energy Association, 2009). In the same way as solar PV resource, wind speed is uncertain; hence, forecasting models are addressed to assure a stable performance of wind energy systems. The idea behind wind forecasting is to reduce the need for reserve energy power (Foley, Leahy, Marvuglia, & McKeogh, 2012) and thus, allow a better performance of the micro grid operation system.

Modeling wind speed for both short and long term forecasting is challenging (Bizrah & Almuhaini, 2015). Forecasting of wind speed is the first and essential step in most wind power prediction systems. Wind speed forecasting approaches may be also categorized according to the input data used, thus, methodologies are the same as those used in solar modeling. Wind resource in micro grid is often modeled with Weibull or Normal hourly PDFs, those that depend on several factors based on registered data such as mean, standard deviation, among others. Table 2-11 summarizes the wind resource modeling methodologies in MG literature.

Table 2-9: Wind resource modeling methodologies in MGs

References	Wind resource modeling
(Holjevac et al., 2015)	Measurement of hourly wind speed
(Wouters et al., 2015)	Hourly Average of wind speed for 1 day
(Tenfen & Finardi, 2015)	Forecast not mentioned for 1 day
(Tsikalakis et al., 2011)	Persistence Method for 1 day every 10 minutes
(Hoke et al., 2013)	Measurement of hourly wind speed for 3 days
(Alharbi & Bhattacharya, 2013)	Average of hourly wind speed
(Zakariazadeh et al., 2014)	Hourly PDF (Bimodal) fit of wind speed (unknown amount of data) to obtain hourly profile
(Nikmehr & Najafi Ravadanegh, 2016)	Daily PDF (Weibull) fit of wind speed (historical data for 1 year) to obtain hourly average profile for 1 year. It implicitly takes into account the seasonality of the resource.
(D. T. Nguyen & Le, 2013)	Hourly PDF (zero-mean Normal) fit of wind speed error considering the hourly average profile of August.
(Su, Wang, Zhang, & Huang, 2014)	Hourly PDF (Normal) fit of wind speed error (historical data for 1 year) to obtain hourly profile
(Bustos et al., 2012)	TS (ARMA) hourly for 20 years
(Pereira et al., 2016)	Measurement of hourly wind for 10 days
(H. Wang & Huang, 2015)	Measurement of data of wind speed for 365 days from historical data
(Su et al., 2013)	TS/Monte Carlo
(Alabedin et al., 2012)	Hourly Discretized PDF (Normal) fit of wind speed error (unknown amount of data) to obtain hourly profile
(Alharbi & Raahemifar, 2015)	Five state discrete PDF (Normal) fit of wind speed error
(Yazdani et al., 2015)	Hourly PDF (Weibull) fit of wind speed historical data for 1 year to obtain hourly profile

a) Equations used in micro grid models to convert wind speed to power

Power output of a wind turbine depends on the wind speed, which varies with time and depends on regional weather patterns and type of landscape (Soman, Zareipour, Malik, & Mandal, 2010). A wind power curve can be used to characterize the performance of a wind turbine by considering the hub height wind speed of the wind turbine (Wan, Ela, & Orwig, 2010). Hence, several references in micro grid literature use different approximations to obtain wind power curves. Most of them consider cut-in, cut-out and rated wind speed to set turbines power production limits due to technical capacities of turbines. Cut-in speed is the minimum wind speed to produce power, at rated wind speed the system will produce rated power and cut-out wind speed is the maximum wind speed to produce power. Also, some references consider the mechanics of the wind speed rotor and air density as explained in (Soman et al., 2010) . Table 2-12 summarizes the equations to convert wind speed into wind power.

Table 2-10:
Equations to convert wind speed into wind power

References	Equation		Observations
(Yazdani et al., 2015), (Bustos et al., 2012)	$P^w = \begin{cases} 0, & \text{if } v < V_{in} \text{ or } v > V_{out} \\ (a+bv+cv^2)\cdot P^w_{rat}, & \text{if } V_{in} \le v \le V_r \\ P^w_{rat}, & \text{if } V_r \le v < V_{out} \end{cases}$	(5)	Second order polinomial approximation to simulate wind power curve
(R. Palma-Behnke et al., 2011)	$P_w = \frac{\rho}{2} c_p A_E v_E^3$	(6)	p is the density of the air, cp is the rotor, Ae is the area of the rotor and Ve is the wind spped
(D. T. Nguyen & Le, 2013),(Zakariazadeh et al., 2014), (J. Zhang et al., 2016)	$P^w = \begin{cases} 0, & \text{if } v < V_{in} \text{ or } v > V_{out} \\ P^w_{rat} \frac{v - V_{in}}{V_r - V_{in}}, & \text{if } V_{in} \le v \le V_r \\ P^w_{rat}, & \text{if } V_r \le v < V_{out} \end{cases}$	(7)	First order approximation to simulate wind power curve
(Logenthiran, 2009)	$P^w = \begin{cases} 0, & \text{if } v < V_{in} \text{ or } v > V_{out} \\ (av^4+bv^3+cv^2+dv+e), & \text{if } V_{in} \le v \le V_r \\ P^w_{rat}, & \text{if } V_r \le v < V_{out} \end{cases}$	(8)	Forth order polynomial approximation to simulate wind power curve

2.3.3 Electrical demand modeling

Demand load consumption is one of the major elements in micro grid modeling due to uncertain behavior and pattern dependence of each consumer and their preferences. Hence, to understand how micro grid operates in an optimal way, it is important to model electricity demand and its variations along the time horizon. Moreover, high-resolution consumption data is needed to take into account the temporal variation of demand load consumption (Kavousian, Rajagopal, & Fischer, 2013).

However, only few works based on MGs have focused on modeling electrical demand due to greater modeling complexity of the models. For larger time scales, methodologies can be classified in terms of statistical methods (e.g. a type of knowledge or characterization of demand uncertainty is known from probability distribution functions (PDFs) that are commonly known or can be estimated from historical data) and typical values (e.g. hourly average profile from historical data and hourly or minutal measurements and estimations). Electricity demand profiles are often modeled with historical data obtaining the hourly average profile. Table 2-13 summarizes the electrical demand methodologies found in MG literature review.

Table 2-11: Electrical demand methodologies

Reference	Methodology
Wang (2010) (M. Q. Wang & Gooi, 2010)	Hourly PDF (seven-step normal) fit for historical hourly average data
Nguyen (2013) (D. T. Nguyen & Le, 2013)	Hourly PDF (Truncated Normal) fit of load demand considering an hourly average profile
Bhuiyan (2014) (Yazdani et al., 2015)	Hourly PDF (Normal) fit for historical hourly average data for 1 year
Pereira (2016) (Pereira et al., 2016)	Predicted hourly profile for 10 days from historical data
Wang (2015) (H. Wang & Huang, 2015)	Hourly profile from test bust system. Data has been taken from (Carpinelli et al., 2013)
Hoke (2013) (Hoke et al., 2013)	Measurement of hourly electrical consumption for 3 days
Holjevac (2015) (Holjevac et al., 2015)	Hourly load profile for 3 different seasons daily curves
(Zakariazadeh et al., 2014)	Hourly profile from test bust system for commercial, industrial and residential loads.

2.3.4 Electricity rates modeling

In the context of electricity price, there are two common types of pricing: flat rates and time-based rates. Under flat rate pricing, customers pay a fixed charge per KWh of electricity consumed independent of the time of usage, thus flat rates are unvarying. Flat rates are often assigned to residential customers, and are the only option in the absence of meters that can record time-differentiated usage (except block rates). A range of time-based rates are currently offered directly to retail customers, including time-of-use pricing (TOU), real-time pricing (RTP), and critical peak pricing (CPP) (Parhizi et al., 2015) (Parhizi, 2015). Also, there are few works in micro grid operation that analyze peak demand charges (Jaramillo, 2016). Normally, MGs works ignore this component, hence, we found this concept to be underexplored in micro grid literature. Table 2-14 summarizes the most common electricity rates found in micro grid literature.

Table 2-12: Electricity rates in micro grid literature

	Type of rate (Charges)				
	Flat (energy)	Flat (energy) + Peak power	RTP (energy)	ToU-2 (energy)	ToU-3 (energy)
References	(Holjevac et al., 2015), (Wouters et al., 2015), (Alabedin et al., 2012), (Quashie & Joos, 2016)	(Jaramillo & Weidlich, 2016)	(M. Q. Wang & Gooi, 2010),(Tsikalakis et al., 2011),(Zakariazadeh et al., 2014), (Hoke et al., 2013), (D. T. Nguyen & Le, 2013), (Su et al., 2014), (Pereira et al., 2016), (Yan Zhang, Zhang, Wang, Liu, & Guo, 2015), (H. Wang & Huang, 2015), (Su et al., 2013), (Kriett & Salani, 2012)	(Kriett & Salani, 2012)	(Tenfen & Finardi, 2015)

3. MICRO GRID ENERGY PRODUCTION ANALYSIS UNDER DIFFERENT BUSINESS MODELS

This work analyzes the micro grid planning, operation, costs and revenues for different business models for several both grid-connected and isolated MG modes.

Business models can be defined by different ways. According to Weill and Vitale (2001) business models comprise among several other things, clients, suppliers, products, information, money and their roles and relationships within the company and between them. Moreover, Rappa (2003) explain that business model is what company needs for sustaining itself by doing business and knowing clearly how the firm generates revenues and its position in the value chain (Weill, 2005) In this context, our description of business model is limited to the scale of the generation equipment or MG and the price and rate mechanism to interact with the grid.

3.1 Description of the arrangements and business models for MGs evaluation

1. Net-Billing and Net-Metering:

In Net-Billing, a two-register meter (or two simple meters) is needed to measure separately energy purchased/sold from and to the grid. Regarding Net-Metering scheme, a single bidirectional meter is needed to measure current flow in two directions. For single-dwellings, Net-Billing is limited by rooftop size and junction box restrictions. In several countries monophasic installations are limited from 6, 8 or 10 kW (10 kW in Chile). Community, commercial and industrial power ranges between the monophasic limit up to 100 kW.

2. Large Distributed Generation (LDG) ranging between 100 kW and 9MW

LGD receives separate payments for energy and capacity products. Energy injections are valued under two different regimes: spot price or stabilized price, where the first is similar to Real-Time Pricing and the latter is similar to a flat energy rate (DS244, 2008). A two-register meter (or two simple meters) is required to measure purchases and exports. Capacity contributions to the grid are valued at a regulated price.

3. Small Distributed Generation (SDG)—incapable of exporting to a grid

SDG involves local generation, much smaller than local consumption. Energy exporting from the MG to an upstream network is not allowed and the ratepayer still buys most energy from the grid. A simple meter is needed due to measure energy purchases.

4. Isolated Micro Grid (IMG)—unable to purchase/sell from and to a grid

IMG is the representative model for isolated communities where power exchange is not allowed or is unfeasible because there is no grid nearby. Since there is no purchase from the local utility, there is no need for revenue meters. However, a simple meter can be used to measure energy consumption in households or communities.

Figure 3-1 presents metering and energy injection under different business models and Figure 3-2 shows the features of each business model.

NB	NM	LDG	SLG*	IMG*
Community & Residential MGs		Community MGs		

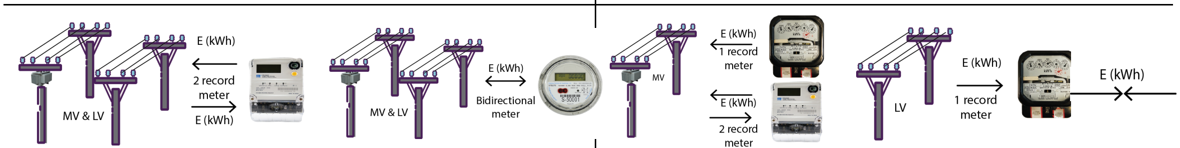


Figure 3-1: Metering and energy injection under different business models

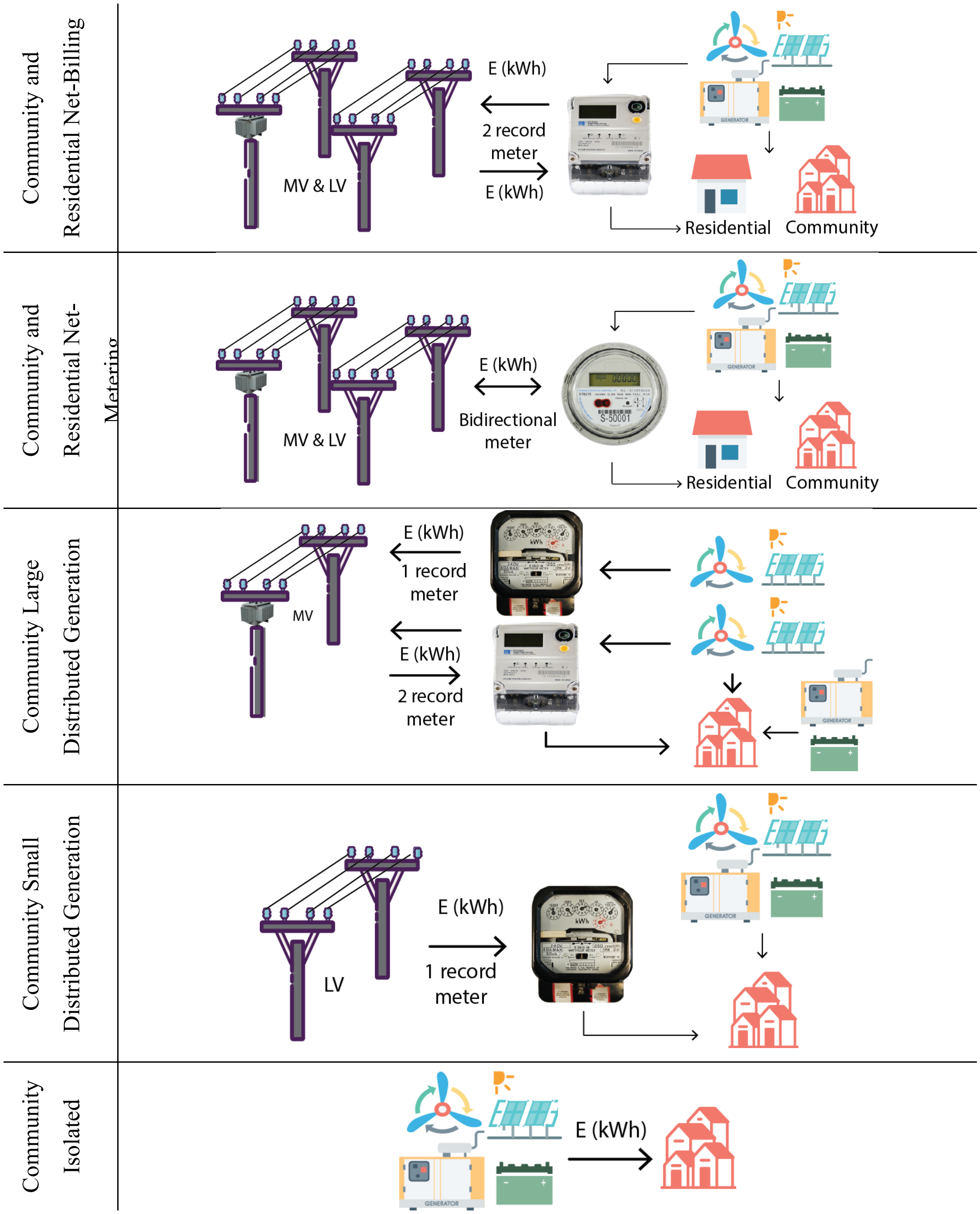


Figure 3-2: MGs arrangements under different business models

Hence, there are several representative micro grid business models with different sizes for each technology. The main components include PV modules, wind turbines, battery energy storage systems, charge controller, diesel generators, the mounting system, inverters, electrical panel, cables and connections, bidirectional and unidirectional meter and the electric grid. Fig. 3-3 shows one of the micro grid modes. DERs composition can be ordered based on a priority list depending on development and operational costs, lifetime and discount rate. Hence, the list of components from the cheapest to the most expensive is the following: Solar PV, which include wiring, inverters, mounting system, among others. Diesel DG, BESS, Demand Response and Wind Energy.

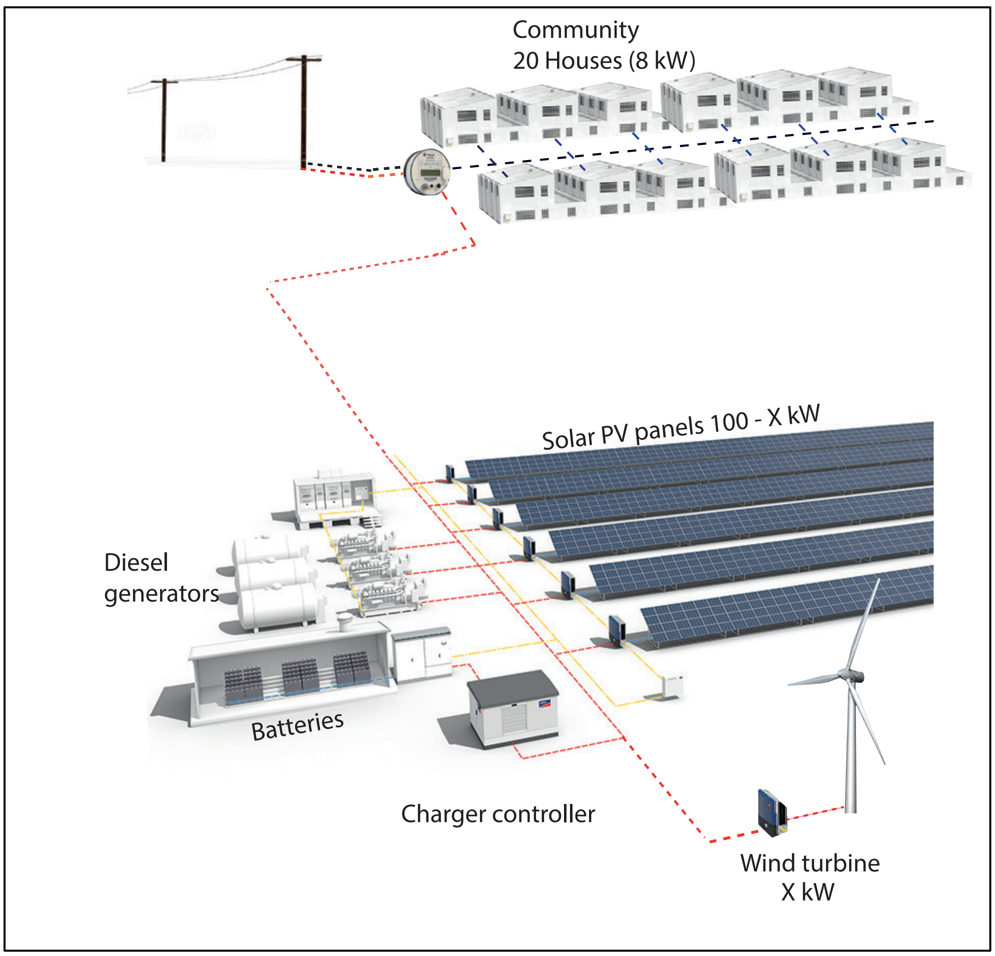


Figure 3-3: Micro grid lay out under Net-Billing business model

4. COMMUNITY MICRO GRID SYSTEM MODEL

This section presents the optimization model that allows optimum sizing and operation for each MG in order to reduce the average cost of supply throughout Chile. the modeling of renewable resources, Electric rates (BT1-BT2-BT3), specifications of the diesel generator and storage battery, as well as economic valuation through the levelized cost of energy for each technology.

4.1 Optimization model

An optimization model is used to obtain the optimal energy management and sizing of micro grid distributed energy resources throughout Chile. A bilevel programming model is needed to minimize investment and operation costs.

4.1.1 Bilevel programming explanation and adaptation to micro grid operation and investment problem

A Bilevel model involves a two-way interaction between the design and investment strategy and energy management system (EMS), which include UC and ED. A Bilevel problem can be transformed into a single level problem by imploring the Karush-Kuhn-Tucker (KKT) formulation to replace the EMS problem by its KKT conditions. The model comprises of replacing the EMS problem with the primal EMS constraints, its feasible dual constraints and the KKT complementary slackness (Quashie, 2016). The structure of the bi-level problem (BLP) program is well suited for interactions of the two problems with different time scale.

A BLP is adopted in this paper to determine the optimal design and operation of several MGs located throughout Chile. MG configuration will depend on several factors: electrical rates prices, solar irradiance, wind speed and diesel cost. Based on that, MGs can be composed of BESS solar PV, WTs, DGs and DR programs. The outer problem

(OP) determines the optimal generation of DERs by minimizing the total investment cost through the horizon time. The Inner problem (IP) determines the optimal UC and ED. The OP transfers sizing MG components to IP. Then, IP determines the cost-minimal operation UC and ED based on previous sizing, and then the optimal operation is sent to OP. The aim is to minimize the total investment and operational cost (Zhang, 2016). Figure 4-1 summarizes the aim and trade off of the bilevel programming and Figure 4-2 represents the BLP flowchart.

The problem is solved with GUROBI, using a MATLAB toolbox called YALMIP (Lofberg, 2004), where relaxations are committed to convex the inner problem and transform the whole problem into a MILP problem. Then, the bilevel solver solves the outer problem repeatedly in a branch-and-bound procedure, with additional equality constraints derived from complementary slackness append, and thus avoids introducing any numerically big-M formulation.

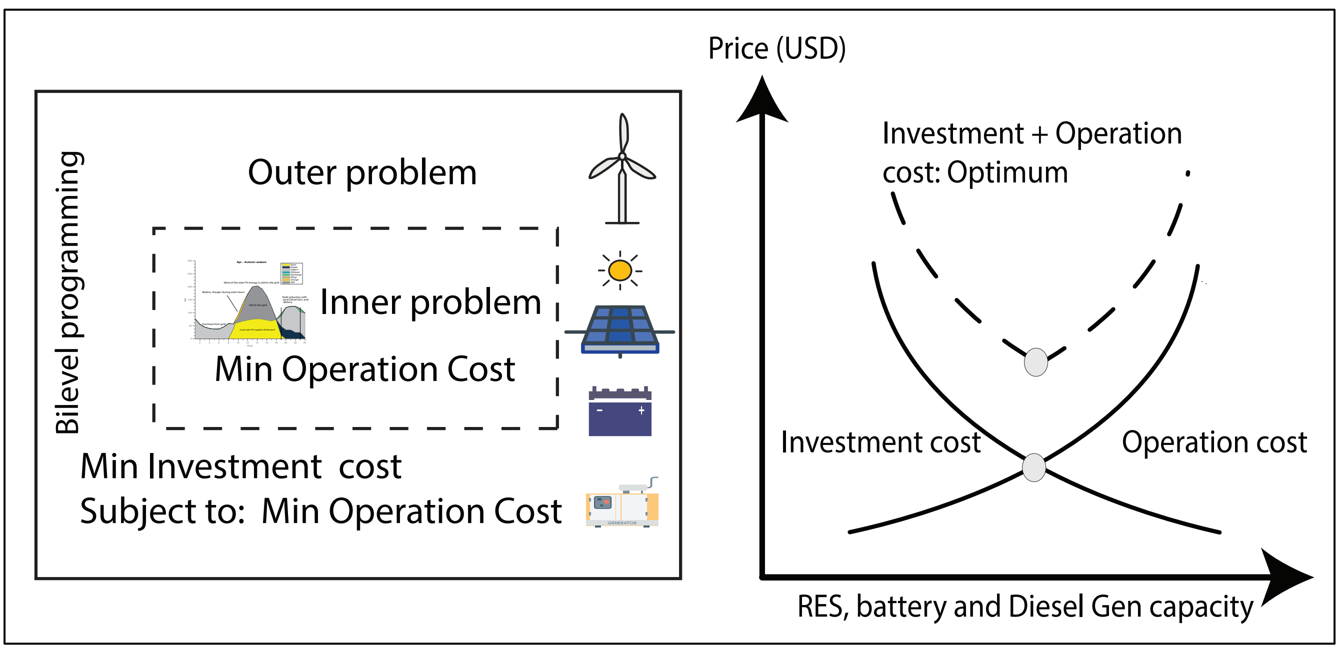


Figure 4-1: Bilevel programming: aim and trade off between operation and investment cost

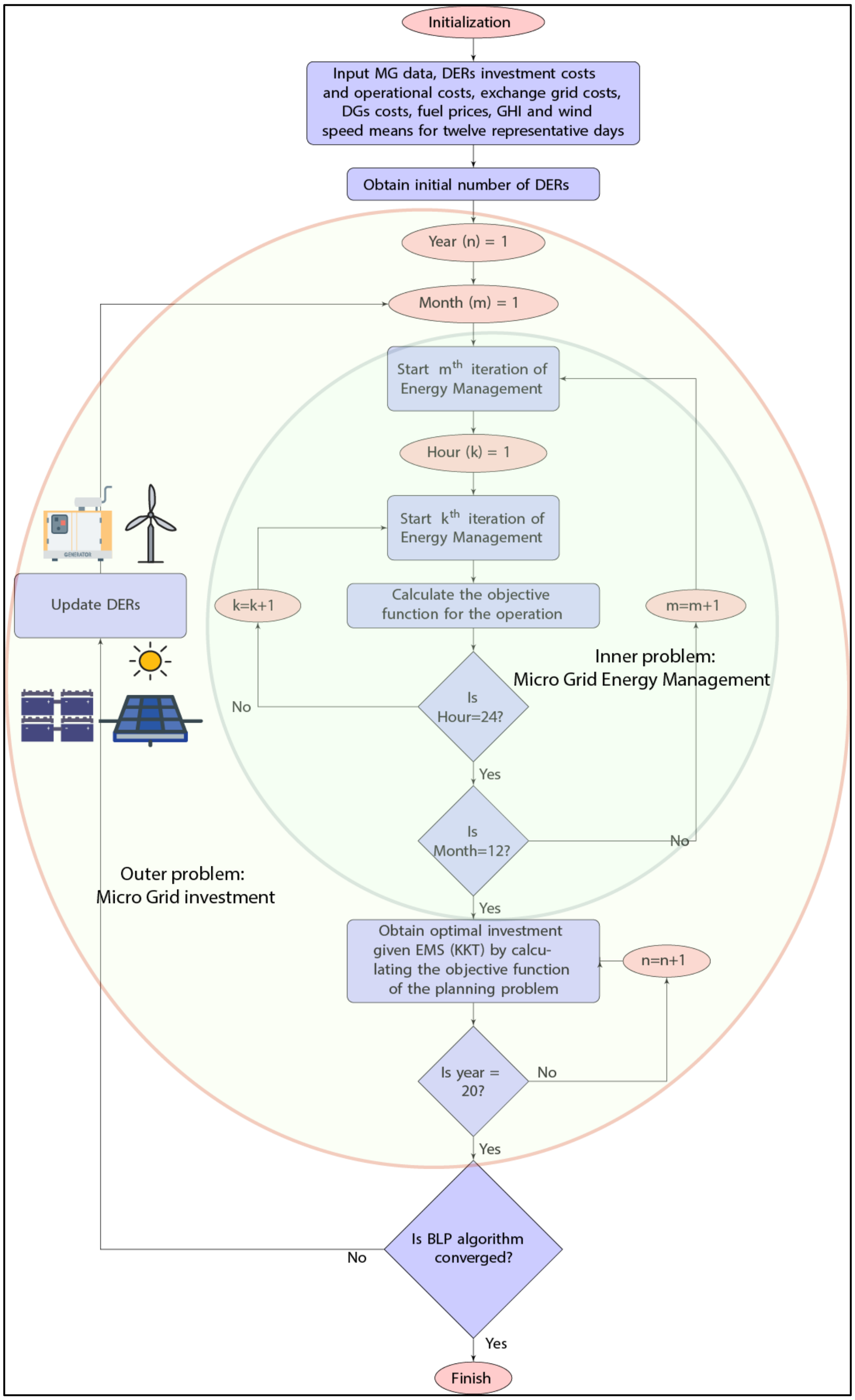


Figure 4-2: BLP Algorithm Flowchart

4.1.2 Indices

t_d index of optimization period, t = 1,2,…,24.

m_w index of optimization week period, m_{wd}=1,2,…,12.

m_{wd} index of optimization weekend period, $m_{wd} = 1{,}2 \ldots{,}12$.

k index of diesel generators, k=1,2

4.1.3 Parameters

η^c, η^d: Charging/Discharging efficiency of battery

SU_k, SD_k: Start-up and shut-down cost of diesel generator k

DR_k, DU_k: Ramp-up and ramp-down limits of diesel generator k

DT_k, $U\square_k$: Minimum down and up time of diesel generator k

BT_{pp}: Peak demand charge (USD/kW-month)

BT_{ppp}: Non-peak demand charge (USD/kW-month)

ET_t: Energy tariff (USD/kWh) in period *t*

IT: Injection energy rate (USD/kWh)

Vll: Value of lost load (USD/kWh)

B_{up}, B_{down}: Maximum shiftable demand (%)

DOD_t : Depth of discharge battery

4.1.4 Variables

Continous variable

$Pe\_buy_{t,m}$: Scheduled purchased energy from the main grid in period t, month m (kWh)

$Pe\_sell_{t,m}$: Scheduled sold energy to the main grid in period t, month m (kWh)

$P_{k,t,m}$: Power generation of diesel generator *k* in period *t*, month *m* (kW)

$P_{t,m}^{up}$: Flexible load demand moved up in period *t,* month *m* (kW)

$P_{t,m}^{down}$: Flexible load demand moved down in period *t,* month *m* (kW)

A^{PV}: Area of PV panels (m^2)

P_{con}: Initial contracted power with distribution network operator (kW).

$P_{t,m}^{PV}$: Power generation of solar PV in period *t,* month *m* (kW)

$P_{t,m}^{wind}$: Power generation of wind energy in period *t,* month *m* (kW)

$Cbat$: Energy installed capacity of BESS (kWh)

$E_{t,m}$: State of charge of BESS in period *t,* month *m* (kW)

$P_{t,m}^{d}$: Power discharged of BESS in period *t,* month *m* (kW)

$P_{t,m}^{c}$: Power charged of BESS in period *t,* month *m* (kW)

$Cdie_k$: Installed capacity of diesel generator *k* (kW)

$P_{t,m}^{shed}$: Load shedding power in period *t,* month *m* (kW)

$P_{t,m}^{Sspill}$: Solar PV power spillage in period *t,* month *m* (kW)

$P_{t,m}^{Wspill}$: Wind power spillage in period *t,* month *m* (kW)

Binary variables

pp: Peak-power indicator. If it is "1", it will be for the entire simulation time

$I_{k,m,t}$: Commitment state of diesel generator *k* in time *t,* in month *m*

$z_{k,m,t}$: Shut-down indicator of diesel generator *k* in time *t,* in month *m*

$y_{k,m,t}$: Start-up indicator of diesel generator *k* in time *t,* in month *m*

$b_{t,m}^{c}$: Charge indicator for BESS in time *t,* in month *m*

$b_{t,m}^{d}$: Discharge indicator for BESS in time *t,* in month *m*

4.1.5 Upper problem of the bilevel model: investment decision

The variables of the OP are the following: A^{PV} which is the total area of the solar PV panels, P^{WT} which is the rated wind power, P^{DG} which is the diesel generator power of each unit and E^{bat} which is the battery energy capacity.

The objective function of the UL is:

$$\min C = \sum_{n=1}^{N^{HOR}} \left(\sum_{k=1}^{N^{COM}} \frac{rf_k \cdot (C_k^{CAP} + C_k^{COMA})}{(1+r)^n} + \frac{105}{N^{wd}} \cdot \sum_{wd=1}^{N^{wd}} \frac{C_{m_{wd}}^{VAR}}{(1+r)^n} + \frac{260}{N^w} \cdot \sum_{w=1}^{N^w} \frac{C_{m_w}^{VAR}}{(1+r)^n} + C_d^{grid} \right) \tag{9}$$

$$C_d^{grid} = BT_{pp} \cdot pp \cdot P_{con} + BT_{ppp} \cdot (1 - pp) \cdot P_{con}$$

Where C is the total cost over the planning horizon (N^{HOR}), C_k^{CAP} and C_k^{COMA} are the investment and, operation and maintenance cost of each technology installed annualized by recovery factor, N^{COM} is the number of components, r is the discount rate, C_d^{grid} is peak demand and non-peak demand cost, $C_{m_w}^{VAR}$ is the variable cost of monthly typical week day and $C_{m_{wd}}^{VAR}$ is the variable cost of monthly typical weekend day These latter include power exchange costs, diesel fuel costs, shed costs, spillage and demand response costs. Variable costs are the principal components of the IP objective function, and they depend on unit sizing and the micro grid operation. It is common to have budget limits. However, the OP only has capacity limits.

The recovery factor is the following:

$$rf_k = \frac{r}{(1-(1+r)^{-n})} \tag{10}$$

where r is the discount rate of each technology.

4.1.6 Lower problem of the bilevel model: optimization of the micro grid operation

The objective function minimizes the hourly operational cost given the cost of diesel fuel for all generating units based on DGs' heat-rates, start-up and shut-down costs, power exchange costs with the grid including energy sales to the grid, peak demand and energy costs, shed cost in case of not having enough energy to supply, renewables spillage cost and demand response cost.

$$\min C^{var} = C_e^{grid} + C^{diesel} + C^{shed} + C^{DR} + C_e^{spill} \tag{11}$$

$$C_e^{grid} = \sum_{m=1}^{M} \sum_{t=1}^{T} Pe\_buy_{m,t} \cdot ET_t - Pe\_sell_{m,t} \cdot T_{inj} \tag{12}$$

$$C^{diesel} = fc\left(\sum_{m=1}^{M} \sum_{t=1}^{T} \sum_{k=1}^{DG} SU_{k,t,m} y_{k,t,m} + SD_{k,t,m} z_{k,t,m} + P_{k,m,t}^2 a_k + P_{k,t,m}\, b_k + I_{k,t,m} c_k\right) \tag{13}$$

$$C^{DR} = \sum_{m=1}^{M} \sum_{t=1}^{T} V^{dr} \cdot P_{t,m}^{up} \tag{14}$$

$$C^{spill} = \sum_{m=1}^{M} \left(\sum_{t=1}^{T} V_t^{w} \cdot P_{t,m}^{Wspill} + V_t^{s} \cdot P_{t,m}^{Sspill} \right) \tag{15}$$

$$C^{shed} = \sum_{m=1}^{M} \sum_{t=1}^{T} Vll \cdot P_{t,m}^{shed} \tag{16}$$

4.1.7 Constraints of the problem

The most common constraints found in the literature are those related to unit commitment- UC, hence, the following constraints are considered:

4.1.8 Power Balance for the micro grid

To assure a reliable operation of the MG, power balance must be satisfied including diesel generation, charge and discharge of battery, up and down demand response, wind and PV generation, power exchanged with the upstream network and shed power.

$$\sum_{k=1}^{DG} P_{k,t,m} + (P_{t,m}^{WIND} - P_{t,m}^{WSpill}) + \left(P_{t,m}^{PV} - P_{t,m}^{SSpill}\right) + Pe\_buy_{t,m} - Pe\_sell_{t,m} - \left(P_{t,m}^{C} - P_{t,m}^{D}\right) + P_{t,m}^{shed} + dup_{t,m} - ddown_{t,m} = D_{t,m} \quad \forall\, t,m \in T,M \tag{17}$$

4.1.9 Min Up/down times of DG

Constraints (13)-(14) assure minimum up and down time constraints for diesel generators which are linearized according to (Zendehdel, Karimpour, & Oloomi, 2008). Constraints (15)-(16) represent the status of on/off binary variables

$$\sum_{h=t}^{t+UT_k-1} I_{k,t,m} \geq UT_k y_{k,t,m} \tag{18}$$

$$\sum_{h=t}^{t+DT_k-1} (1 - I_{k,t,m}) \geq DT_k y_{k,t,m} \tag{19}$$

$$y_{k,t,m} + z_{k,t,m} \leq 1 \tag{20}$$

$$y_{k,t,m} - z_{k,t,m} = I_{k,t,m} - I_{k,t-1,m} \tag{21}$$

4.1.10 Min-Max ramp rates of DG

Diesel generators have ramping up and ramping down limits to assure that they cannot respond instantaneously

$$P_{k,t,m} - P_{k,t-1,m} \le UR_k\left(1 - y_{k,t,m}\right) + P_k^{min} y_{k,t,m} \tag{22}$$

$$P_{k,t-1,m} - P_{k,t,m} \le DR_k\left(1 - z_{k,t,m}\right) + P_k^{min} z_{k,t,m} \tag{23}$$

4.1.11 Min-Max power limits of DG

Diesel generators cannot exceed their own capacity generation limits.

$$P_k^{min} I_{k,t,m} \le P_{k,t,m} \le P_k^{max} I_{k,t,m} \tag{24}$$

4.1.12 Electrical storage system constraints

Charging and discharging power limits of the battery are considered in (20)-(21). BESS limits and dynamics are well represented in (22)-(23). Finally, (24) considers that BESS cannot be charged and discharged at the same moment.

$$0 \le P_{t,m}^c \le b_t^c P^{cmax} \tag{25}$$

$$0 \le P_{t,m}^d \le b_t^d P^{dmax} \tag{26}$$

$$E^{min} \le E_{t,m} \le E^{max} \tag{27}$$

$$E_{t+1,m} = E_{t,m} + d_{t,m}\left(\eta^c P_{t,m}^c - \frac{P_{t,m}^d}{\eta^d}\right) \tag{28}$$

$$b_t^c + b_t^d \le 1 \tag{29}$$

4.1.13 Shed constraints

Load shedding cannot exceed the limit of load shed and cannot be greater than the demand at any time slot t.

$$0 \leq P_{t,m}^{shed} \leq P^{shedmax} \tag{30}$$

4.1.14 NCRE curtailment

$$0 \leq P_{t,m}^{s,w} \leq P^{ws\max} \tag{31}$$

$$0 \leq P_{t,m}^{s,s} \leq P^{ss\max} \tag{32}$$

4.1.15 Grid Power Exchange

$$-P^{gridmax} \leq P_{t,m}^{grid} \leq P^{grid\max} \tag{33}$$

4.1.16 Demand Response Constraints

$$\sum_{m=1}^{M}\sum_{t=1}^{T} dup_{t,m} = \sum_{m=1}^{M}\sum_{t=1}^{T} ddown_{t,m} \tag{34}$$

$$\begin{pmatrix} B_{do} \\ B_{up} \end{pmatrix} \cdot D_{t,m} \geq \begin{pmatrix} dup_{t,m} \\ ddown_{t,m} \end{pmatrix} \tag{35}$$

4.2 Micro grid elements

Effective MG components depend not only on available technologies (solar PV, WTs, BESS), but on an abundance of renewable resources for a given site. They also require the flexibility for clients to connect or disconnect appliances, and the ability to postpone their usage. The availability of better pricing from a neighboring network is another significant option for MG components.

In this sub-section, DER technology modeling is explained. Electrical rates are also scrutinized in terms of peak demand charges. We also present an explanation of how the levelized cost of energy is assessed.

4.2.1 Solar PV model

As said above, operation of the PV plants depend mainly on GHI and temperature cell. Thus, module efficiency can be modeled by a simplified expression found in Watts (2013) such as the following:

$$\eta_{25º,1.5\,AM} = p \cdot \left(q \cdot \frac{G}{G_0} + \left(\frac{G}{G_0}\right)^m \right) \cdot (2 + r + s) \tag{36}$$

Where G is the incident irradiance on the modules. Go is 1000 W/m2 and factors p,q,r,m,s depend on the module used (Kyocera 250 W).

From SolarGIS we obtain the average of PR for one year, which consider most of the terms in the PR equation. Moreover, an R-gain factor is considered by (Watts, 2013) which consider the maximum power point tracking of the PV system with optimum inclination and slope. “The gain (R) is measured with respect to GHI (e.g. a gain of 6% in Calama means that an array configured with its optimal orientation, inclination and

HSAT would have an incident energy in the module 32% higher than it would if it were oriented horizontally, receiving the expected GHI" (Watts, 2014). Finally, output power of PV plant ($P_{pv,i}$) at the i-th hour of the day is obtained with the following expression:

$$P_{PV,i} = G_i \cdot R_{gain} \cdot \eta_i \cdot A_{PV} \tag{37}$$

Where G_i is the GHI at i-th hour of the day, η_i is the modules efficiency at i-th hour of the day and A_{PV} is the area of the PV plant.

4.2.2 Wind energy model

In the case of wind energy, hourly measurement profile methodology is used and 24 typical days are presented from 2010 with data from Explorador Eólico from Universidad de Chile (UChile, 2012). From (D. T. Nguyen & Le, n.d.; Zakariazadeh et al., 2014) and (J. Zhang et al., 2016) we obtain the equation to transform wind speed into wind power where distributed wind turbine Endurance 50 kW MODEL is suited and we obtain the reference wind speed for the wind power from manufacturer datasheet. Thus, V_{in}=3 m/s, V_{out} = 25 m/s, and V_r = 10 m/s.

$$P^W = \begin{cases} 0, & if\ v < V_{in}\ or\ v > V_{out} \\ a \cdot v^2 + b \cdot v + c, & if\ \ V_{in} \le v \le V_r \\ d \cdot v + e & if\ V_r \le v \le V_{out} \end{cases} \tag{38}$$

Furthermore, the information provided by the manufacturer considers a reference air density measured at sea level of ρ_r=1.225 kg/m^3, hence, for cases where the wind turbine is installed at higher heights, wind power curve and rated wind speed must be corrected by using the following expression (Santana, Falvey, Ibarra, & García, 2014):

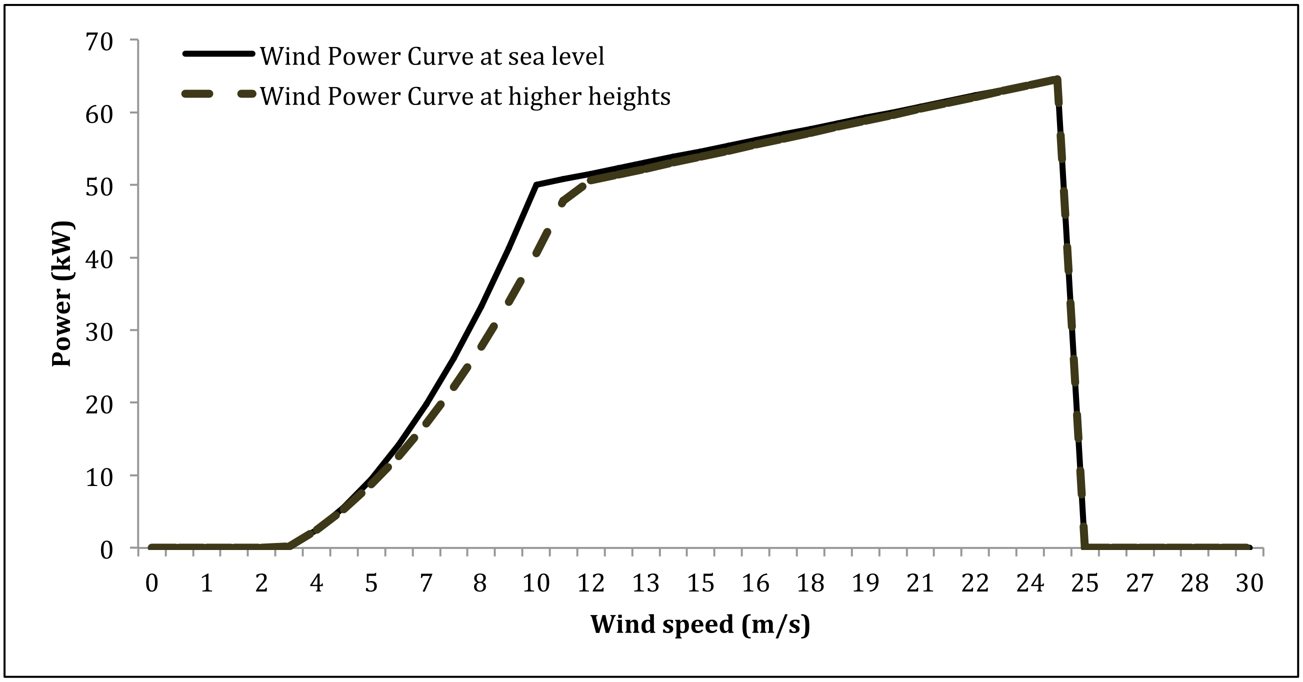
$$v_a = v_r \cdot \sqrt[3]{\frac{\rho_r}{\rho_a}} \tag{39}$$

where va correspond to adjusted reference wind speed , vr is the reference wind speed at sea level and pa is the air density at a certain height. The wind power curve at sea level can be approximated by using the following parameters:

Table 4-1:
Values of Endurance approximation wind power curve factors at sea level

Factor	Value
a	0.69
b	-1.83
c	-0.71
d	1
e	40

However, each wind power curve depends on the reference wind speed, which varies due to air density. Hence, several wind power curves are adapted to the model with different factors. An example case of the approximate wind power curve of the Endurance e-120 50 kW in Calama (rho =0.95) model and the effect of the air density in its performance is presented in the figure below:



4.2.3 Electric rates model

The most common type of electrical rates for residential dwellings, according to Chilean regulatory policy, is the "Baja Tensión 1" (BT1) (Low Voltage 1), which combines energy and capacity rate into one energy rate. Also, ToU rates are available in certain areas for one utility. For residential communities as opposed to single-dwellings, "Baja Tensión 2" (BT2) is one of several rate schemes in which costumers pay for capacity and energy separately. All other tariffs are similar to this one. This paper is

Figure 4-3: Endurance Wind Power Curve with the effect of air density at different heights

focused on ToU and BT2, which charge consumers by their consumption at peak and non-peak time, using a peak rate and non-peak rates.

In Chile consumers are qualified as peak or non-peak, comparing annual peak demand with average consumption in peak hours (18:00 – 23:00 PM). If the ratio between mean consumption and maximum demand is greater than 0.5, the ratepayer will be billed as a peak consumer. Otherwise, if it is lower, the client will be billed as a non-peak consumer.

The following expression demonstrates the regulatory rate policy for Chile during a one-year period from April to September, for central interconnected system (SIC) and for the entire year for northern interconnected system (SING) in Chile.

$$\frac{\sum_{t=18:00}^{T=23:00} PeBUY_t}{5} \geq 0.5 \cdot D_{max} \tag{40}$$

Also, if the hourly peak consumption is greater than 0.85 times the maximum demand during five consecutive days, the rate considered will be the most expensive one.

Hence, the challenge is to reduce the maximum demand during peak hours and also reduce the average consumption during peak hours.

4.2.4 Diesel generator model

Diesel generator as peak generation power supplies the lack of electricity led by RES in the same way as BESS systems. The diesel generator model corresponds to a Cummins C55 D5 and the performance yield of DG based on diesel fuel depends on its load level, thus, its fuel consumption ratio was obtained from the datasheet and can be seen in the following table:

Table 4-2:
Diesel generator model specifications: Power factor and fuel consumption ratio (l/hr) at different load levels

	Diesel generator Cummins C55 D5 – Power factor: 0.8			
Load level	25%	50%	75%	100%
Liters per hour	3	6	10	13

Hence, heat-rates (ag,bg,cg) parameters used in diesel fuel consumption function are adjusted according to Table 4-2. However, as RES penetration increase, the cycling of generators increases (NREL, 2012) a fact that is often not accounted for in micro grid planning.

4.2.5 Battery energy storage system model

BESS systems are ideally suited for community and household solar PV grids. Storage systems can provide emergency back-up, load-shifting, peak-shaving and DR programs. Technical components of the battery used are based on the *Tesla* powerpack BESS, as seen in Table 4-3.

Table 4-3:
BESS parameters: Round-Trip efficiency, Depth of Discharge, Power charge/discharge and lifetime

Tesla Powerpack 210 kWh	Round-Trip Efficiency (%)	Depth of Discharge (%)	Power Charge/Discharge (kW)	Cycle life (cycles)	Lifetime (years)
	89%	100%	50	3650	10

4.2.6 Demand Response model

Demand response programs (e.g. load shifting) depend on consumer preferences and their consumption behaviors. Hence, programs may not be applicable to every country and every case will depend on household appliances equipment. In this line, Stamminger (2008) propose that between 5-20% of household appliances could postpone or anticipate their load consumption (Dietrich, Latorre, Member, Olmos, & Ramos, 2012). As our model only includes residential consumption, shiftable demand limit has been set at 20%. Regarding the price of load shifting program, is set at 0.23 USD/kWh as explained in (Alharbi & Bhattacharya, 2013).

4.2.7 Economic assessment: Levelized Cost of Energy

Technologies that comprise Micro grid business models will be evaluated under Levelized Cost of Energy (LCOE) which represents the price of electricity of a certain technology that allows investor to earn their Investment (I), Operation (O) and Maintenance (MA) cost over the lifetime of the energy plant (Branker, Pathak, & Pearce, 2011; Kästel & Gilroy-Scott, 2015; Pawel, 2014). LCOE can be calculated as the ratio between present value of total costs and present value of energy produced by the equipment during its lifetime (Watts et al., 2015):

$$LCOE = \frac{\sum_{i=0}^{N} \frac{I_i + O_i + MA_i}{(1+r)^i}}{\sum_{i=0}^{N} \frac{E_i}{(1+r)^i}} \tag{41}$$

where r is the discount rate of the energy plant.

4.2.8 Demand Model

In order to assess the difference between weekdays and weekend days regarding electrical demand consumption, two different profiles are chosen by month. Hence, the system is prepared for peak demand along the week and weekends. By this way, the MG capacity is over dimensioned to assure that demand is supplied by different technologies.

5. CASE STUDY: RESIDENTIAL AND COMMUNITY SCALE MICRO GRID ANALYSIS THROUGHOUT CHILE

This section examines available renewable resources, energy purchase and sales prices, and latitude/longitude of evaluated locations. Investment, operation and maintenance prices for DERs are also presented.

Because Chile stretches from near the equator, all the way to Antarctica, its landscapes and climates offer a myriad of conditions and resources, suitable for global representation.

5.1 Locations considered and their main features

In order to understand the cost-effective potential of deploying micro grid throughout the country, 17 communities located in 15 different regions are studied. For each location, the following local resources, electricity rates including stabilized prices under Chilean regulation, diesel fuel price and demand data was used:

- The hourly mean GHI for 12 representative days from years 2004-2015
- The hourly mean wind speed for 12 representative days from years 1980-2013
- Annual electricity demand for 1251 low voltage clients in Santiago from year 2000.
- The electricity retails rate named “Baja Tension 1” (BT1) and “Tarifa horaria residencial” (THR), which are flat and ToU-3 rates and they only have a energy charge, and “Baja Tension 2” (BT2) and "Baja Tension 3" (BT3) which combines capacity (partial and peak power consumption) separately from energy.
- Short-term nodal prices for Interconnected central system (SIC), Interconnected Northern system (SING) and Medium systems from April to September of 2016.

The Exchange rate used is the average dollar observed in Chile between 2016 and 2017 (1 USD = $673 CLP).

The geographical range of the study comprise 3900 kilometers, with Putre (XV region) as the northernmost city and Punta Arenas (XII region) as the southernmost city, covering 100% of the population of the country and the most important PV and wind energy potential. Radiation data was obtained from Chile's Explorador Solar resource database (UChile, 2016). Wind speed data was obtained from Chile's Explorador eólico resource database. Diesel prices data was obtained from Chile's Bencina en Linea resource database. Demand data was obtained from Chilectra, the main distribution utility in Santiago. Finally, electricity rates were obtained from each utility's tariff reports and short-term nodal prices (stabilized prices) from Chile's Comisión Nacional de Energía (CNE, 2016).

5.2 Places with highest rates

Linares (BT1 tariff retail rate: 0.27 $US/kWh and BT2 peak power: 0.24 $US/kWh) and Osorno (BT1 tariff retail rate: 0.26 $US/kWh and BT2 peak power: 0.24 $US/kWh) had the highest electricity rates. The city with highest GHI is Calama with an average of 7.54 kWh/m2-day and the city with the highest wind speed is Punta Arenas with an average of 6.26 m/s at 45 m. The cities with the higher and lower diesel fuel price are Calama (0.76 $US/l) and Coyhaique (0.67 $US/l), respectively.

5.3 Solar resources for communities

In Chile, due to cloud covering, coastal cities have less solar irradiance than inland cities. This can be seen in Figure 5-2 (Watts et al., 2015). The GHI data used has a resolution of 60 min and represents irradiances at exact times referenced to GMT/UTC – 4 time (UChile, 2016). Of the locations observed in this study, Calama had the highest daily GHI average Punta Arenas had the lowest (4.2 kWh/m2-day).

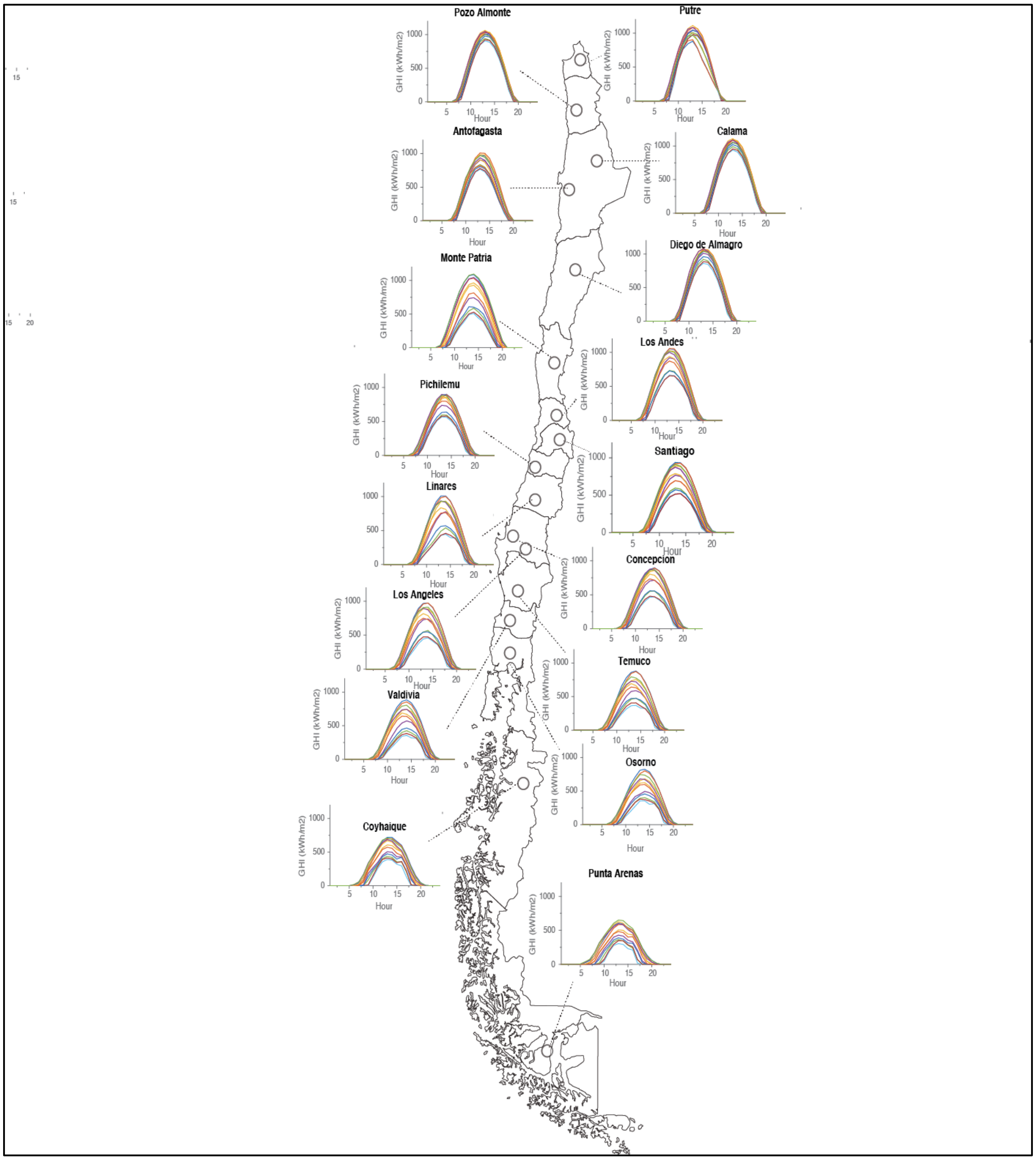


Figure 5-1: Solar irradiance throughout Chile

5.4 Wind resource for communities

In Chile, wind speed varies strongly throughout the territory and behaves in different ways depending on the time of the day.

The wind speed data used has a resolution of 60 min and represents wind speed at exact times referenced to GMT/UTC – 4 time (UChile, 2012). Of the locations observed in this study, Punta Arenas had the highest total wind speed (6.26 m/s hourly average) and Los Andes had the lowest (1.77 m/s average). Fig. 5-2 shows the annual hourly average wind speed for all locations. Table 5-1 summarizes key features of each location used in the study including city, coordinates, region, average GHI, annual PR, altitude, wind speed, diesel fuel price, Solar PV yield with and without HSAT considering a 1 kW panel with an inverter efficiency of 96% and coefficient of losses of 14% and solar PV yield gain. Table 5-2 shows retail rates for each site and Table 5-3 shows nodal prices for each site.

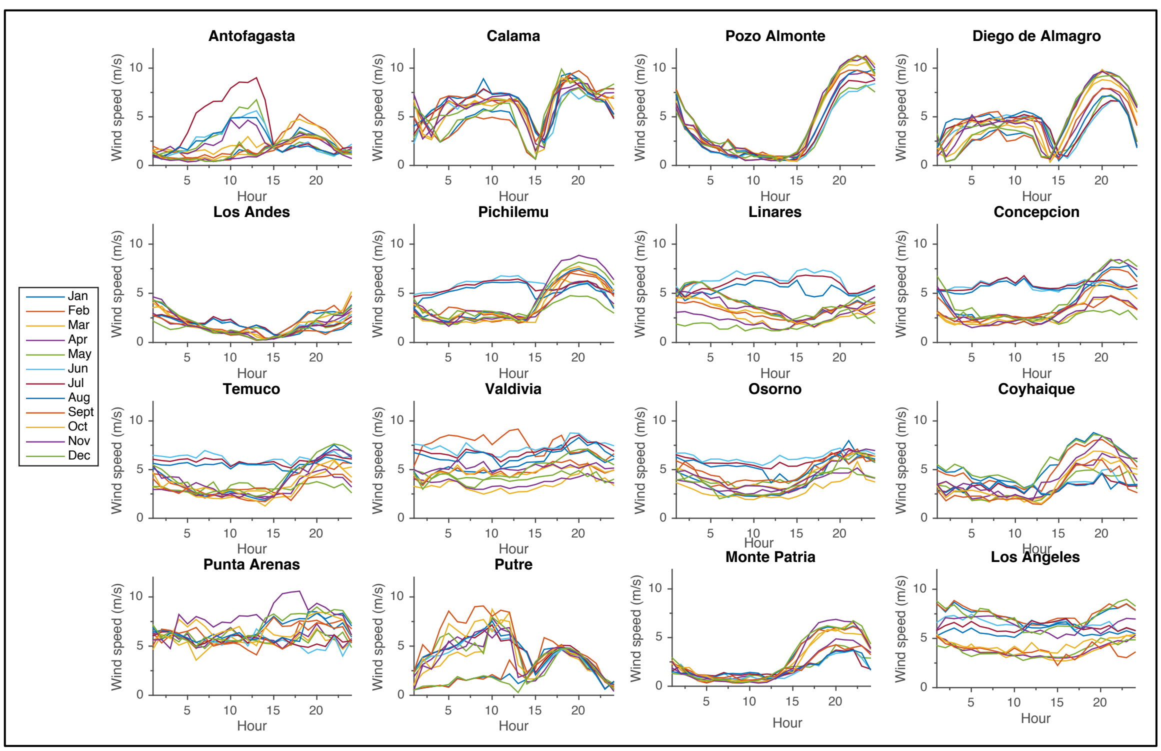


Figure 5-2: Annual Hourly Wind Speed from different days for all locations.

Table 5-1:
Input data for each location: Coordinates, average GHI 2004-2015, Altitude, PR, Optimal inclination, Solar PV yield, R gain, average wind speed and diesel fuel price.

Location	Region	Lat	Long	GHI average 2004-2015	Height	PR	Optimal inclination angle	Solar PV yield	Solar PV yield with HSAT	R Gain	Wind speed @ 45 m	Diesel Fuel Price
				kWh/m2-day	m	p.u.		kWh/kWp	kWh/kWp	p.u.	m/s	$US/l
Putre	XV	-18.2	-69.55	7.13	3559	0.81	18	1975	2528	1.28	3.76	0.72
Pozo Almonte	I	-20.26	-69.77	7.20	1033	0.78	20	1925	2504	1.30	4.04	0.73
Calama	II	-22.46	-68.91	7.54	2275	0.78	22	2073	2741	1.32	5.95	0.76
Antofagasta	II	-23.63	-70.38	6.24	69	0.77	24	1693	2061	1.22	2.12	0.74
Diego de Almagro	III	-26.39	-70.04	7.18	790	0.77	26	1945	2466	1.27	4.43	0.73
Monte Patria	IV	-30.7	-70.95	6.53	428	0.77	31	1739	2181	1.25	2.29	0.75
Los Andes	V	-32.84	-70.58	6.37	903	0.78	33	1732	2173	1.25	1.77	0.72
Santiago	XIII	-33.48	-70.6	4.97	566	0.78	33	1488	1827	1.23	4.34	0.72
Pichilemu	VI	-34.39	-72	5.41	21	0.80	34	1496	1808	1.21	3.89	0.69
Linares	VII	-35.85	-71.59	5.45	163	0.77	36	1492	1870	1.25	4.05	0.69
Concepción	VIII	-36.8	-73.04	5.20	24	0.81	37	1428	1742	1.22	5.52	0.74
Los Angeles	VIII	-37.46	-72.34	5.39	135	0.79	37	1494	1865	1.25	4.14	0.67
Temuco	IX	-38.75	-72.56	4.22	221	0.76	39	1266	1520	1.20	5.43	0.75
Valdivia	XIV	-39.83	-73.22	4.12	8	0.81	40	1233	1513	1.23	4.52	0.78
Osorno	X	-40.58	-73.1	4.21	51	0.80	41	1115	1350	1.21	3.99	0.76
Coyhaique	XI	-45.58	-72.03	4.18	325	0.84	46	1146	1365	1.19	1.86	0.78
Punta Arenas	XII	-53.17	-70.9	3.53	0	0.00	53	1050	1217	1.16	6.26	0.75

Table 5-2:
Retail rates for each location: BT1 retail rate, ToU retail rate and BT2 retail rate

Location	BT1 Tariff retail rate ($US/kWh)	Night BT1 Tariff retail rate ($US/kWh)	Peak BT1 Tariff retail rate ($US/kWh)	Energy Injection ($US/kWh)	BT2 Tariff energy rate ($US/kWh)	BT2 Tariff power rate ($US/kW-month)	BT2 Tariff peak power rate ($US/kW-month)	BT2 Tariff retail rate ($US/kWh)	BT2 Tariff peak retail rate ($US/kWh)
Pozo Almonte	0.18	0.12	0.23	0.08	0.10	16.66	21.96	0.14	0.15
Antofagasta	0.17	0.12	0.22	0.09	0.11	15.21	22.10	0.14	0.16
Calama	0.17	0.12	0.22	0.09	0.11	15.21	22.10	0.14	0.16
Diego de Almagro	0.16	0.11	0.20	0.08	0.10	16.39	19.76	0.13	0.14
Monte Patria	0.20	0.14	0.26	0.10	0.12	21.75	25.50	0.17	0.18
Los Andes	0.20	0.14	0.26	0.11	0.13	15.88	22.57	0.16	0.18
Pichilemu	0.20	0.14	0.27	0.11	0.13	20.72	26.11	0.17	0.19
Linares	0.27	0.19	0.35	0.11	0.14	32.84	43.76	0.22	0.24
Concepción	0.20	0.14	0.26	0.11	0.14	11.93	18.16	0.16	0.18
Los Angeles	0.25	0.18	0.32	0.10	0.12	26.37	36.24	0.19	0.21
Temuco	0.21	0.15	0.27	0.11	0.13	3.17	18.51	0.14	0.18
Valdivia	0.20	0.14	0.26	0.11	0.13	17.65	24.20	0.17	0.18
Osorno	0.26	0.19	0.34	0.12	0.14	25.65	43.07	0.20	0.24
Coyhaique	0.23	0.16	0.30	0.09	0.11	31.21	38.26	0.18	0.20
Santiago	0.17	0.12	0.22	0.10	0.12	9.88	16.01	0.14	0.16
Punta Arenas	0.19	0.13	0.25	0.08	0.10	15.94	24.03	0.13	0.15
Putre	0.24	0.17	0.31	0.09	0.09	41.63	44.66	0.18	0.19

Table 5-3:
Nodal Prices throughout Chile

Location	Electrical substation	Nearest Node	Stabilized price ($CLP/kWh)	Power Nodal price ($CLP/kW-month)	Monohmic stabilized price ($CLP/kWh)	Monohmic Stabilized price ($US/MWh)
Pozo Almonte	Pozo Almonte	Pozo Almonte	32.4	5640	40.8	62.5
Antofagasta	Antofagasta	Laberinto	31.9	5552	40.2	61.4
Calama	Calama	Crucero	31.6	5485	39.8	60.9
Diego de Almagro	Diego de Almagro	Diego de Almagro	33.7	6439	43.3	66.2
Monte Patria	Monte Patria	Pan de Azúcar	41.0	5001	48.5	74.1
Los Andes	san rafael	Polpaico	43.1	5455	51.3	78.4
Pichilemu	Alcones	Rapel	44.0	5430	52.1	79.6
Linares	Linares	Ancoa	43.0	5377	51.0	78.0
Concepción	Concepción	Charrua	40.1	4909	47.4	72.5
Los Angeles	Los angeles	Charrua	40.1	4909	47.4	72.5
Temuco	Temuco	Temuco	41.2	5014	48.7	74.5
Valdivia	Valdivia	Valdivia	46.7	5168	54.5	83.3
Osorno	Osorno	Valdivia	46.7	5168	54.5	83.3
Coyhaique	Aysén 23	Aysén 23	60.2	7324	71.1	108.7
Santiago	El salto	Cerro Navia	44.4	5569	52.7	80.5
Punta Arenas	Punta Arenas -3 puentes	Punta Arenas	39.8	9002	53.3	81.5
Putre	Chuño	Parinacota	33.7	6046	42.7	65.3

The Exchange rate used is the average dollar observed in Chile between 2016 and 2017 (1 USD = $673 CLP).

5.5 Capital and operational costs and initial parameters

The following are the investment and maintenance costs for LDG, CNB and RNB, useful life and discount rate of distributed energy resources (Tables 5-4 and Table 5-5) as well as fuel consumption rates, on / off costs (liters) and ramp up/down for diesel generators (Table 5-6).

Table 5-4:
Capital and Maintenance cost of Solar PV, Wind Turbines and Diesel Generators

	Capital Cost ($US/kW) LDG/CNB/RNB	**Maintenance Cost ($US/kW-year)**	**Lifetime (years)**	**Discount rate**
PV array	1100/1310/1610[1]	1% of initial Inv Cost	20	10%
Wind Turbines	1710/2650/3500[2]	3% of initial Inv Cost*	20	10%
Diesel Generators	300/300/350[3]	15	10	10%

[1]: Public auction in Solar rooftops program committed by Min Energía, Chile.

[2]: NREL document and (Malheiro et al., 2015)

[3]: Cummins D66 cotización

Table 5-5:
Capital and Maintenance cost of Battery

	Capital Cost ($US/kWh)	**Maintenance Cost ($US/kWh-year)**	**Lifetime (years)**	**Discount rate**
Battery energy storage system	300[1]	5	10[3]	6%[2]

[1]: Projected price by 2020 according to EIA
[2]: NREL battery report
[3]: Assumption based on Tesla Powerpack 10 years lifetime

Table 5-6:
Diesel generators input information: heat-rates, shut-down and start-up costs, Min Time up and Time down and Max ramp-up and ramp-down.

DG	ag	bg	cg	Shut-down Cost	Start-up Cost	Min Time-up	Min Time-down	Max ramp-up	Max ramp-down
	lt/kWh2	lt/kWh	[lt]	(lt)	(lt)	(hr)	(hr)	(kW)	(kW)
1	0.002	0.223	0	0	0	0	0	30	30
2	0.003	0.224	0	0.4	0.4	0	0	60	60

5.6 Aggregated and individual residential demand

Single-payer demand is used for residential MGs in each of the seventeen sites modeled. Aggregated demand for fifteen customers is used to model community MG consumption.

Residential demand has a peak demand of 7.5 kW and an annual consumption of 18 MWh (3 MWh monthly consumption). Community demand, on the other hand, has a peak power of 69 kW and an annual energy consumption of 273 MWh (25 MWh monthly). The residential and community demands are the same for all locations, based on twelve weekdays and twelve weekend days, as presented in Figure 5-3.

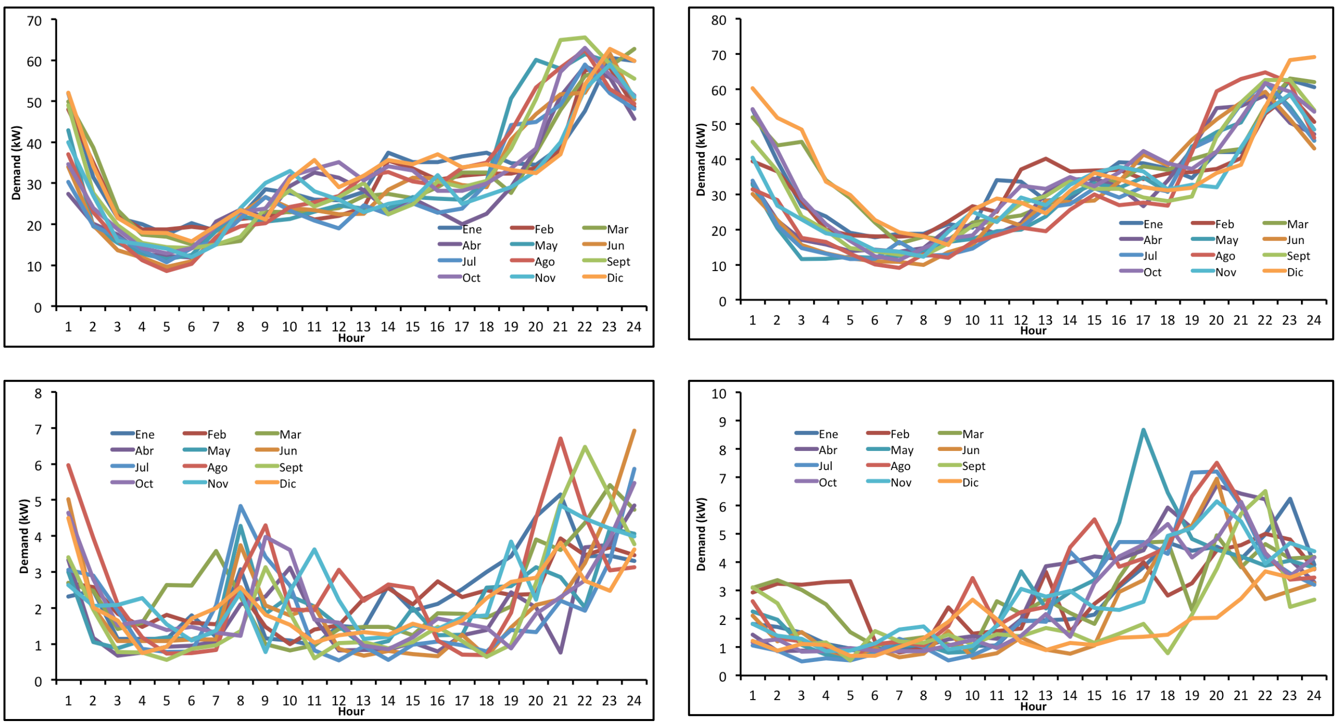


Figure 5-3: Residential and Community electrical demand for week and weekend days in a year for each MG

5.7 Modeling assumptions for community and residential Micro Grids

The following assumptions were considered for the modeling of the optimal sizing and operation of the residential and community micro grids:

- Electrical consumption demand profile is the same for each location in community MGs
- Electrical consumption demand profile is the same for each location in residential MGs
- Diesel generators have a lifetime of 12.000 hours, which represents 10 years of useful time.

- Tesla PowerPack batteries have a lieftime of 3650 cycles, considering that one cycle corresponds to the complete charge/discharge of the battery. This is equivalent to 10 years of useful time.
- In case that in community MGs with BT2-BT3 rates, measured power is almost zero, consumer can still sell energy surplus to the grid, taking advantage of the electrical junction box and available infrastructure.

6. RESULTS: OPTIMAL SIZING AND ENERGY MANAGEMENT FOR COMMUNITY AND RESIDENTIAL MICRO GRIDS EVALUATED UNDER DIFFERENT BUSINESS MODELS THROUGHOUT CHILE

This section will present the results obtained from long-term planning for community (i.e. CNB, CNM, SLG, LDG, IMG) and residential (i.e. RNB and RNM) MGs under different business models throughout Chile. Each site has different renewable resources (i.e. solar and wind), different levels of energy purchase and sale prices, as well as different price levels for peak power and diesel fuel. The electrical demand is the same for each of the locations, which includes one day type of week and one day type of weekend for each month of the year.

The distributed energy resources offer that the MG can install and use to supply demand is composed of: Solar PV, wind turbines, BESS, a more efficient and economical diesel generator, a more flexible but less Economic diesel generator and demand management. In addition, energy and power can be purchased from grid as well as surplus energy can be sold to the grid in the corresponding business models.

In this way, according to the conditions of resources, price levels and costs, the planning of the micro grid under different business models allows to optimally size and operate different technologies and capacities of these to satisfy the demand. Thus, in places with good solar resources solar PV is installed (e.g. Calama), while in places with low irradiance (e.g. Punta Arenas) solar PV is not installed.

The difference between the community and residential micro grid is mainly based on the tariff regime applied, since in the latter the maximum demand is restricted to 10 kW and there is no power component associated with the tariff (i.e BT1 tariff), as if it exists in the community MG. In this sense, there are two tariff alternatives in the community MG by choosing a BT2 or BT3 tariff for the payment of power, one more expensive than the other, and the planning allows to know if it is viable economically to use diesel generation, demand management or BESS to reduce the power consumption of the network and hence, cutting peak demand and avoiding the payment of the most expensive charge for power.

6.1 Community Micro Grid planning: Optimal Energy Management and sizing for Calama, Santiago and Punta Arenas under Net-Billing scheme

Below is the planning of the comunity MG for the areas of Calama, Santiago and Punta Arenas under the Net-Billing business model, which remunerates the energy component of the injection to the network. These zones are chosen to show the importance of the availability of local resources, and prices of the purchase rates, mainly given the large distance between each of these locations.

Thus, given the 24-day community electricity demand, diesel fuel prices for each zone, energy purchase and sale prices, power tariff prices, renewable resources available (solar and wind), The peak-time differences between SIC, SING and medium-sized systems, and assuming the Net-Billing scheme, the optimum sizing and energy management for each community MG under the Net-Billing scheme in the areas of Calama , Santiago and Punta Arenas is obtained, allowing to make comparisons of energy costs per level by technology, monomic costs of the network and average costs of supply for each of these locations.

6.1.1 Optimal sizing for community micro grid under Net-Billing scheme for Calama, Santiago and Punta Arenas

The optimal sizing of the micro-community network will depend heavily on the availability of the removable resource and location.

In Calama the solar resource is abundant (7.22 kWh / m2-day) and the wind resource is good (6 m / s), which allows to install 85 kWp of Solar PV with a power factor of 24% and 15 kW of energy Wind power with a power factor of 33%, and levelized cost of energy of 96 US/MWh and 135 US/MWh respectively. To reduce peak demand, 7.5 kVA of diesel generation is installed at a levelized cost of energy of 248 US / MWh. Then the net present cost of the investment, operation and maintenance of the micro-grid is M $ US 357 with an average cost of supply of 153 US/MWh and the linear payback of the investment corresponds to 11 years.

In Santiago, the solar resource is good (6 kWh / m2-day), which allows to install 65 kWp of solar PV at a levelized cost of energy of 129 US / MWh with a power factor of 22%. To reduce peak demand, 10 kVA of the economical diesel generator and 12.5 kVA of the flexible diesel generator are installed with levelized cost of energy of 254 US/MWh and 298 US/MWh respectively. Then, the net present cost of investment, operation and maintenance of the micro grid is M $ US 363 with an average cost of supply of 157 US/MWh and the linear investment payback corresponds to 12 years.

Finally, at Punta Arenas, the wind resource is very good (6.11 m / s), which allows the installation of 25 kW of wind power at a cost of 99 US/MWh with a power factor of 35%. To reduce peak demand, 6.25 kVA of the economical diesel generator and 12.5 kVA of the flexible diesel generator are installed, with energy costs of 314 US / MWh and 361 US / MWh, respectively. The net present cost of the investment, operation and maintenance of the micro network is M$US 351 with an average cost of supply of 150 US / MWh and the linear payback of the investment corresponds to 8 years.

Figure 6-1 shows the installed capacities and the levelized costs of energy for each technology according to the location and the average cost of supply for each micro-grid

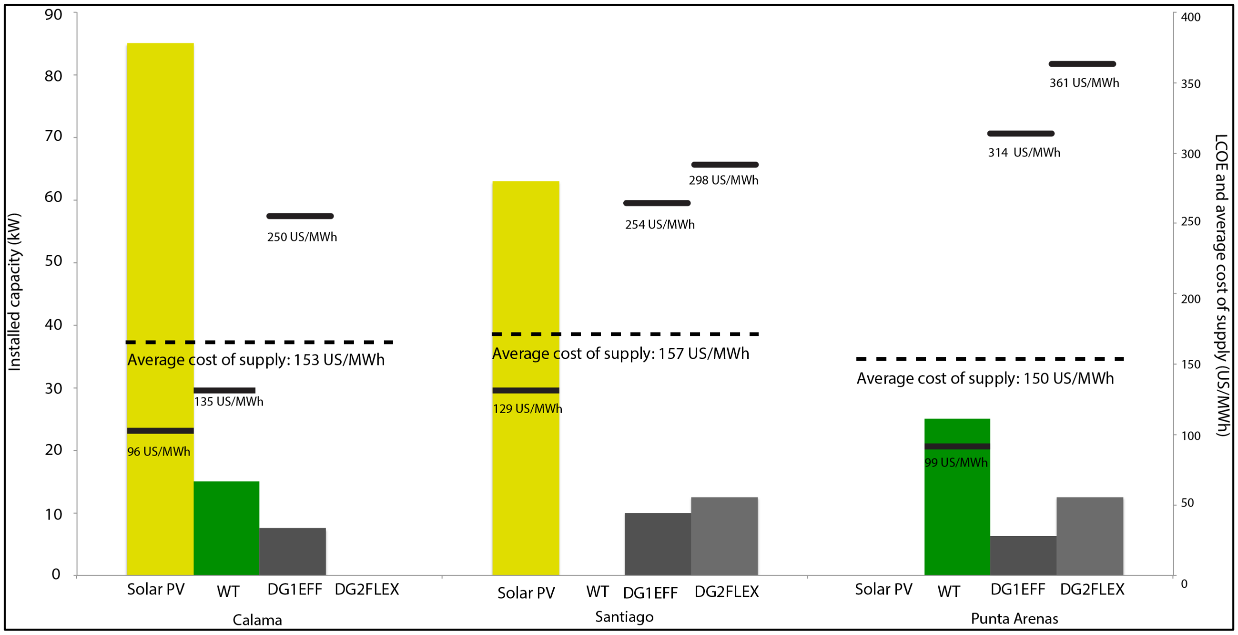


Figure 6-1: Installed capacity and LCOE for every technology and average cost of supply for community MGs in Calama, Santiago and Punta Arenas

6.1.2 Optimal Energy Management for community micro grid under Net-Billing scheme for Calama, Santiago and Punta Arenas

Regarding energy management of each community MG under the Net-Billing scheme, it is mentioned that in Santiago Solar PV is used for self-supply and the surplus is injected into the upstream network. Also, Diesel Generation and demand management programs are technologies capable enough to cut peak demand during peak months of the SIC (i.e. April - September). In the case of Calama, it takes advantage of abundant renewable resources to use Solar PV and wind energy, mainly for self-supply and inject surplus to the grid. In addition, diesel generation is used to reduce peak demand throughout the year along with demand management programs during autumn and winter. Finally, in the case of Punta Arenas, there is a lack of solar resource and solar PV is not used, instead the wind resource is used to install a wind turbine and supply a part of the community consumption. In addition, diesel generation is used and flexible load is managed to non-peak hours to avoid paying the most expensive rate for power in the peak months of the SIC. Figure 6-2 shows the optimal energy management for summer and winter seasons in a typical weekday for a community micro grid under the Net-Billing scheme in Calama, Santiago and Punta Arenas.

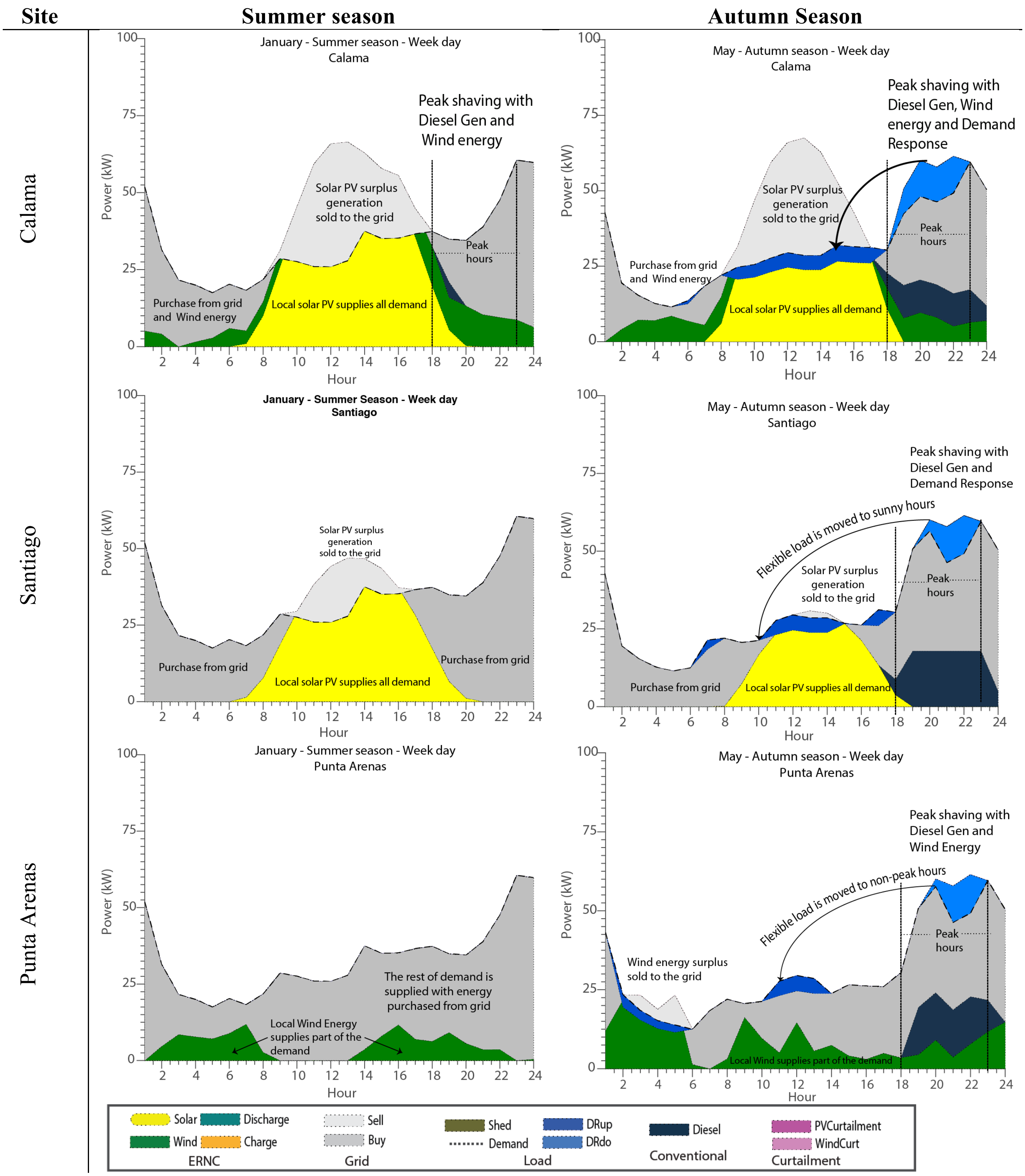


Figure 6-2: Optimal Energy Management for community micro grid under Net-Billing scheme for Calama, Santiago and Punta Arenas

i) Detailed energy generation per technology and self-sufficiency regarding electrical demand in community MGs in Calama, Santiago and Punta Arenas under Net-Billing scheme.

Optimal sizing and energy management of community micro grid for each site under Net-Billing scheme allows to take decisions to supply community demand consumption in the short and long term. Therefore, detailed energy generation by each technology can be obtained to show the contribution of different DERs that comprise micro grids. Thus, in the horizon time of 24 days the following is obtained:

In Calama, solar resource is abundant, thus 11.6 MWh are generated reaching 64% of total demand. However, part of this energy is injected to the upstream network. Regarding wind energy, 2.9 MWh are generated, reaching 16% of demand consumption and part of this latter is injected to the grid. Then, self-sufficiency from renewables reaches 50% of the total demand.

In Santiago, there is lack of wind resource. However, solar resource is good which contributes generating 6.6 MWh, reaching 37% of total demand. If surplus energy is taken into account, self-sufficiency from renewables reaches 32% of the total demand.

Finally, in Punta Arenas, there is a lack of solar resource but instead eolic resource is very good, which contributes generating 6.5 MWh reaching 36% of total demand. If surplus energy is taken into account, self-sufficiency from wind energy reaches 34% of the total demand.

Fig. 6-3 shows percentages of renewable generation: solar and wind energy, demand response, diesel generation, purchase of energy from/to grid and self-sufficiency percentage provided by renewables regarding total demand.

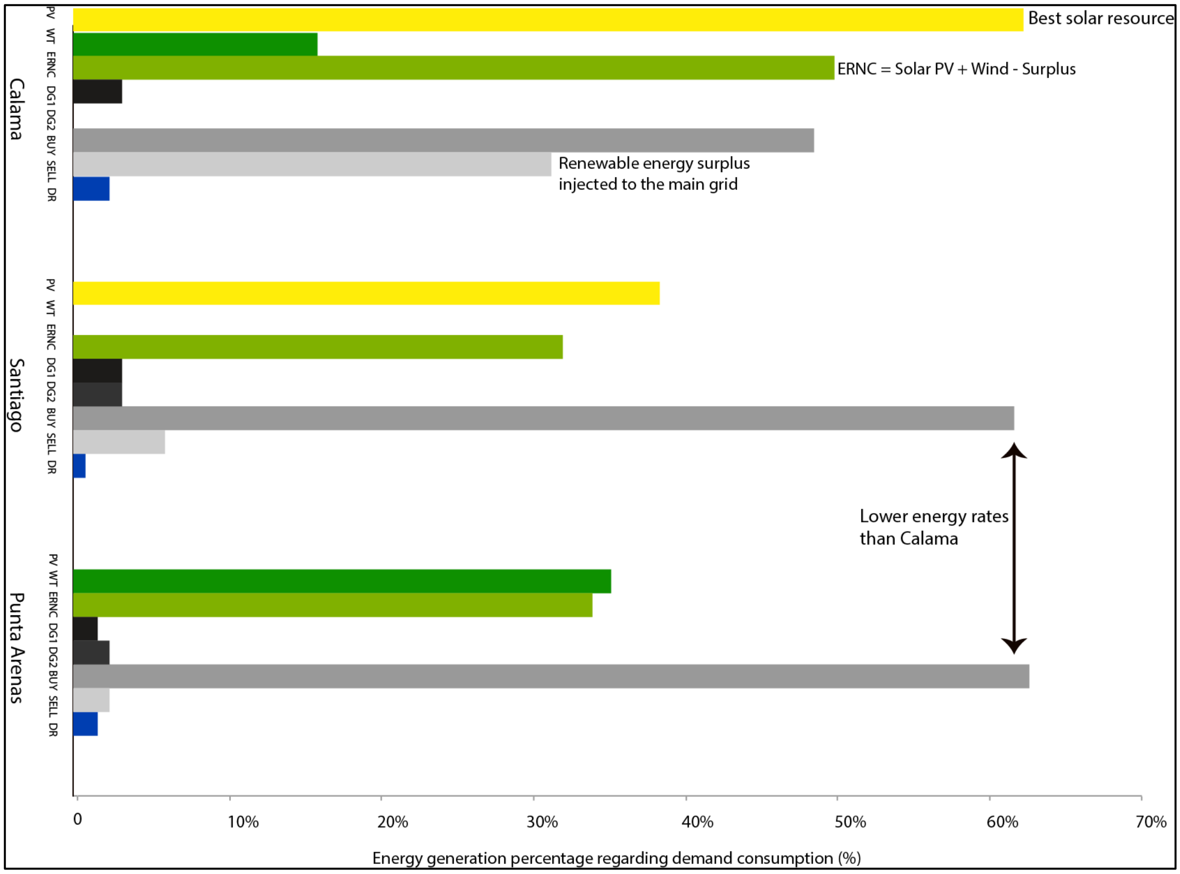


Figure 6-3: Detailed energy generation per technology and self-sufficiency regarding electrical demand in community MGs in Calama, Santiago and Punta Arenas under Net-Billing scheme.

6.2 Community and residential micro grid planning: optimal sizing and energy management throughout Chile under different business models

The results of the micro grid planning are presented in this section: optimal sizing and energy management for all locations throughout Chile, from Putre to Punta Arenas for community micro grids (CNB, CNM, SLG, LDG and IMG) and residential micro grids (RNB and RNM). In the same way that the optimal micro grid planning for Calama, Santiago and Punta Arenas for a community micro grid evaluated under the Net-Billing scheme was shown, the results are shown for other locations, with different levels of renewable resource availability, different levels of energy rates, diesel fuel prices and injection rate, among others according to the corresponding business model. Figure 7-4 summarizes the optimal planning for the areas of Calama, Santiago and Punta Arenas under the Net-Billing scheme and shows that the same is done throughout Chile.

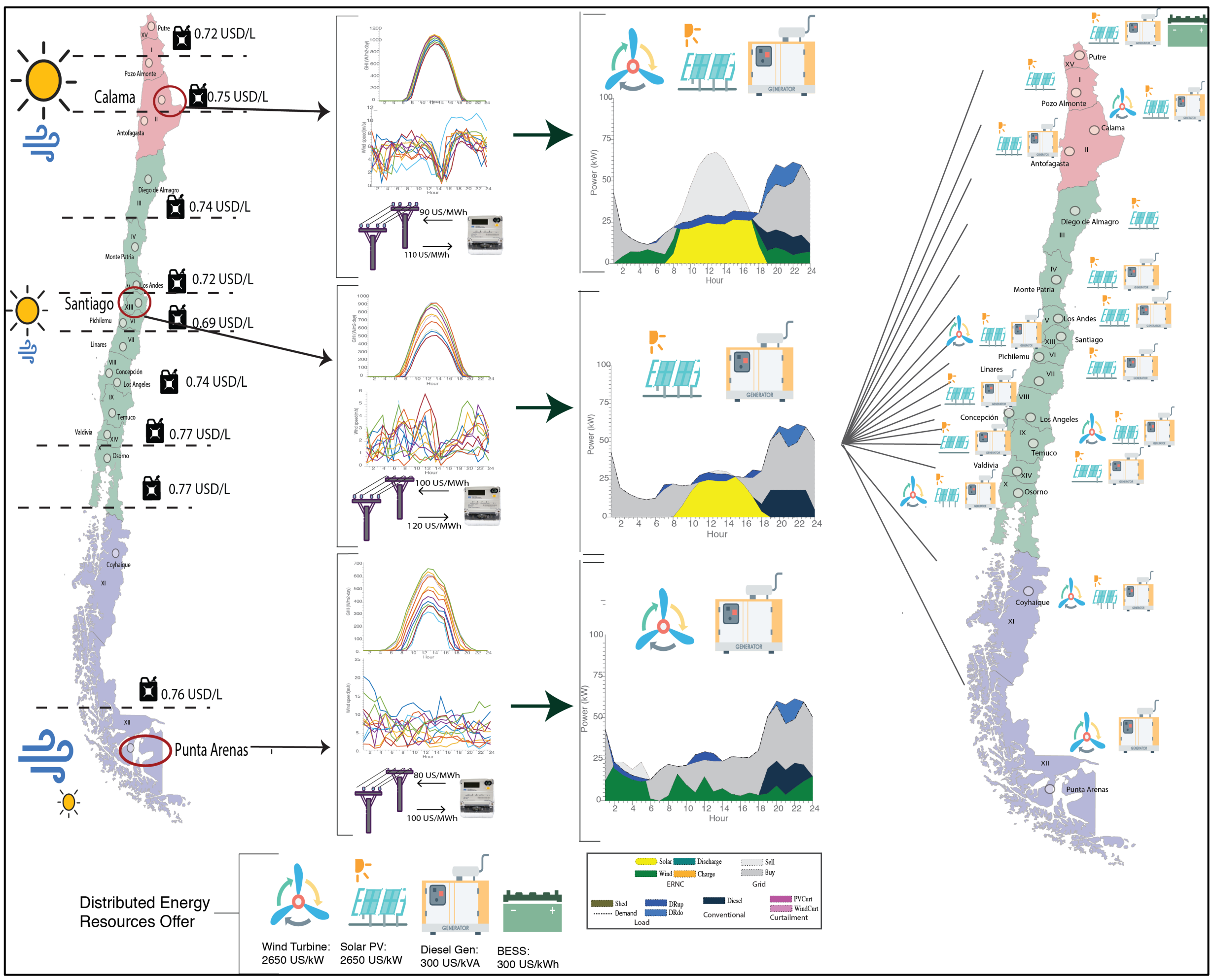


Figure 6-4: Micro grid planning scheme: Optimal sizing and energy management for community and residential micro grids under different resources conditions, price and cost levels

Then, several analyses are done, which include families of optimal planning solutions for community and residential micro grids throughout Chile and families of comparisons between different families of solutions under different business models. This allows to know general and specific features of each community and residential micro grids. Thus, the following cases will be analyzed:

- Community and residential micro grid reduce peak demand and self-supply a part of demand consumption with renewable energy sources
- Community and residential micro grids self-supply a part of demand consumption and the rest of demand is supplied by the upstream network
- Community and residential micro grids self-supply the most of demand consumption with DERs, minimizing the purchase of energy from grid.
- Comparison of Community Net-Billing and Community Net-Metering
- Comparison of Residential Net-Billing and Residential Net-Metering
- Comparison of Community Net-Billing and Residential Net-Billing
- Comparison of Community Net-Billing and Large Distributed Generation (PMGD)
- Solar PV deployment throughout Chile
- Wind energy deployment throughout Chile
- BESS deployment throughtout Chile
- Diesel generation Inflexibility
- Demand Response deployment

6.2.1 Optimal planning solutions for community and residential micro grids throughout Chile

Long-term planning for community and residential micro grid, which aims to minimize the costs of investment, operation and maintenance of these networks, allows us to know different families of solutions for each of the evaluated business models. In this way, knowing the optimum sizing and energy management of the micro grid, it is possible to characterize the community micro grids in the following families of solutions:

- **The micro grid is a grid-connected solar or wind community that reduces peak demand**: it takes advantage of solar or wind energy to self-supply and also manages demand efficiently to shifts flexible demand and uses diesel generation for peak shaving due to expensive power purchase rates. This generally occurs in Calama, Pozo Almonte, Los Andes, Santiago, Concepcion and Punta Arenas.

- **The micro grid is a solar community connected to the grid**, which takes advantage of the good solar resource to self-supply demand and the rest of it is supplied with energy from the grid due to cheap energy and power purchase prices. This happens in Diego de Almagro and Pozo Almonte.
- **The micro grid is a solar or wind community that minimizes the purchase of energy from the grid**, which uses solar or wind resource, demand management and diesel generation to supply most of the demand. In this way it minimizes the purchase of energy to the grid given the high prices of energy and power purchase from grid. This generally occurs in Monte Patria, Putre, Los Angeles, Valdivia, Osorno and Coyhaique and

Table 6-1 summarizes the families of solutions for community micro grids throughout Chile and shows the most important characteristics of each of them, while figure 6-5 shows the diversity of solutions throughout Chile.

Table 6-1:
Families of solutions for community micro grids throughout Chile

Solar - Wind -Demand Side Management	Family
	The micro grid is a grid-connected solar or wind community that reduces peak demand
	The micro grid is a solar community connected to the grid
	The micro grid is a solar or wind community that minimizes the purchase of energy from the grid

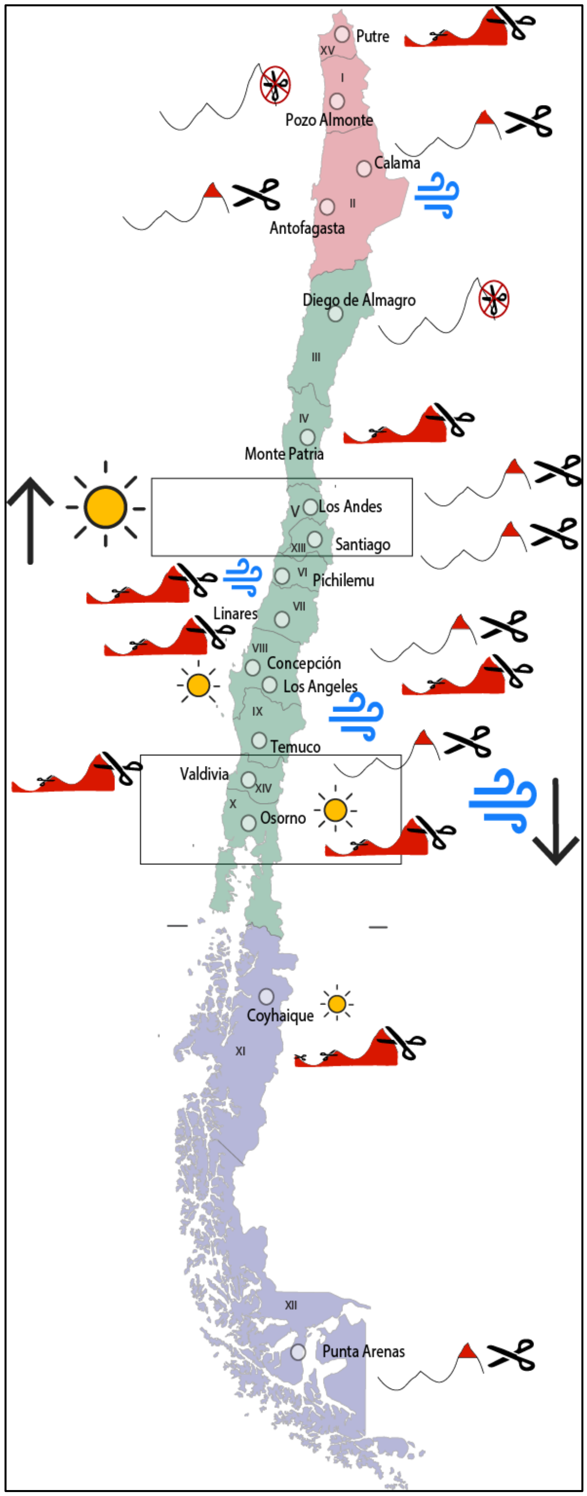


Figure 6-5: Families of solutions for optimal community micro grid planning throughout Chile

And residential micro grids (RNB and RNM) can be characterized with the following families:

- **Micro grid is a solar or wind residence that reduce peak demand at peak times**: it uses the solar or wind resource to self-supply part of demand and uses diesel generation for peak shaving because energy purchase prices are expensive at peak times. This happens in Pozo Almonte, Los Andes, Concepción and Punta Arenas.
- **Micro grid is a solar or wind residence that supplies the rest of demand from the grid**: it takes advantage of the good solar and/or wind resource to self-supply part of the demand and the rest of it is supplied with energy from the network due to economical purchase energy prices from grid. This occurs in Calama, Diego de Almagro, Santiago, Antofagasta.
- **Micro grid has a lack of renewable resources and only reduces peak demand at peak times**: it does not have enough renewable resources to self-supply a part of the demand and, therefore, it only uses diesel generation to reduce peak demand in peak hours. This happens in Temuco.
- **Micro grid has a lack of renewable resources and minimizes the purchase of energy from the grid**: it does not have enough renewable resources to self-supply a part of the demand and the energy purchase prices are very expensive. Thus, Diesel generation is used to minimize the purchase of energy from grid. This happens in Osorno.
- **Micro grid is a distributed energy resource residence that minimizes the purchase of energy from the grid**: it uses the solar or wind resource and diesel generation to supply most of the demand. In this way, it minimizes the purchase of energy from the grid given the high energy purchase prices. This occurs in Putre, Monte Patria, Los Angeles, Valdivia and Coyhaique.

Table 6-2 summarizes the families of solutions for residential micro grids throughout Chile and shows the most important characteristics of each of them, while figure 6-6 shows the diversity of solutions throughout Chile.

Table 6-2: Family solutions for Residential Micro Grids throughout Chile

Solar - Wind -Demand Side Management	Families
	Micro grid is a solar or wind residence that reduce peak demand at peak times
	Micro grid is a solar or wind residence that supplies the rest of demand from the grid
	Micro grid is a distributed energy resource residence that minimizes the purchase of energy from the grid
	Micro grid has a lack of renewable resources and only reduces peak demand at peak times
	Micro grid has a lack of renewable resources and minimizes the purchase of energy from the grid

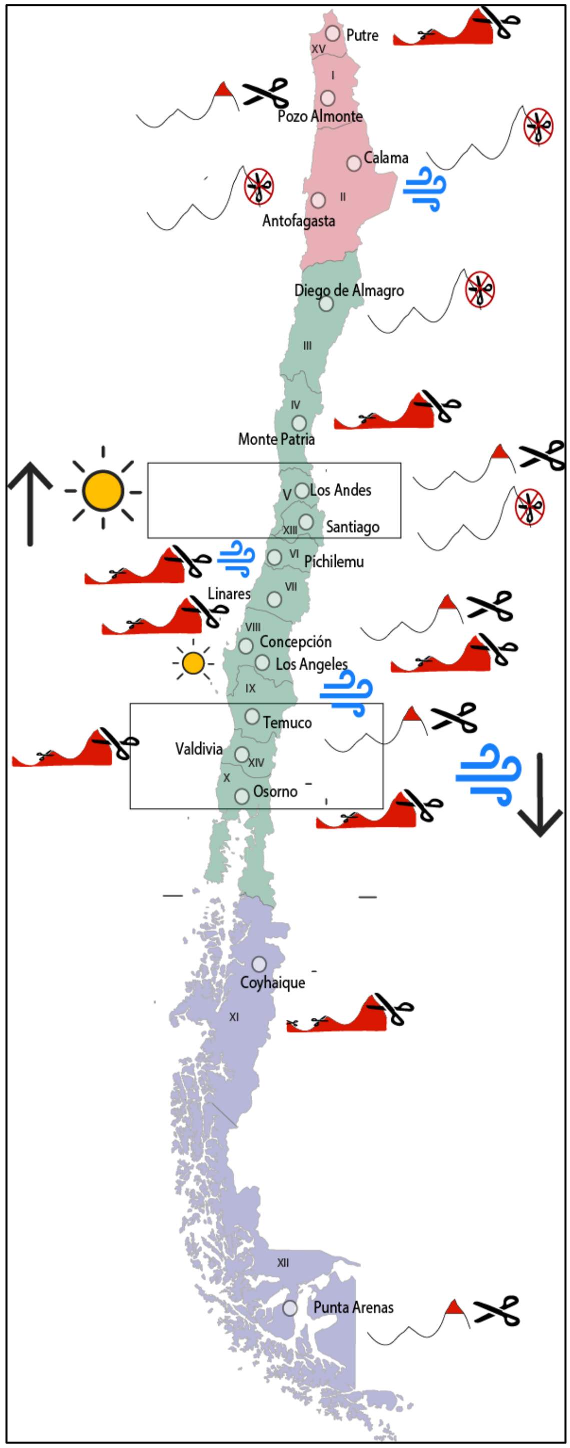


Figure 6-6: Family solutions for Residential Micro Grid planning throughout Chile

6.2.2 Comparisons of solutions for community and residential micro grid planning

The families of general solutions for community and residential micro grids evaluated under different business models allow analyzing the following families of comparisons:

- Community Net-Billing and Community Net-Metering:

The differences between the Net-Billing and Net-Metering model in community micro grids are very few, given that the price of injection and purchase of energy are similar. In this way, we have a different energy balance, a different measurement, but the value is similar throughout Chile. Figure 6-7 shows energy management for some places under a Net-Billing regime (on the left) and under a Net-Metering regime (on the right). Figure 7-8 shows the differences and similarities of Net-Billing and Net-Metering in community micro grids.

For this reason, the difference in energy sales prices between a Net-Billing model and a Net-Metering model varies between $ 10 US / MWh and $ 30 US / MWh for the evaluated zones. However, this difference allows a greater local development of solar PV and, therefore, to make better use of the solar resource of the zone. This occurs in the micro-grid of Calama, one of the sites with the largest solar resource in the country, which also has a good wind resource. In this way, in a Net-Billing regime, solar and wind generation are installed, which allows reducing peak demand. However, in the Net-Metering regime, only solar generation is installed, taking advantage of the good solar resource, supplying 100% of the demand in hours of greater irradiance and injecting all surplus into the grid.

Regarding the average costs of supply, the Net-Metering program for a residential community allows reducing the cost of supply against the Net-Billing program, between

1 $ US / MWh and 10 $ US MWh. Table 6-13 shows the differences regarding installed capacity and average costs of supply between the Net-Billing and Net-Metering regimes.

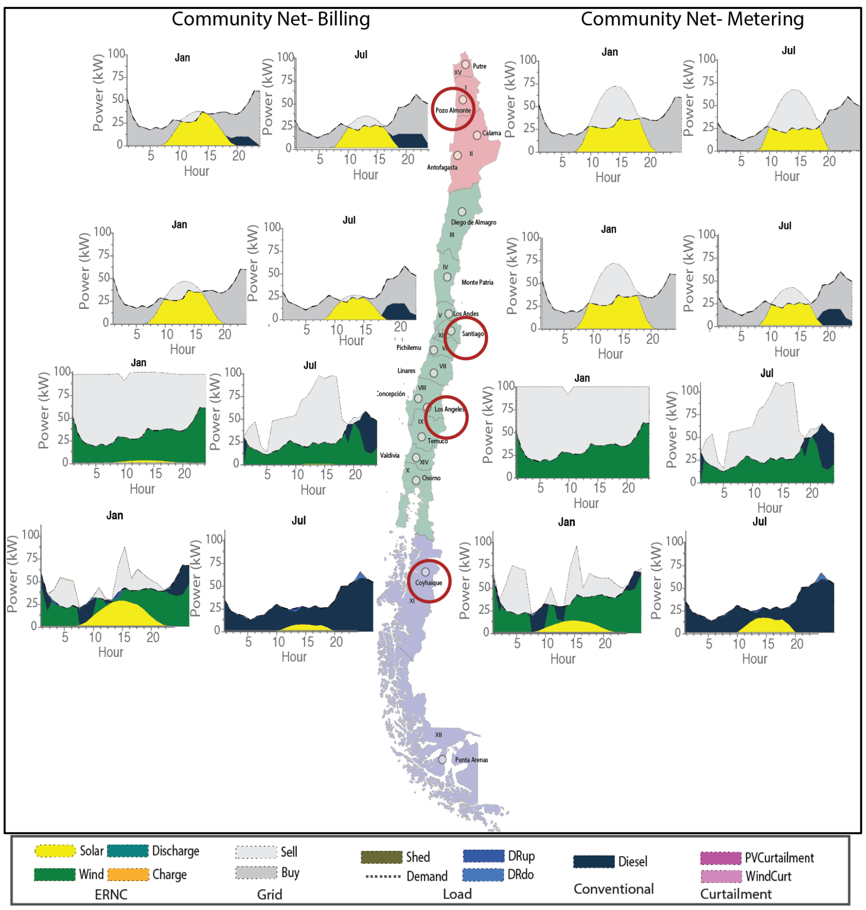


Figure 6-7: Differences and similarities between community Net-Billing and community Net-Metering Micro Grid Energy Management throughout Chile

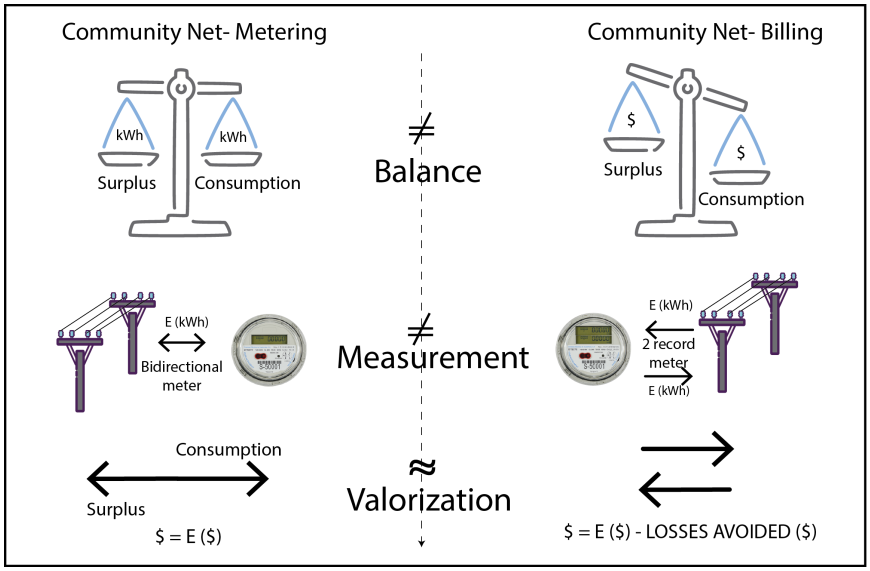


Figure 6-8: Differences and similarities between community Net-Billing and community Net-Metering throughout Chile by deploying MGs. Based on Watts, 2016.

- Residential Net-Billing and Residential Net-Metering

On the contrary, the differences between residential Net-Billing and residential Net-Metering are many, since as in the BT1 tariff there is no explicit charge for power, in Net-Metering injection rate will be equal to the energy purchase tariff. Approximately two times the Net-Billing injection rate. This allows a greater local development of solar PV and therefore, a higher remuneration for the sale of surplus energy to the grid. Figure 6-9 shows the differences in energy management between RNB and RNM in Diego de Almagro, Los Andes, Temuco and Punta Arenas and Figure 6-10 shows the differences between RNB and RNM regarding balance, measurement and valorization.

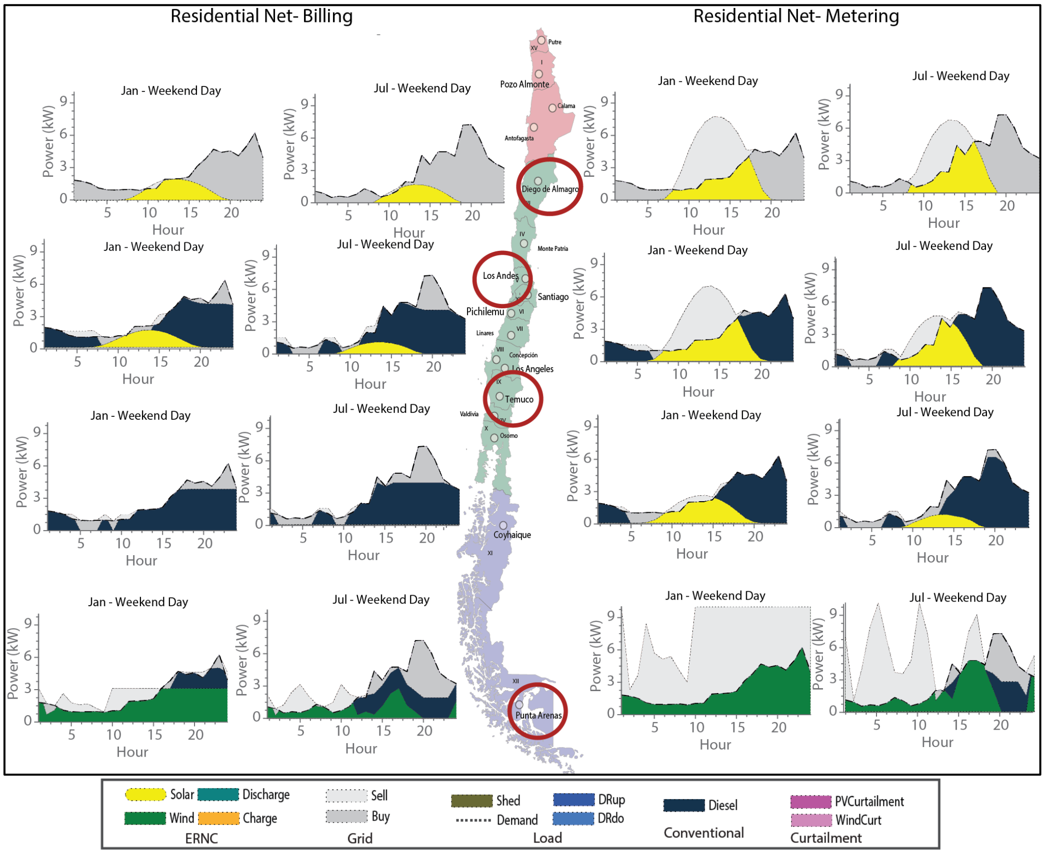


Figure 6-9: Differences between Residential Net-Billing and Residential Net-Metering

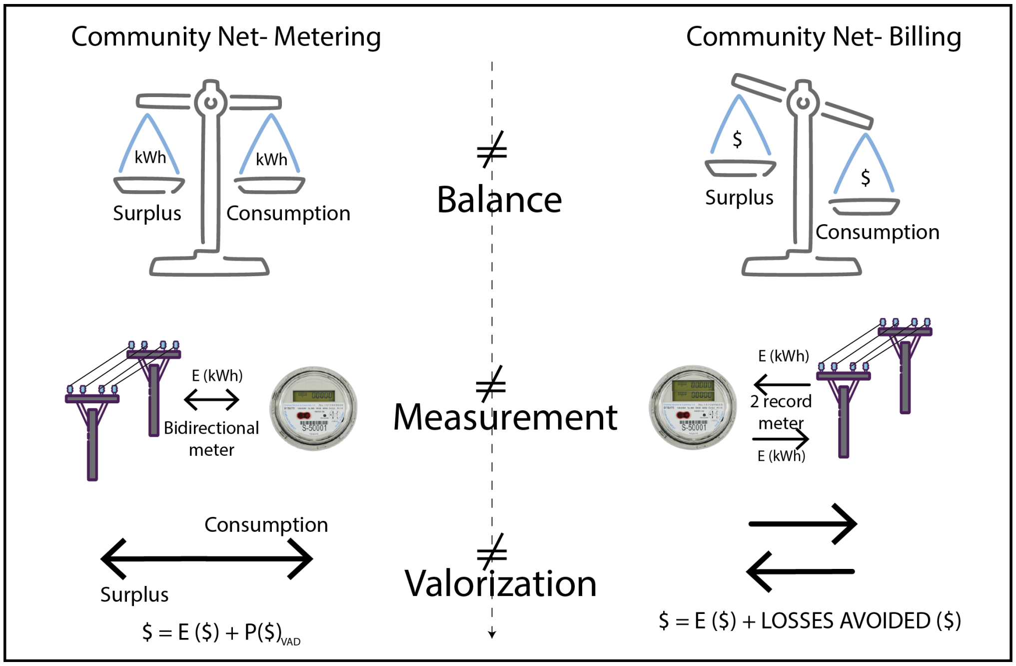


Figure 6-10: Differences and similarities between residential Net-Billing and residential Net-Metering throughout Chile by deploying MGs. Based on Watts, 2016.

- Community Net-Billing and Residential Net-Billing

By taking advantage of the lower investment costs of renewable technologies mainly (solar and wind) because subadditivity of costs, higher PV and wind solar capacity is installed in proportion to the demand in a grouped community of houses that in a single home. This allows solar PV to be installed in places with low irradiance (Coyhaique, Temuco, Osorno) and self-sufficiency. The same happens in the wind case. In spite of having a low wind resource (Osorno, Pichilemu), the lower investment costs allow to install a wind turbine and to supply a part of the demand. Figure 6-11 shows the differences between RNB and CNB in Monte Patria, Santiago, Concepción and Temuco

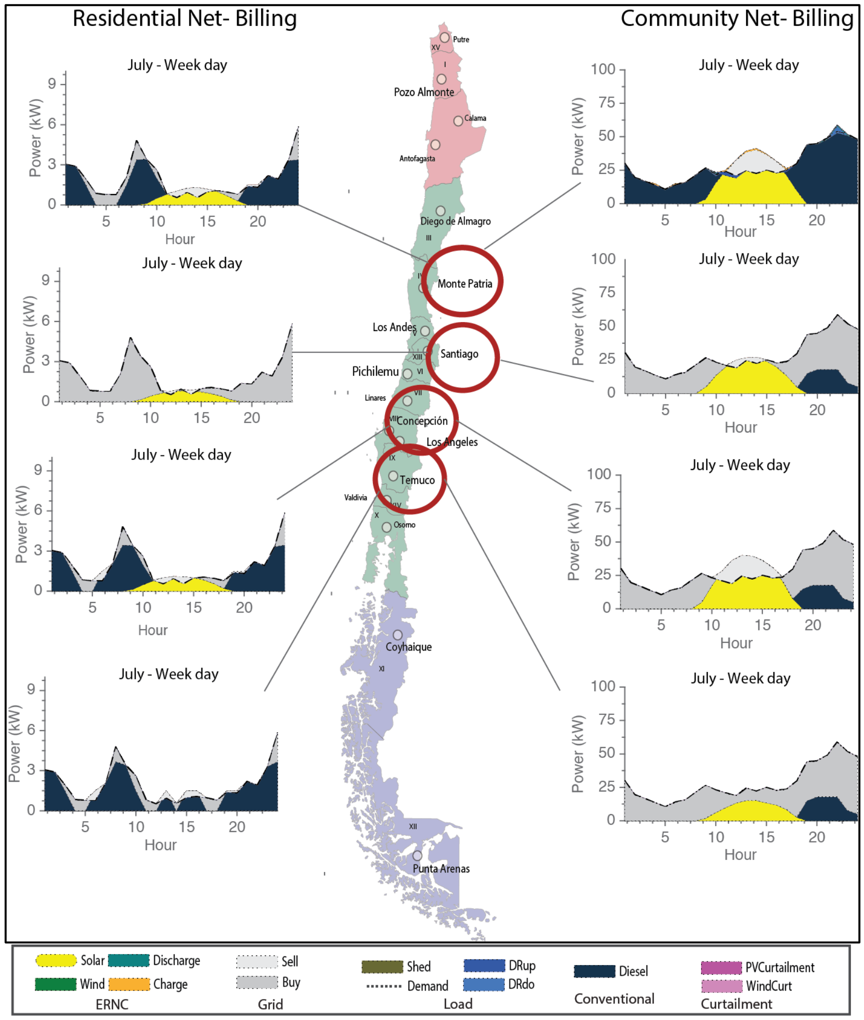


Figure 6-11: Differences between Community Net-Billing and Residential Net-Billing

- Large Distributed Generation and Community Net-Billing

The decision of whether LDG or CNB is appropriate will depend on injection prices (stabilized and Net-Billing), demand and energy purchase prices of the place. As in the comparison of community Net-Billing and residential Net-Billing, there is a difference of costs in the renewable deployment, allowing a subadditivity of costs in LDG in comparison with CNB. If there is a large plot of land and the stabilized price of the nearest trunk substation is high, it will be convenient to install a PMGD. In this way LDG is suitable mainly in areas where there is a good solar resource, demand is high (maximizing self-supply) and the injection price is not so much lower than the Net-Billing price.

- Community Net-Billing MG and community Isolated MG

In both business models, the self-sufficiency provided by renewable sources reduces the cost of supply of the micro grid. However, the Net-Billing community is backed up by the network in case there is any failure in some distributed energy resource.
Regarding installed capacity, more diesel capacity and greater storage capacity with batteries are needed in the isolated micro-grid, because it supplies most of the demand with diesel generation, batteries and demand management. Therefore, the average costs of supply will always be higher in the isolated case than in the Net-Billing case, unless the payment for consumption rating "peak present" is very expensive and the purchase of energy from the grid must be minimized.

- Small DG and Isolated Commmunity Micro Grids

The difference between SDG and IMG is that in the former, it is possible to buy energy from the grid if it is needed, but in both cases the surplus cannot be injected into the grid. This allows the community micro grid to know that they need to have the support of the network against contingencies. In this way, in areas with relatively cheaper energy and power purchase rates, it will always be more economically feasible to be connected to the distribution network. On the other hand, in areas with higher energy and power purchase rates, and in case there are no contingencies in distributed energy resources, it would be more economically feasible to disconnect from the grid or to minimize the purchase of energy. Figure 6-12 shows the differences in energy management in Pozo Almonte, Linares, Osorno and Valdivia and the average costs of supply.

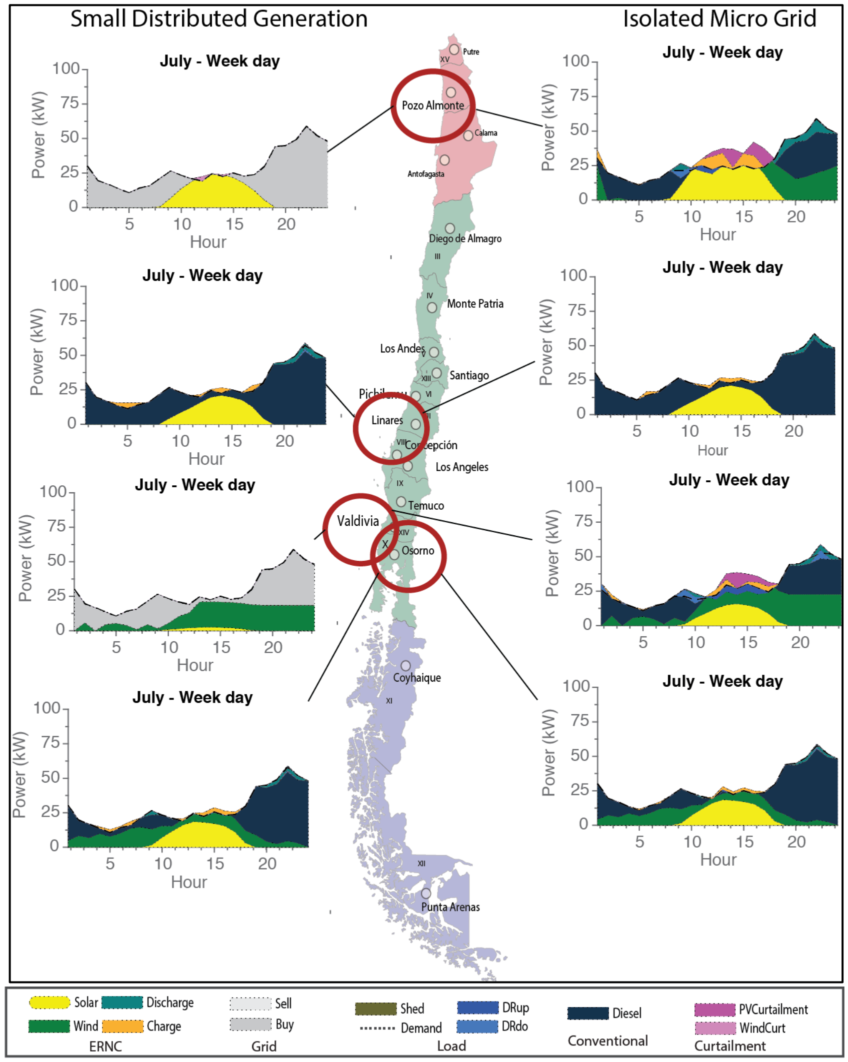


Figure 6-12: Differences between Community Small DG and IMG

- Solar PV deployment throughout Chile

Chile has a very good solar resource from Santiago to the North and even in several places in the South. This allows community and residential level to be economically viable to install solar panels for self-sufficiency. However, while demand is higher in community micro grids and therefore the installed capacity of renewable technologies goes up, taking advantage of the subadditivity of costs, the greater will be the self-sufficiency provided by solar PV allowing the deployment of photovoltaic technology in places with low irradiance (e.g. Coyhaique). Whilst in residential micro grids, average self-sufficiency is more expensive and therefore, it is only economically viable to install solar PV from the north up to Concepción. Figure 6-14 shows the percentages of solar PV installed capacity relative to the total installed capacity of each micro grid under CNB and RNB. Hence, community MGs allow solar PV deployment in almost every location in Chile.

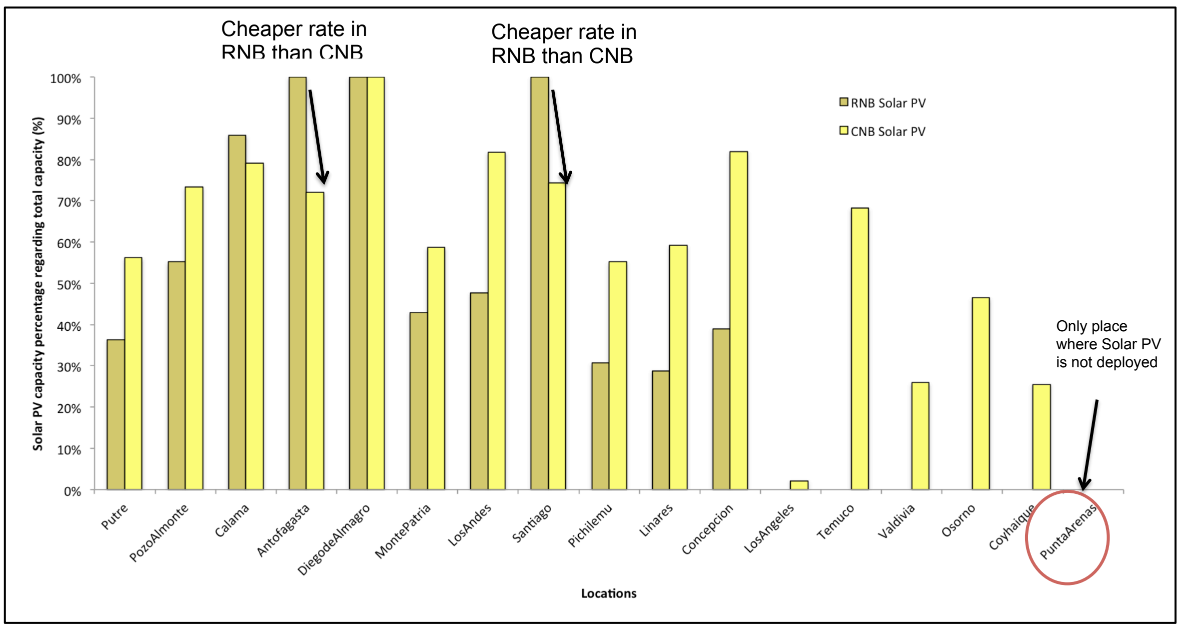


Figure 6-13: Solar PV installed capacity percentage regarding total installed capacity in RNB and CNB throughout Chile

- Wind Energy Deployment throughout Chile

In the case of wind energy, Chile has a very good wind resource mainly in the South and in several areas throughout Chile. This allows the community and residential level to be economically feasible to install wind turbines to self-supply part of the demand, and unlike solar PV, to reduce peak demand, partially or completely avoiding the use of diesel generation and the purchase of energy from the grid in sites with more expensive peak power rates for community micro grids. However, the volatility and intermittence of the wind resource does not allow an exact planning of the distributed energy resources, which implies an oversizing of the diesel generation and a minimum of energy coming from the network. Finally, Wind energy deployment is economically viable under Net-Billing scheme in community MGs located in Calama, Pichilemu, Los Angeles and from Valdivia to the south and in residential MGs located in Calama, Los Angeles, Valdivia, Coyhaique and Punta Arenas. Figure 7-13 shows wind energy deployment throughout Chile under Net-Billing scheme for CNB and RNB. As capital costs raise in RNB in comparison with CNB, it can be noted that there is effectively a lack of good wind resource or very volatile wind resource since it does not install at a residential level in Pichilemu and Osorno.

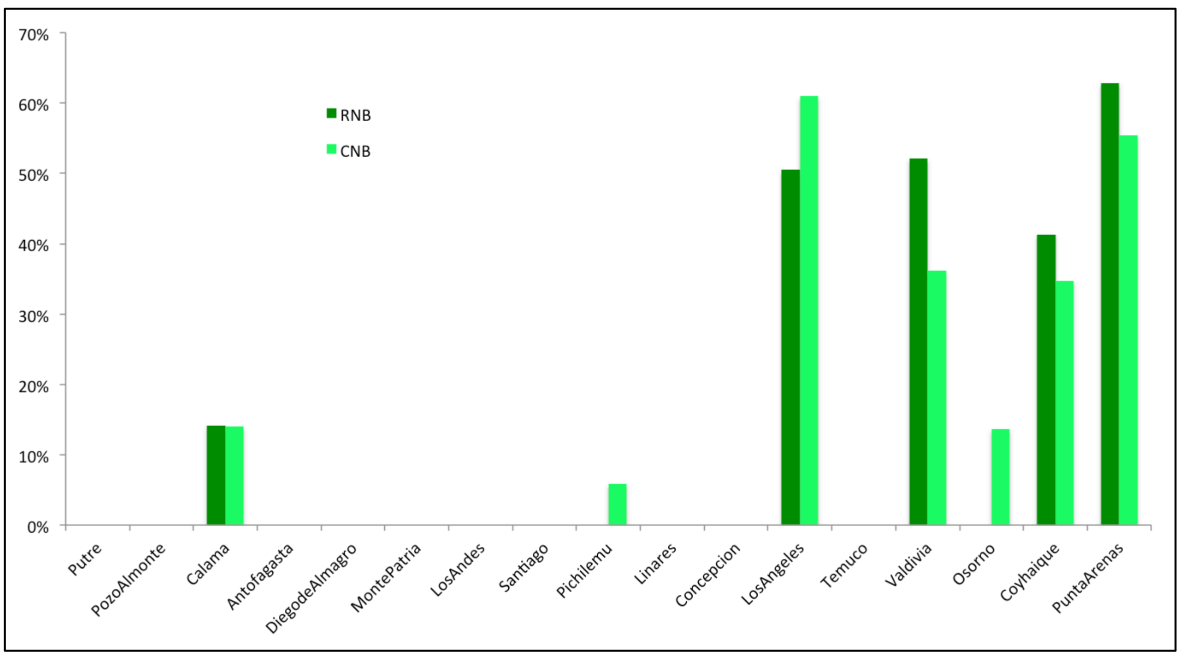


Figure 6-14: Wind energy installed capacity percentage regarding total installed capacity in RNB and CNB throughout Chile

- BESS deployment throughout Chile

Battery energy storage systems are an alternative for energy arbitrage. Thus, MGs could buy energy from grid when prices are lower and charge the BESS and then when prices are higher discharge the stored energy from BESS to supply part of the demand. However, BESS deployment depends on how much solar PV capacity is available and energy and peak power prices. If these latter are low and there is enough solar PV capacity, BESS deployment will not be economically viable. Unlike, when energy and peak power prices are high and there is enough solar PV capacity, BESS is a complementary alternative to Diesel generation and demand response programs to supply peak demand. However, BESS are still not the principal alternative to supply peak demand due to the following:

- High inflexibility due to slow state of charge (4 hours to charge-discharge)
- Low useful time (5000 cycles), which implies replacing in the short term and
- High capital cost (300 US/kWh)

Hence, diesel generation is still the first alternative to supply peak demand, followed by demand response programs and then BESS. Figure 7-16 shows the BESS operation in each typical day of each month in a year in Santiago under Isolated Micro Grid Business model. It can be seen that BESS is charged during diurnal hours where solar PV is available and discharged during peak demand hours. Also, in peak months in SIC (from April to September) during night, when electrical consumption is low, the BESS is charged with diesel generation to reduce the peak demand in peak hours and the diesel generation oversize.

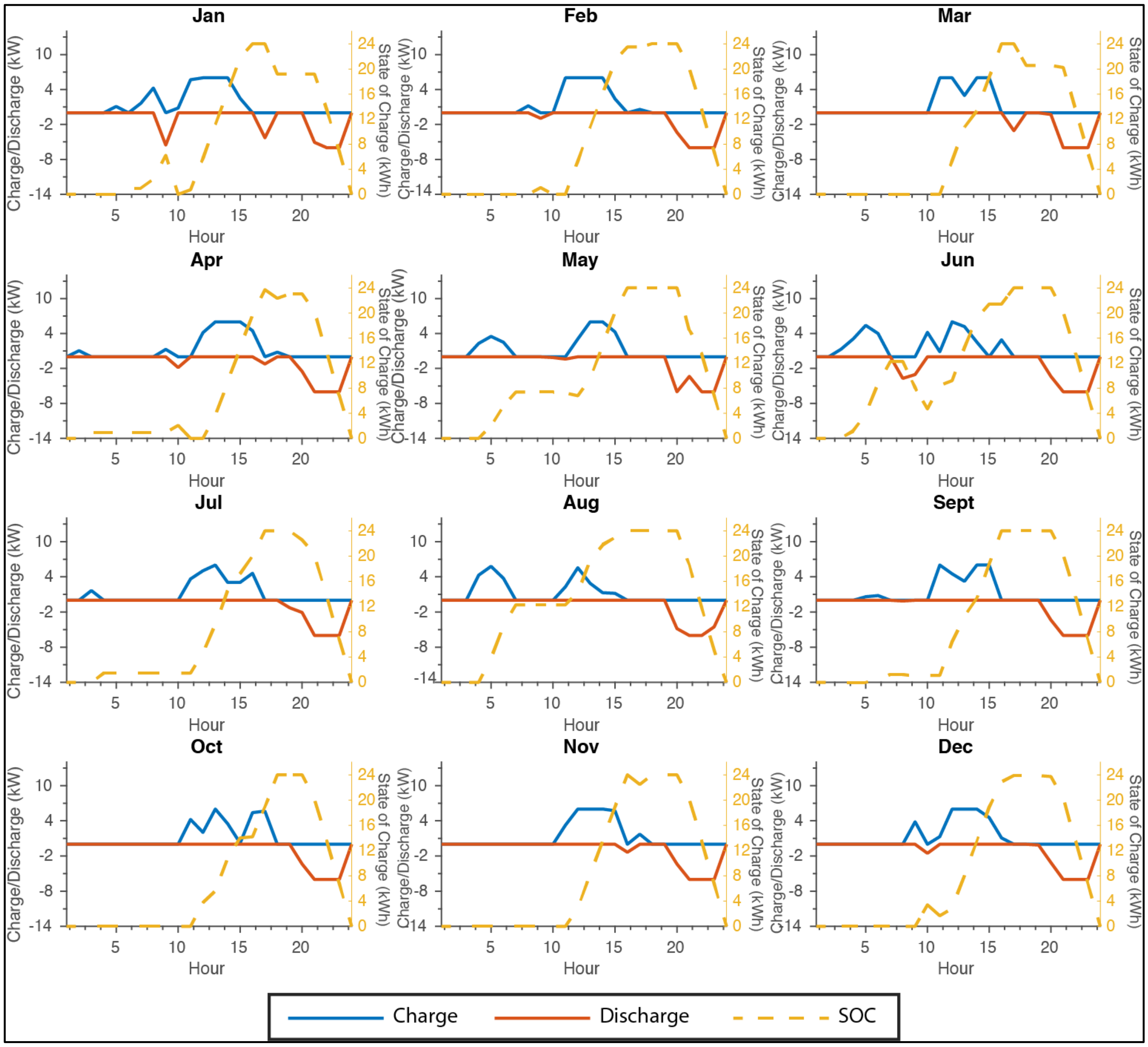


Figure 6-15: BESS operation in a community MG under Isolated scheme for 12 week days.

6.3 MG diesel generators inflexibility regarding costs

Diesel generators are fast enough to supply small demand ramps (30 kW - 60 kW). Cummins C55 (55 kVA) generators take eight seconds to start-up and operates at maximum load. In addition fuel usage does not exceed 0.3 lts at power-up. However, when it comes to larger ramps, higher diesel capacity is required, forcing the system to use the more flexible but more expensive diesel generator (it consumes more liters per kWh, around 0.28 l/kWh vs. 0.24 l/kWh of the generator more economical). Thus, the marginal cost of the diesel generator does not always correspond to the most economical diesel generator, even though it is the generator capable of providing an additional kWh in the next hour, but it is the least economical generator that provides the additional kWh due to the low flexibility of the economic generator. Thus, in a large part of the energy management, the economic diesel generator is the inframarginal generator, since it limits its production for lack of flexibility even when the generator is still able to provide the additional kWh, and the most flexible generator is the supramarginal generator as it provides additional kWh even though it is more expensive. This is also due to the fact that the less efficient generator has turn-on and turn-off costs and a minimum power to ignite (10 kW) and therefore, in addition, turning off the machine or turning it on at a technical minimum means higher costs than providing the kWh with the most efficient generator. This can be seen in Figure 6-17, which shows the horizontal static supply curves (i.e. without ramp or on/off constraints) and the sum of diesel generation in each hour of the energy management of the micro grid (points).

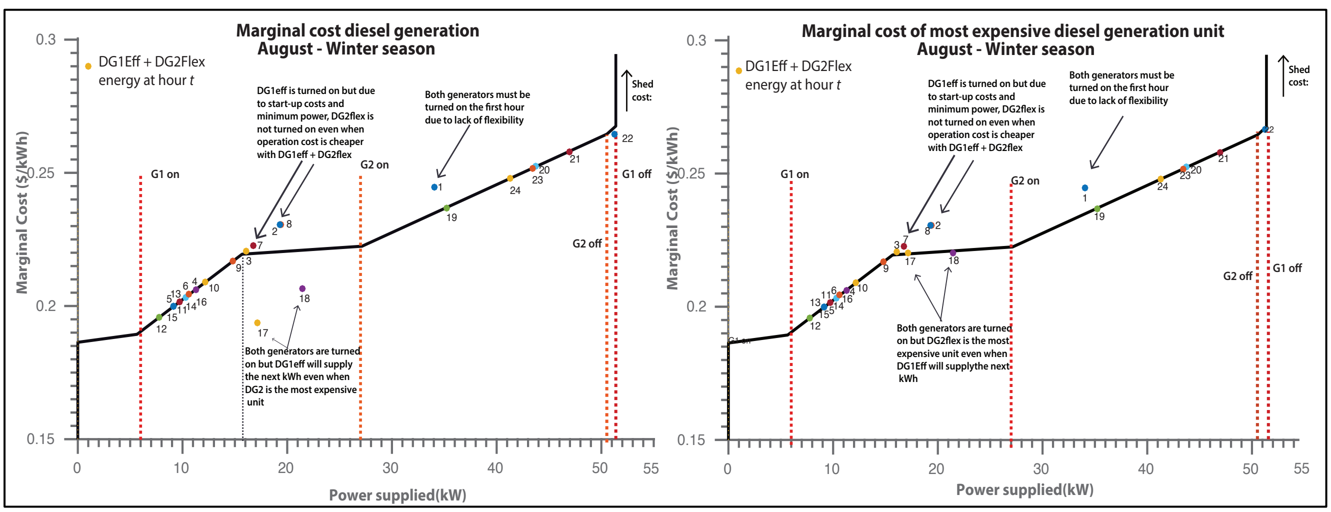


Figure 6-16: Marginal cost of diesel generation and marginal cost of most expesive unit In Temuco under IMG business model in a week day

6.4 Demand response: peak shaving by moving flexible demand to sunny hours

Demand management programs allow the movement of flexible loads at peak hours (20% of hourly demand) where the decision to buy energy from the grid could mean a higher cost given the context of Chilean regulation (similar to a critical peak pricing during 6 hours of the day) to hours where there is greater solar resource (e.g. 10:00-17:00 hrs.). However, to manage the demand it is necessary to have a good solar resource in the site and power and energy purchase prices are enough expensive to use demand management programs efficiently. In the Net-Billing model, even when surpluses can be injected into the network and revenue is generated, it is more economically feasible to move flexible load to reduce the peak power and thus avoiding a more expensive. In summary, demand response programs are feasible only if there is enough solar PV and consumers are proactive and organize their schedule according to peak demand charges. However, demand response is only cost-effective when there is enough solar PV capacity because flexible loads can be rescheduled to be used during 10:00 a.m. to 6:00 p.m. Hence, the benefits of DR depend on how much solar PV capacity is available.

Figure 6-18 shows the effect of demand management for the community micro grid located in Calama evaluated under the Net-Billing scheme.

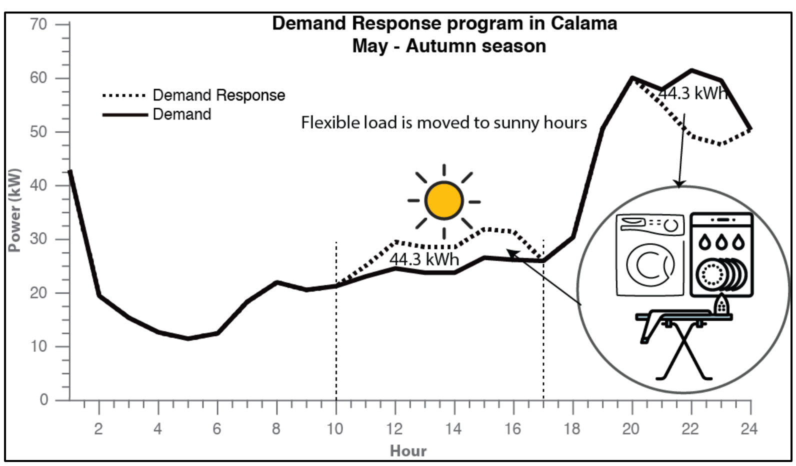


Figure 6-17: Flexible load rearrangement with demand response program in Calama under Net-Billing MG business model

6.5 Peak demand reduction with several technologies under peak power charges

Under the context of the currently regulated tariffs BT2 and BT3 in Chile, the community micro-grid, depending on where it is located and the interconnected system to which it belongs, will maximize peak shaving during peak hours (18:00 – 23:00) if peak rates are expensive to avoid that the consumption is rated as "present in peak demand" and pay a higher price for the power contracted or measured. In this way, when the power purchase fee is very expensive, it is more economically viable to reduce peak demand with diesel generation, demand management programs and energy storage systems. Figure 6-19 shows the comparison of the effect of the peak power charge in the energy management of the community micro grid located in Santiago under the Net-Billing scheme for a peak month (April) and a non-peak month (March). Thus, reducing the purchase of energy from the grid during the first peaking month of the year (April for the case of SIC) avoids the payment of the most expensive charge for power. In contrast, in the non - peak months for the SIC (March - summer in the figure) the purchase of energy is maximized, since in the case of Santiago the energy purchase rate is relatively cheap (0.09 US / kWh). The aim of the community micro grid located in Santiago is, therefore, the reduction of peak demand in the peak months with any technology that allows supplying that lack of energy.

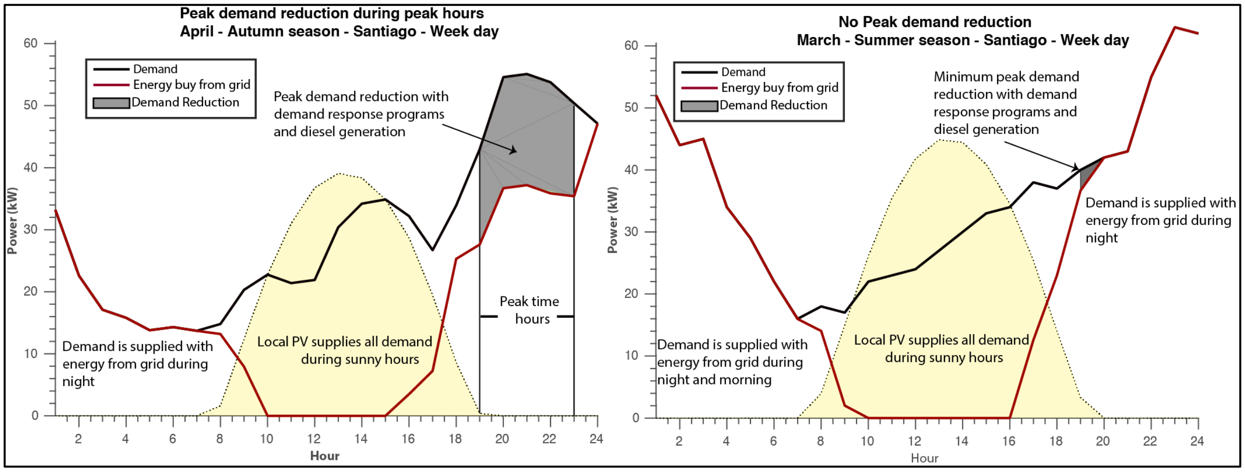


Figure 6-18: Comparison of Peak shaving during peak and no peak months in Santiago under Net-Billing business model

7. CONCLUSIONS OF COMMUNITY AND RESIDENTIAL MICRO GRID PLANNING AND EVALUATION UNDER DIFFERENT BUSINESS MODELS

This investigation shows the planning of community and residential micro grids in terms of optimum sizing and operation to reduce supply costs throughout Chile, from Putre to Punta Arenas. Renewable resources (solar and wind) were considered unique for each zone, diesel oil prices and prices for the purchase and sale of energy to the grid as well as prices for peak power payment in the case of BT2 and BT3 tariffs. Each community consists of 15 houses with a peak power of 69 kW and an annual energy consumption of 273 MWh, while the residential demand corresponds to the consumption of a house that has its power limited to 10 kW, a peak demand of 7.5 kW and an annual consumption of 18 MWh, as it opts for a BT1 tariff with dynamic prices and has an annual consumption of energy equivalent to 10 MWh.

Both in community and residential micro grids, it is feasible to self-supply demand through renewable sources to supply part of the demand in daytime for solar PV and throughout the day in the case of widn energy. This allows to displace generation or more expensive supply (network and diesel) for cheaper renewable generation which reduces the cost of supply of the micro grid. However, since investment costs are lower at the community level, solar PV self-supply varies in comparison with residential level. Thus, in the community micro grid solar PV is installed from Putre (6.81 kWh / m2-day) to Coyhaique (4.11 kWh / m2-day) while in the residential micro grid it is installed from Putre to Concepción (4.6 kWh / M2-day). Thus, Solar PV deployment is economically viable to self-supply part of the demand from Putre to Coyhaique in community MGs and from Putre to Linares in residential MGs.

In the case of wind energy, the variation is smaller, but in the residential case only wind turbines are installed in areas with good resource. Therefore, in the areas of Pichilemu and Osorno wind turbines are not installed at residential level, whereas if it occurs at community level. Wind energy deployment is economically viable to self-supply part of the electrical consumption from Osorno to Punta Arenas in community MGs and from Valdivia to Punta Arenas in residential MGs.

For community micro grids, the business models considered to evaluate the long-term planning were Net-Billing, Net-Metering, PMGD, Norma-4 and isolated. The results were grouped into families of solutions according mainly to the levels of purchase / sale of energy and power payments (qualifying consumption as present in peak time or partly in peak time).

Three families of solutions were determined for the operation of the community micro grid: i) Micro grid is highly comprised of renewable resources that self-supply demand during some hours of the day and due to the high prices peak power rates, peak demand is reduce mainly with both diesel generation and Demand management. Hence, the most expensive payment for power is avoided. Then, in the second family of solutions ii) the renewable self-sufficiency is used during some hours of the day, and given the high prices of peak power rates the purchase of energy from the network is minimized, avoiding a higher payment of power. In this sense, the option of disconnecting the micro grid from the network could be evaluated and energy could still be injected in case of surpluses. Finally, third family solution corresponds to iii) self-supply with renewable generation is used during some hours of the day, and given the low energy and power prices, the rest of the demand is supplied with energy from the grid.

For residential micro grids, the business models considered to evaluate the long-term planning were Net-Billing and Net-Metering. The evaluation of these throughout Chile under the residential scheme allowed to describe the operation and behavior of each micro-grid in five different families of solutions: i) the renewable self-sufficiency is used during some hours of the day, and due to the high prices of the dynamic tariffs, diesel generation is used to reduce peak demand, avoiding the payment of centralized energy supply during peak hours. Then, in the second family of solutions ii) the renewable self-sufficiency is used during some hours of the day, and given the higher prices of energy of the dynamic tariffs regarding the previous family, the purchase of energy from the upstream network is minimized by supplying the rest of the demand with diesel generation.

In the third family of solutions iii) the renewable self-sufficiency is used in daytime, and due to the low prices of dynamic tariffs, the rest of the demand is supplied with energy from the network.

In the fourth family of solutions iv) the renewable resource is low and no renewable technologies are installed. However, the prices of the dynamic tariffs are high and, therefore, diesel generation is installed to reduce peak demand. Finally, in the fifth family of solutions there is something similar to the previous family, v) the renewable resource is low and renewable technologies are not installed to self-supply a part of the demand, and the prices of the dynamic tariffs are high. Hence, micro grid minimizes the purchase of energy from the grid at all times, supplying most of the demand with diesel generation.

The families of solutions for community and residential micro grids allow to dimension the operation of each of them evaluated under different business models throughout Chile. However, different results were found in each of the evaluated areas: installed capacity, use of diesel generation, demand management or battery energy storage sytstems to reduce peak demand, centralized supply from the grid, among others. Thus, it is also possible to differentiate the micro and residential networks evaluated under the business models previously explained in terms of average costs of supply, energy level of each technology, net present value of the investment, operation and maintenance of each micro grid, return on investment, incremental rate of return, among others.

The development of community and residential micro grids connected to the distribution network allows reducing peak demand. Hence, reducing the average cost of supply and generating savings for the community or residence in the long term. The latter varies depending on the business model evaluated. In addition, the use of diesel technology and demand management allows to flexibilize energy consumption and supply demand ramps when there is a lack of renewable resources and supply peak generation when demand and energy prices and power payments are high. Thus, micro grids connected to the network can buy energy from the grid when demand and energy prices are low. For residential micro-grids, dynamic tariffs also make possible to avoid a higher energy payment by peak shaving this demand with diesel generation.

Thus, the micro grid with lower levelized cost of energy of solar PV technology is located in Calama (community: 93 US / MWh; residential: 103 US / MWh), given the high solar resource of the area. Regarding wind technology, the lowest levelized cost of energy was recorded in Punta Arenas and Los Angeles (community: 120 US/MWh; residential: 150 US / MWh). In the case of diesel generation, the lowest levelized cost of energy of efficient diesel generator (170 US / MWh) was registered in Los Angeles, due to lower fuel prices, while the more flexible generator with lowest levelized cost of energy (220 US / MWh) Was registered in the same place. Finally, regarding battery energy storage systems, the lowest levelized cost of energy was recorded in Putre (170 US / MWh), given the high prices of diesel fuel, good solar resource in the area and high energy prices.

The micro grid evaluated under Net-Billing with lowest average cost of supply is located in Los Angeles (135 US / MWh). The same happens in the case of community Net-Metering (135 US / MWh), given the great wind potential of the area. In the community micro grid evaluated under norma-4, the location with the lowest average cost of supply is Diego de Almagro (143 US / MWh), given the great solar potential and low energy purchase and peak power prices. Regarding the development of micro grids with PMGDs, the lowest average cost of supply was obtained in Los Andes (12 US / MWh), due to the great solar potential of the zone, besides a higher price stabilized to inject energy surpluses regarding other areas. Finally, the lowest average cost of supply recorded in an isolated micro grid was obtained in Los Angeles (164 US / MWh).

Regarding residential micro grids, the lowest average cost of supply under a Net-Billing scheme was obtained in Diego de Almagro (155 US / MWh) due to good solar resource and low energy retail prices. On the other hand, in a Net-Metering scheme the lowest average cost of supply was registered in Linares (-274 US/MWh) due to high retail energy prices and hence, high injection energy surplus price due to Net-Metering scheme.

Given the values of average costs of supply of the community and residential micro grid long-term planning, it was possible to classify and compare the different business models that were used for the evaluation of micro grids. In this way, there are few

differences between a Net-Billing scheme and a Net-Metering scheme at the community level, given the similar value of energy injection to the grid.
On the contrary, the differences between a Net-Billing scheme and a Net-Metering scheme at the residential level are significant, since the valuation of the energy injection to the network in the Net-Metering case is about double the Net- Billing, allowing a greater local development of renewable generation.

The Community Net-Billing Scheme, being limited to 100 kW, does not allow more renewable generation (RES) to be installed in areas where there is a good solar and wind resource (e.g. Calama). The high investment costs and the low flexibility of energy storage systems force the micro-grid to use diesel generation in places where peak power payment is relatively high. In addition, in places where energy purchase and peak power rates are higher, one of the solutions is to reduce purchasing power as much as possible, since there are sufficient technologies to support generation deficits while still taking advantage of energy exports to the grid, which in principle, in places with high radiation and high wind speed, it is profitable to sell a kWh to the network from a renewable technology. While in places with a lack of solar and wind resource (e.g. Coyhaique, Temuco, Osorno), the injection rate is not sufficient to pay the additional kWh of the renewable generation.

In the case of Net-Metering, even when capacity is limited to 100 kW, it is possible to install more capacity than necessary in areas where there is a good solar or wind resource (e.g. Calama, Diego de Almagro, Punta Arenas, among others.
Even though the injection rate is equivalent to the purchase rate, diesel generation is still needed in most of communities to reduce peak demand.

In the case of SLG, the aim is to self-consume all the energy that is generated, and buy the network the deficit. In this way, in places with good solar radiation (e.g. Calama) solar PV is installed to allow the battery to be charged and used at peak times where peak power rates are higher.

In the case of LDG, in the same way as the other cases, diesel generation is needed to satisfy part of the peak demand and thus avoiding a higher payment for peak power. LDG is economically viable when it is a self-sufficient plant that can inject surplus to grid.

In the IMG case, the micro network is totally disconnected from the network and there is no local centralized supply option. Therefore, the comparison between sites is if the investment, operation and maintenance costs are more convenient when there is renewable resources availability. Hence, community MGs under IMG installs DERs as much as possible to supply the demand and in case there are energy surpluses, energy storage systems are used to discharge them in hours that demand is greater.

In summary, this paper shows that for community and residential micro grids it is possible to self-supply demand through RES. Development of such a grid system, when connected to a distribution network, enables a reduction in peak-time demand and overall supply cost.

MG business models were evaluated for seventeen locations in Chile. They were representative of diverse geographic and climatic conditions, providing a national context for our examination, the results of which can be extrapolated to inform similar pursuits on an international level.

Another important aspect of our findings is the potential for consumers to sell back energy surpluses, in both single-dwelling and community settings. By exporting energy to the grid, especially in locations with high radiation or wind speed, renewables can be not only more efficient, but also profitable.

The results of our investigation indicate that energy self-sufficiency is economically viable with multiple micro grid deployment throughout Chile. However, the ramifications of this research have a usefulness which is worldwide.

8. FUTURE WORK

According to the results obtained from the optimal design and operation of each community and residential micro grid evaluated through different business models, the future work that is needed to deploy micro grids in the selected areas is summarized in the following ideas:

- Obtain electricity consumption every 15 minutes for a one year horizon of each community and residential in the areas evaluated, in order to size each micro grid taking into account demand variations.
- Stochastic modeling for renewable resources (solar and wind), in order to measure the seasonality and temporality of the resource.
- Incorporate heat consumption and Carbon heat and power (CHP)
- Obtain real measured data in-situ, such as wind series and solar irradiance profiles, in addition to diesel costs. Also know the currents costs of the equipment and the technical implications of the micro grid such as wiring losses, MPT efficiency, inverters, etc. In addition, optimize the operation of the system for a full year considering the current conditions facing the system that may affect its operation.
- Evaluate BT4 rates for optimum sizing for different micro grids.

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A P P E N D I C E S

APENDIX A: COMMUNITY AND RESIDENTIAL MICRO GRID PLANNING ANALYSIS

We describe the optimal sizing and energy management for the evaluation of the aforementioned business models for residential and community micro grids located throughout Chile. This shows the installed capacity and power factors of each technology, the annualized investment, operation, maintenance and total costs for each micro-grid, the levelized energy cost for each technology, average costs of supply and the energy generated monthly and also annually, years of return on investment, internal rate of return and annual equivalent cost.

1. Optimal Sizing and Energy Management for Community Net-Billing

The economic viability of developing community micro grids under the Net-Billing scheme depends primarily on the renewable resource availability in the area and on energy purchase / sale prices and peak power tariffs. In this way, the optimum sizing and operation of the micro grid is obtained under a scheme that only pays the energy component of the energy injection to the grid.

a) Scenarios operation and energy management of each MG

The operation of the micro-net under the Net-Billing scheme can be classified into four possible operating scenarios and vary from place to place depending on the factors mentioned above:

- **Micro grid is a solar or wind community connected to the grid that reduces peak demand**: it uses solar or wind energy to self-supply and inject surpluses into the grid and also manages demand efficiently to make load shifting and uses diesel generation for peak shaving because the purchase prices of energy and power of the network are expensive. This occurs in Calama, Antofagasta, Pozo Almonte, Los Andes, Santiago, Concepcion, Temuco and Punta Arenas.

- **Micro grid is a solar community connected to the network**: it uses the good solar resource to self-supply demand and inject the surplus to the grid and the rest of the demand is supplied with energy from the grid since the energy and power purchase prices are more economical. Case of Diego de Almagro.
- **Micro grid is a community of distributed energy resources that minimizes the purchase of energy to the grid**: it uses the solar or wind resource, demand management and diesel generation to supply most of the demand. In this way it minimizes the purchase of energy to the grid given the high prices of energy and power purchas from the grid. Cases of Monte Patria, Putre, Pichilemu, Linares, Los Angeles, Valdivia, Osorno and Coyhaique.

b) MG Size and annualized cost of investment, operation and total costs of DERs

Regarding installed capacity in the micro grid under Net-Billing business, solar PV is installed throughout most of Chile: from Concepción to Putre with power factors between 18% and 24%, the maximum being The case of Calama that has a high irradiance (7.44 kWh / m2-day). In some cases in the south where the available solar resource is lower (Temuco and Valdivia) it is economically feasible to supply demand with PV solar generation, but with power factors of 15%. Finally, in other cases where the irradiance and production is even lower (Coyhaique and Osorno), it is still economically feasible to self-supply with power factors of 14%

Regarding wind energy, wind turbines are installed mainly in southern Chile where there is a good wind resource (Pichilemu and Los Angeles to the South), allowing to supply demand most of the day. Its power factors range from 25% (e.g. Osorno) to 49% (e.g. Punta Arenas).

Regarding BESS, they are installed in places where peak power is reduced, where there is a good renewable mix and the price of diesel fuel is relatively high (eg Monte Patria, Putre, Osorno and Coyhaique), since it allows charging the battery in daytime with solar generation and discharge it in hours of peak demand.

Regarding diesel generation, it is installed in all evaluated areas except in communities that pay cheap energy and power prices (e.g. Diego de Almagro). It is the most economical technology to reduce peak demand at times that there is no available solar resource and to meet demand in case of reducing peak power to the maximum. For cases of good solar resource, but where energy and power purchase rates are not relatively high, it is sufficient to reduce peak demand with diesel generation.

Obviously, in places with higher energy and power purchase rates (e.g. Putre, Monte Patria, Pichilemu, Linares, Los Angeles, Valdivia, Osorno and Coyhaique). Over-energized resources are over-installed to minimize measured demand or contracted power. On the other hand, in places with cheaper purchase rates (e.g. Los Andes, Santiago, Antofagasta, Pozo Almonte, Concepcion, Temuco and Punta Arenas), there is no need for so much generation installed capacity, except for diesel generators to reduce peak demand and reduce Costs for community. Finally, in places with even cheaper energy and power purchase rates (e.g. Diego de Almagro), the most expensive power tariff is paid and the available solar resource in the area is used to install solar PV.

The lower energy and power tariffs allow a lower investment in distributed energy resources, such as Diego de Almagro (0.03 US / kWh), Punta Arenas (0.04 US / kWh), while higher energy and power tariffs prices implies a greater investment in DERs, such as Monte Patria, Los Angeles, Valdivia, Osorno and Coyhaique (0.21 US / kWh).

Table 6-3 summarizes power factors, optimal installed capacity (S) for each location, and annualized costs ($ MUSD / year) of investment (I), operation and maintenance (OM), total costs and average costs.

Table 1-1:
CNB MG Size: Installed capacity of Solar PV, Wind, BESS, DG1eff & DG2flex ,power factors, investment, operational and total annualized costs

	Solar PV					Wind					BESS					DG1Eff					DG2Flex					MG DGs Total					
	f	S	I	M	T	f	S	I	M	T	f	S	I	M	T	f	S	I	OM	T	f	S	I	OM	T	f	S	I	OM	MG	Mean
Locations	%	kW	$	$	$	%	kW	$	$	$	%	kWh	$	$	$	%	kW	$	$	$	%	kW	$	$	$	%	kW	$	$	$	$/kWh
Putre	22	100	15	1	17	0	0	0	0	0	17	14	1	0	1	30	39	2	21	23	30	25	1	14	15	25	167	19	36	55	0.20
PozoAlmonte	22	52	8	1	9	0	0	0	0	0	0	0	0	0	0	15	19	1	5	6	0	0	0	0	0	19	71	9	6	15	0.05
Calama	24	85	13	1	14	33	15	5	1	6	0	0	0	0	0	11	7	0	1	2	0	0	0	0	0	23	107	18	4	22	0.08
Antofagasta	19	51	8	1	9	0	0	0	0	0	0	0	0	0	0	15	20	1	5	6	0	0	0	0	0	17	71	9	6	15	0.05
DiegodeAlmagro	23	55	8	1	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	55	8	1	9	0.03
MontePatria	19	100	15	1	17	0	0	0	0	0	17	4	0	0	0	29	40	2	21	23	29	26	1	15	16	24	167	19	37	56	0.21
LosAndes	21	100	15	1	17	0	0	0	0	0	0	0	0	0	0	10	10	0	2	2	8	13	1	2	2	13	122	16	5	21	0.08
Santiago	18	65	10	1	11	0	0	0	0	0	0	0	0	0	0	9	10	0	2	2	8	13	1	2	2	12	88	11	4	15	0.06
Pichilemu	18	90	14	1	15	27	10	3	1	4	0	0	0	0	0	30	39	2	20	22	26	25	1	12	13	25	164	20	34	54	0.20
Linares	18	100	15	1	17	0	0	0	0	0	0	0	0	0	0	30	42	2	21	23	28	27	1	14	15	25	169	19	36	55	0.20
Concepcion	18	100	15	1	17	0	0	0	0	0	0	0	0	0	0	9	10	0	2	2	8	13	1	2	3	12	122	16	5	21	0.08
LosAngeles	18	3	1	0	1	46	97	30	8	38	0	0	0	0	0	18	36	2	10	12	18	23	1	7	8	25	158	33	25	58	0.21
Temuco	15	48	7	1	8	0	0	0	0	0	0	0	0	0	0	10	10	0	2	2	8	13	1	2	2	11	71	9	4	13	0.05
Valdivia	15	42	6	1	7	38	58	18	5	23	0	0	0	0	0	21	37	2	16	17	19	24	1	10	11	24	161	28	31	58	0.21
Osorno	14	77	12	1	13	25	23	7	2	9	20	1	0	0	0	28	40	2	21	23	24	26	1	12	13	22	166	22	36	58	0.21
Coyhaique	15	42	7	1	7	38	58	18	5	23	15	2	0	0	0	21	40	2	15	17	17	25	1	8	10	21	165	28	28	56	0.21
PuntaArenas	0	0	0	0	0	49	23	7	2	9	0	0	0	0	0	5	6	0	1	1	5	13	1	1	2	19	42	8	4	12	0.04

c) MG energy generation to supply community demand consumption

The energy production of renewable technologies that comprise each micro grid depends mainly on the availability of the solar and wind resource of the area. If you have a low-resource renewable scenario, you can supply the demand by purchasing energy and power from the grid or by using diesel generators.

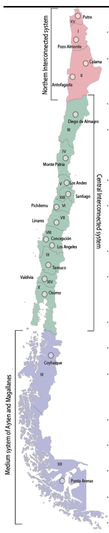
When there is a good solar resource (i.e. Calama), the production of energya comes mainly from solar PV ranging from 60% of energy regarding demand for one day of the week of May (Autumn season) and 63% On a weekday type of the month of January (Summer season). At the same site, wind generation accounts for 15% of demand in one typical weekday of summer and 16% of demand in one typical weekday of autumn. The

sum of renewable generation, not counting surpluses that are injected into the grid, allows 50% self-sufficiency in the summer case and 48% in the case of autumn.
Moreover, the purchase of energy from the grid represents 50% of the energy demanded in the summer case, and 48% in the case of autumn. This slight difference is mainly due to the need of peak shaving and to avoid paying a more expensive power purchase fee.
Table 6-5 summarizes the energy generated and the representation of the energy demanded in the case of Calama for a summer month and a month of Autumn. Then, the same is done for the 12 months of the year and the percentages can be seen in table 6-4, which summarizes the total generation by technology for each location and the percentage that represents regarding demand.
In places with high energy and power rates (Putre, Monte Patria, Linares, Linares, Osorno, Los Angeles, Coyhaique and Valdivia) the diesel generation is provided from both the economic generator and the flexible generator, and contributes from 33% (Los Angeles, Coyhaique and Valdivia) to 64% (Linares) of energy to supply the demand. In these same places, the purchase of energy and power is low ranging from 0.01% to 0.03% of energy to supply the demand.
In places with cheaper power purchase prices than the aforementioned places, the diesel generation comes from the cheaper but less flexible generator, which contributes from 1% (Punta Arenas) to 10% (Antofagasta) of energy to supply demand and from the most flexible generator that contributes from 2% (Punta Arenas) to 3% (Temuco, Los Andes, Santiago and Concepción).

On the other hand, in places where power purchase prices are cheaper, most of the demand is supplied by the grid reaching 68% of demand (i.e. Diego de Almagro).

The total demand in the 24-day horizon time corresponds to 21 MWh. In places with good solar resources (Santiago to the North), community demand is mainly supplied by solar PV generation in daytime from 37% self-supply to 63%.

Table 1-2
MG Energy consumption under CNB mode: Energy generated during horizon time and its percentage regarding demand in each location



Energy	LOAD				GRID				ERNC								CONV			
Locations	Shed		DR		Purchased		Sold		Solar PV		Wind		ERNC Self-consumption		BESS		DG1EFF		DG2FLEX	
	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%
Putre	0.0	0%	0.4	2.0%	0.0	0.03%	-5.7	32%	12.9	71%	0.0	0%	7.2	40%	0.005	0.03%	6.7	37%	4.3	24%
PozoAlmonte	0.0	0%	0.2	1.1%	10.6	58%	-0.7	4%	6.6	36%	0.0	0%	5.8	32%	0.0	0%	1.7	9%	0.0	0%
Calama	0.0	0%	0.3	1.9%	8.7	48%	-5.6	31%	11.6	64%	2.9	16%	8.9	50%	0.0	0%	0.5	3%	0.0	0%
Antofagasta	0.0	0%	0.2	0.8%	11.1	61%	-0.4	2%	5.7	31%	0.0	0%	5.3	29%	0.0	0%	1.7	10%	0.0	0%
Diego de Almagro	0.0	0%	0.0	0.0%	12.2	68%	-1.3	7%	7.1	39%	0.0	0%	5.8	32%	0.0	0%	0.0	0%	0.0	0%
MontePatria	0.0	0.%	0.4	2.0%	0.0	0%	-4.1	23%	11.2	62%	0.0	0%	7.1	39%	0.0	0%	6.7	37%	4.3	24%
LosAndes	0.0	0%	0.1	0.4%	10.3	57%	-5.3	29%	11.9	66%	0.0	0%	6.6	37%	0.0	0%	0.5	3%	0.6	3%
Santiago	0.0	0%	0.1	0.5%	11.3	62%	-0.9	5%	6.7	37%	0.0	0%	5.7	32%	0.0	0%	0.5	3%	0.6	3%
Pichilemu	0.0	0%	0.3	1.8%	0.0	0%	-3.5	19%	9.5	52%	1.5	8%	7.5	42%	0.0	0%	6.8	38%	3.8	21%
Linares	0.0	0%	0.3	1.5%	0.0	0%	-3.6	20%	10.1	56%	0.0	0%	6.5	36%	0.0	0%	7.2	40%	4.4	24%
Concepcion	0.0	0%	0.1	0.5%	10.5	58%	-3.8	21%	10.3	57%	0.0	0%	6.5	36%	0.0	0%	0.5	3%	0.6	3%
LosAngeles	0.0	0%	0.2	0.9%	0.0	0.03%	-13.7	76%	0.3	2%	25.5	141%	12.2	68%	0.0	0%	3.6	20%	2.3	13%
Temuco	0.0	0%	0.1	0.4%	12.9	72%	0.0	0%	4.1	23%	0.0	0%	4.0	22%	0.0	0%	0.6	3%	0.6	3%
Valdivia	0.0	0%	0.2	1.0%	0.0	0.02%	-5.7	31%	3.7	20%	12.8	71%	10.8	60%	0.0	0%	4.6	25%	2.7	15%
Osorno	0.0	0%	0.2	1.3%	0.0	0.02%	-1.4	8%	6.3	35%	3.2	18%	8.1	45%	0.0	0%	6.4	36%	3.5	20%
Coyhaique	0.0	0%	0.2	1.1%	0.0	0%	-5.3	29%	3.6	20%	12.7	70%	11.0	61%	0.0	0%	4.7	26%	2.4	13%
PuntaArenas	0.0	0%	0.2	1.0%	11.4	63%	-0.3	2%	0.0	0%	6.5	36%	6.2	34%	0.0	0%	0.2	1%	0.3	2%

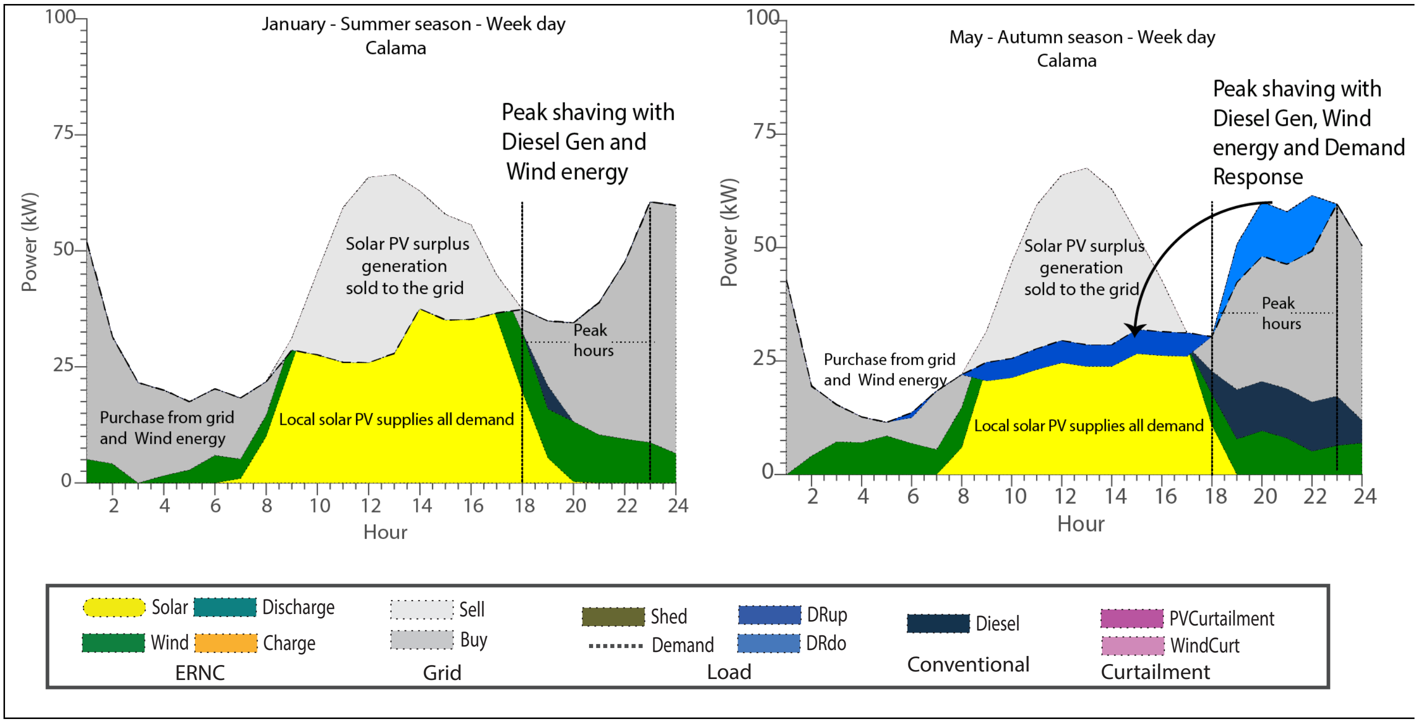


Figure 1-1: Micro Grid Energy Management in Calama: Winter and Summer week days

Table 1-3:
MG Energy consumption under CNB mode: Energy generated during a typical summer day and autumn day and each percentage regarding demand in the case of Calama

		kWh	%	+%	kWh	%	+%
ERNC	Solar	502	63%	**50%**	446	60%	**48%**
	Wind	118	15%		120	16%	
	BESS	0	0%		0	0%	
CONV	Diesel	0	0%	**0%**	28	4%	**9%**
GRID	BUY	**395**	50%	**50%**	**355**	48%	**48%**
	SELL	(218)	28%	-	(208)	(28)%	-
LOAD	DR	0	0%	**0%**	58	6%	**6%**
	SHED	0	0%		0	0%	
	Demand	797	100%	**100%**	742	100%	**100%**

i) Detailed daily operational costs for the case of Calama

The community micro grid located in areas where there is a good renewable resource (e.g. solar or wind) as the case of Calama, tends to self-supply the demand as much as possible and in case of peak power purchase rate is relatively high, micro grid will avoid buying energy at peak hours through two technologies: efficiently managing the electrical demand by transferring flexible load (e.g. washing machine, dishwasher, ironing) from peak hours to daytime when there is enough solar generation, and through Diesel generation, which is fast and enough flexible to supply generation ramps due to wind resource intermittency and volatility. Hence, the costs of efficiently managing fuel demand and costs are higher during Autumn - Winter, even though for the SING case, the peak hours are extended for the whole year. Given the above, energy purchase costs are also lower in autumn-winter months. Regarding revenues for energy sales to the grid, these latter are higher in summer-spring months due to the greater renewable production in daytime. Table 6-6 summarizes the costs of fuel, demand management, energy purchases/sales, and power purchase for the Calama case for each week (W) and weekend (WD) of the year.

Table 1-4:
Daily operational costs: fuel, grid exchange costs, demand response, peak power costs and revenues from selling energy to grid for the case of Calama.

				Jan US	Feb US	Mar US	Apr US	May US	Jun US	Jul US	Aug US	Sep US	Oct US	Nov US	Dec US	12 days MUS	Year MUS
Technology	Diesel	DG1Eff	W	0	5	5	5	5	1	5	5	5	5	1	0	41	894
			WD	4	0	3	5	5	5	5	5	5	5	1	5	47	415
		DG2Flex	W	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			WD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Grid	BUY	W	42	39	39	34	38	37	34	33	39	35	36	41	449	9734
			WD	43	42	49	36	34	35	33	35	37	41	38	50	473	4141
		SELL	W	-19	-22	-25	-22	-19	-19	-19	-16	-21	-22	-24	-19	-247	-5344
			WD	-19	-18	-23	-23	-20	-18	-21	-22	-21	-22	-22	-22	-250	-2192
		POWER	W - WD	34	38	34	35	34	35	34	34	35	35	34	34	415	12610
	Load	DR	W	0	0	0	0	13	0	5	10	9	2	0	0	39	853
			WD	0	0	0	4	5	5	6	11	6	3	1	0	40	350

d) Levelized costs of Energy of Distributed Energy Resources for every community micro grid under Net-Billing scheme

The economic feasibility of installing distributed energy resources in a Net-Billing regime is based on that the energy costs of these latter technologies are lower than the costs of connection and purchase of energy from the network. The objective of reducing investment and operating costs is translated into shifting the energy purchased from the grid through renewable generation and to inject surpluses in the case of having and using efficient diesel generation to reduce peak demand, thus avoid paying a higher peak rate.

The Net-Billing scheme presents economic viability for self-sufficiency and to inject surpluses into the grid in cases where there is a good solar resource and/or the injection price exceeds 110 US / MWh (Linares).

On the other hand, in most cases, the levelized cost of energy purchase and power costs under the regime that the distribution network operator assigns as a peak rate is greater than the levelized cost of energy of a micro grid throughout Chile, except in places (Santiago, Temuco and Concepción) where self-sufficiency is economically viable, but energy and non-peak power costs are still cheaper than diesel and demand management costs.

If Levelized cost of energy and power of the network is equivalent to zero, it means that the micro grid minimized the purchase of energy from the grid, because the price is very high.

In general, the proposed scheme is economically viable throughout Chile, using renewable resources, diesel generation and managing demand efficiently for self-sufficiency and peak shaving. The most economically viable micro-grid under the Net-Billing scheme is one with a good renewable resource (i.e. Los Angeles: $ 135 / MWh, Calama: $ 154 / MWh). On the other hand, the least economically viable micro-grid is the one where the renewable resources are low (GHI: 3.22 kWh / m2-day and wind speed: 4 m / s) and the prices of energy and power rates are expensive as the case of Osorno that has an average cost of supply of 205 US / MWh. Table 6-7 shows the levelized cost of energy for DERs and grid and average cost of supply under Net-Billing scheme.

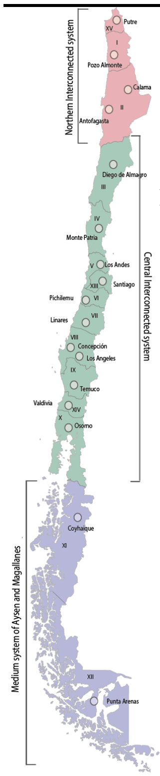
Table 1-5:
Levelized Cost of Energy (LCOE) for micro grid DERs and grid: Investment LCOE, Operation and Maintenance LCOE, and total LCOE expressed in USD/MWh. under Net-Billing business model

Locations	DG1			DG2			SolarPV			BESS			Wind			uLCOE	Grid	uGrid
	I	OM	ST	I	OM	ST	I	M	ST	I	M	ST	I	M	ST	O	O	T
Putre	19	206	**225**	19	212	**230**	95	8	**103**	176	22	**197**	0	0	**0**	**189**	**0**	**179**
PozoAlmonte	37	199	**236**	0	0	**0**	97	8	**105**	0	0	**0**	0	0	**0**	**170**	**186**	**162**
Calama	50	198	**248**	0	0	**0**	89	8	**97**	0	0	**0**	108	28	**135**	**160**	**203**	**154**
Antofagasta	38	201	**239**	0	0	**0**	110	9	**119**	0	0	**0**	0	0	**0**	**179**	**182**	**165**
DiegodeAlmagro	0	0	**0**	0	0	**0**	93	8	**101**	0	0	**0**	0	0	**0**	**101**	**170**	**143**
MontePatria	20	214	**234**	19	221	**240**	109	9	**118**	160	20	**179**	0	0	**0**	**193**	**0**	**186**
LosAndes	59	193	**252**	74	224	**298**	102	9	**111**	0	0	**0**	0	0	**0**	**220**	**211**	**166**
Santiago	60	194	**254**	74	225	**299**	119	10	**129**	0	0	**0**	0	0	**0**	**227**	**167**	**156**
Pichilemu	18	195	**213**	21	204	**226**	116	10	**126**	0	0	**0**	138	35	**174**	**185**	**0**	**181**
Linares	19	198	**217**	20	205	**225**	120	10	**130**	0	0	**0**	0	0	**0**	**191**	**0**	**182**
Concepcion	62	199	**261**	72	230	**302**	118	10	**128**	0	0	**0**	0	0	**0**	**230**	**197**	**169**
LosAngeles	32	189	**221**	33	196	**229**	118	10	**128**	0	0	**0**	76	20	**96**	**169**	**0**	**135**
Temuco	57	201	**258**	76	235	**311**	145	12	**157**	0	0	**0**	0	0	**0**	**242**	**197**	**188**
Valdivia	25	217	**242**	27	228	**256**	138	12	**150**	0	0	**0**	97	25	**122**	**192**	**0**	**183**
Osorno	20	215	**235**	23	225	**249**	150	13	**162**	143	18	**161**	144	37	**180**	**197**	**144**	**205**
Coyhaique	28	218	**247**	34	232	**265**	145	12	**158**	185	23	**208**	87	22	**110**	**197**	**0**	**177**
PuntaArenas	103	211	**315**	114	248	**362**	0	0	**0**	0	0	**0**	79	20	**99**	**259**	**163**	**151**

e) Investment, Operation and Maintenance net present value and average cost of supply for community Micro Grid under Net-Billing scheme

Each optimum configuration of the community micro grid evaluated under the Net-Billing program represents the best economic option to meet demand in a 20-year horizon given the costs of investment, maintenance and operation of technologies and the purchase / sale prices of Energy. The net present cost value of investing in distributed energy resources in CNB micro grids comprised of 15 houses with a peak demand of 69 kW at a capital cost rate of 10% over a time horizon Of 20 years varies between 69 M $ US (i.e. Punta Arenas Case) and 285 M $ US (i.e. Los Angeles Case), while operating costs, which include the costs of energy purchase/sale to the network,, on/off of diesel generators and fuel, load shedding, demand response and maintenance, vary between 29M $ US (Los Angeles) and 365M $ US (Temuco) totaling a net present cost value between 313 $ MUS (Los Angeles) and 478 M $ US (Osorno), whose average cost of supply varies between 157 USD/MWh and 196 US/MWh. In Los Angeles, the solar resource (5.22 kWh / m2-day) and wind power (5.2 m / s) are used to minimize the purchase of power from the grid taking advantage of self-sufficiency while in Osorno, peak power rates are very high and there is a lack of renewable resources, which implies a higher cost in technological development to supply the demand. In addition, given the high cost of purchasing energy and power from the grid, the micro-grid maximizes diesel generation usage to meet demand. Finally, the return on investment (seen as the year in which the micro-grid starts to generate savings) varies between 5 (Linares) and 14 years (Pozo Almonte, Monte Patria and Valdivia). This mainly depends on energy prices and peak / non-peak power rates and renewable resources availability. In the case of Linares, there is a good solar resource (5.45 kWh / m2-day) and compared to the high monomic energy price (271 US / MWh), PV solar and diesel generation allow short-term savings. In contrast, in Pozo Almonte, the renewable solar resource is good and the monomic price of energy is low. Although it is economically feasible to develop a community micro grid, the differences with the project that consist on supplying the entire demand with energy from the grid are few. Finally, in Monte Patria and Valdivia, solar and wind resources are good, but not enough to generate savings in the short term. Regarding the incremental internal rate of return between the project without micro grid and with micro grid it varies between 13% (Pozo Almonte) and 22% (Osorno). Table 6-8 shows the net present cost values for investment, operation and maintenance, total costs, payback, incremental internal rate of return and monomic prices for community micro grids evaluated under Net-Billing scheme.

Table 1-6:
Micro Grid Net present value and average cost of supply



Locations	INV Total M$US	COMA Total M$US	Total M$US	Average supply Cost $US/MWh	IRR %	PAYBACK Years	Monohmic price $US/MWh
Putre	164	252	416	178	20%	8	222
PozoAlmonte	77	300	376	170	13%	14	166
Calama	154	203	358	163	14%	11	174
Antofagasta	76	309	385	170	14%	12	174
DiegodeAlmagro	72	260	332	155	16%	10	156
MontePatria	161	273	433	181	14%	14	199
LosAndes	140	247	387	174	17%	9	195
Santiago	95	269	363	170	15%	12	167
Pichilemu	170	250	420	175	16%	11	206
Linares	160	264	424	180	28%	5	272
Concepcion	140	254	394	182	15%	11	190
LosAngeles	285	29	313	157	21%	7	234
Temuco	73	365	438	189	19%	8	205
Valdivia	235	191	425	185	13%	14	201
Osorno	189	289	478	196	22%	7	274
Coyhaique	236	177	413	183	17%	9	226
PuntaArenas	69	282	351	166	19%	8	169

1.1.2 Optimal sizing and energy management for community Net-Metering

The economic viability of developing community micro grids under the Net-Metering scheme depends primarily on the renewable resource availability in the area and on energy purchase / sale prices and peak power tariffs. In this way, the optimum sizing and operation of the micro grid is obtained under a scheme that remunerates the energy component of the energy injection to the grid plus avoided costs for distribution network operator.

a) Scenarios operation and energy management of each MG

The operation of the micro-net under the Net-Billing scheme can be classified into four possible operating scenarios and vary from place to place depending on the factors mentioned above:

- **Micro grid is a solar or wind community connected to the grid that reduces peak demand**: it uses solar or wind energy to self-supply and inject surpluses into the grid and also manages demand efficiently to make load shifting and uses diesel generation for peak shaving because the purchase prices of energy and power of the network are expensive. This occurs in Calama, Antofagasta, Pozo Almonte, Los Andes, Santiago, Concepcion, Temuco and Punta Arenas.
- **Micro grid is a solar community connected to the network**: it uses the good solar resource to self-supply demand and inject the surplus to the grid and the rest of the demand is supplied with energy from the grid since the energy and power purchase prices are more economical. Case of Diego de Almagro.
- **Micro grid is a community of distributed energy resources that minimizes the purchase of energy to the grid**: it uses the solar or wind resource, demand management and diesel generation to supply most of the demand. In this way it minimizes the purchase of energy to the grid given the high prices of energy and power purchas from the grid. Cases of Monte Patria, Putre, Pichilemu, Linares, Los Angeles, Valdivia, Osorno and Coyhaique.

b) MG size and annualized cost of Investment, Operation, Maintenance and total costs of DERs

Regarding installed capacity in community micro grid evaluated under Net-Metering scheme, solar PV is installed, reaching the limit established by the distributed generation law 20.571 throughout most of Chile: from Concepción to Putre with power factors between 18% and 24%, being the maximum the case of Calama that has a high irradiance (7.44 kWh / m2-day). In some cases in the south where the available solar resource is lower (Temuco and Valdivia) it is economically feasible to supply demand with PV solar generation, but with power factors of 15%. Finally, in other cases where the irradiance and production is even lower (Coyhaique and Osorno), it is still economically feasible to self-supply with power factors of 14%.

Regarding wind energy, wind turbines are mainly installed in southern Chile where there is a good wind resource (Pichilemu and Los Angeles to the South), allowing to supply demand most of the day. Its power factors range from 25% (e.g. Osorno) to 49% (e.g. Punta Arenas).

BESS are installed in places where peak power is reduced to the maximum, where there is a good renewable resource and the price of diesel fuel is relatively high (e.g. Putre). Similar situation occurs in the Net-Billing scheme, and since the injection rate is similar to the energy purchase rate, there are no differences between one scheme and another. This allows to charge the battery in daytime with solar generation and discharge it in hours of peak demand.

Regarding diesel generation, it is installed in all evaluated areas except in communities that pay cheap energy and power prices (e.g. Diego de Almagro). It is the most economical technology to reduce peak demand at times that there is no available solar resource and to meet demand in case of reducing peak power to the maximum. For cases of good solar resource, but where energy and power purchase rates are not relatively high, it is sufficient to reduce peak demand with diesel generation.

Obviously, in places with higher energy and power purchase rates (e.g. Putre, Monte Patria, Pichilemu, Linares, Los Angeles, Valdivia, Osorno and Coyhaique). Over-energized resources are over-installed to minimize measured demand or contracted power. On the other hand, in places with cheaper purchase rates (e.g. Los Andes, Santiago, Antofagasta, Pozo Almonte, Concepcion, Temuco and Punta Arenas), there is no need for so much generation installed capacity, except for diesel generators to reduce peak demand and reduce Costs for community. Finally, in places with even cheaper energy and power purchase rates (e.g. Diego de Almagro), the most expensive power tariff is paid and the available solar resource in the area is used to install solar PV.

Lower energy and power tariffs allow less investment in distributed energy resources, such as the case of Diego de Almagro, Pozo Almonte and Punta Arenas, while more expensive energy and power tariffs imply greater investment in DERs, as is the case of Coyhaique (0.23 US / kWh).

Table 6-9 summarizes the power factors, optimal installed capacity (S) for each location and the annualized costs ($ MUSD / year) of investment (I), operation and maintenance (OM), total costs of the micro The average cost of supply using Solar PV, Wind, BESS and Diesel Generators.

Table 1-7:
Community Net-Metering MG Size: Power factors, Installed capacity, Investment, operation and maintenance and total annualized costs of SPV, WTs, BESS, DG1EFF, DG2FLEX and average cost of supply.

	Solar PV					Wind					BESS					DG1Eff					DG2Flex					MG DGs Total					
	f	S	I	M	T	f	S	I	M	T	f	S	I	M	T	f	S	I	OM	T	f	S	I	OM	T	f	S	I	OM	MG	u
Locations	%	kW	$	$	$	%	kW	$	$	$	%	kWh	$	$	$	%	kW	$	$	$	%	kW	$	$	$	%	kW	$	$	$	$/E
Putre	22	100	15	1	17	0	0	0	0	0	18	18	1	0	1	30	39	2	20	22	30	24	1	14	15	25	168	19	36	55	0.20
PozoAlmonte	22	100	15	1	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	100	15	1	17	0.06
Calama	24	96	15	1	16	33	4	1	0	2	0	0	0	0	0	14	17	1	4	5	0	0	0	0	0	24	117	17	6	23	0.08
Antofagasta	19	100	15	1	17	0	0	0	0	0	0	0	0	0	0	16	12	1	3	4	12	13	1	3	3	16	125	17	7	24	0.09
DiegodeAlmagro	23	100	15	1	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	100	15	1	17	0.06
MontePatria	19	100	15	1	17	0	0	0	0	0	0	0	0	0	0	28	42	2	22	24	29	26	1	15	16	26	168	19	38	57	0.21
LosAndes	21	100	15	1	17	0	0	0	0	0	0	0	0	0	0	10	10	0	2	2	8	13	1	2	2	13	123	16	5	21	0.08
Santiago	18	100	15	1	17	0	0	0	0	0	0	0	0	0	0	10	10	0	2	2	8	13	1	2	2	12	123	16	5	21	0.08
Pichilemu	18	95	15	1	16	27	5	2	0	2	0	0	0	0	0	31	42	2	22	24	25	26	1	12	13	25	168	19	36	55	0.20
Linares	18	100	15	1	17	0	0	0	0	0	0	0	0	0	0	31	44	2	23	25	26	27	1	13	14	25	171	19	37	56	0.20
Concepcion	18	100	15	1	17	0	0	0	0	0	0	0	0	0	0	10	10	0	2	2	8	13	1	2	2	12	123	16	5	21	0.08
LosAngeles	0	0	0	0	0	46	100	31	8	39	0	0	0	0	0	17	38	2	11	13	18	22	1	6	7	27	159	34	25	59	0.22
Temuco	15	100	15	1	17	0	0	0	0	0	0	0	0	0	0	9	9	0	1	2	8	13	1	2	3	10	122	16	5	21	0.08
Valdivia	15	19	3	0	3	38	81	25	6	31	0	0	0	0	0	21	37	2	15	17	21	24	1	10	11	24	160	31	32	63	0.23
Osorno	14	78	12	1	13	25	22	7	2	9	0	0	0	0	0	29	40	2	22	24	24	25	1	12	13	23	166	22	36	58	0.21
Coyhaique	15	18	3	0	3	38	82	25	6	32	0	0	0	0	0	21	39	2	15	17	18	26	1	9	11	23	165	31	31	62	0.23
PuntaArenas	0	0	0	0	0	49	38	12	3	15	0	0	0	0	0	5	6	0	1	1	4	13	1	1	2	19	57	13	5	17	0.06

c) MG energy generation to supply community demand consumption

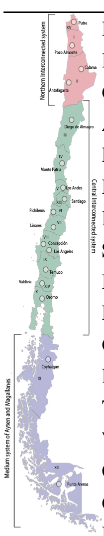
The energy production of renewable technologies that comprise each micro grid depends mainly on the availability of the solar and wind resource of the area. If you have a low-resource renewable scenario, you can supply the demand by purchasing energy and power from the grid or by using diesel generators.

When there is an abundant solar resource (e.g. Calama), energy production is mainly provided by solar PV ranging from 63% on a typical weekday of May (Autumn season) and 66% on a typical weekday of December (Summer season). Moreover, the purchase of energy from the network represents 49% of the energy demanded in the summer case, and 44% in the case of Winter. This is mainly because during autumn and Winter the demand is greater and therefore, there is a greater need to reduce peak demand and avoid a payment for more expensive power. In the case of diesel generation, it is used throughout the year in Calama, because the peak hours in the SING are extended for the whole year. However, in Autumn and Winter the use is higher (9% more) and also demand management programs are used, taking advantage of the good solar resource of the area, moving flexible loads to daytime. Figure 6-21 shows the energy management for the case of Calama and Table 6-11 summarizes the energy generated and the amount of energy demanded in the case of Calama for a typical weekday in summer month and a typical weekday of winter. Then, the same is done for the 12 months of the year and the percentages can be seen in table 6-10, which summarizes the total generation by technology for each location and the percentage that represents regarding demand.

In places with very expensive power purchase prices (eg Putre, Monte Patria, Linares, Osorno, Los Angeles, Coyhaique and Valdivia) the diesel generation energy is provided by both the generator generator and the flexible generator and contributes to supply demand from 33% (Eg Los Angeles) and 65% (eg Linares). In these same places, the purchase of energy and power is low ranging from 0.02% to 0.03% of energy to meet demand. Finally, in areas with cheaper energy purchase prices and power payments (Santiago, Los Andes, Punta Arenas, Calama, Antofagasta, Temuco, Diego de Almagro and Pozo Almonte), the economic generator supplies between 1% and 3% of the annual demand and most of the demand is supplied by energy from the grid ranging between 49% (eg Punta Arenas) and 63% (eg Pozo Almonte and Diego de Almagro).

The total energy demanded in the 24 days of evaluation corresponds to 18 MWh with a peak of 69 kW. In areas with good solar resources (Santiago to the north), community demand is mainly supplied by PV solar generation during daytime hours. While in areas with a good wind resource (Los Angeles to the south) demand is mainly supplied by wind generation throughout the day, given its high volatility and intermittency. Finally, self-consumption from RES under the Net-Metering program varies throughout the evaluated zones ranging between 34-35% (e.g. Temuco, Linares) and 67% (e.g. Los Angeles). The case of Temuco and Linares is due to lack of renewable resources in the zone, supplying the most of the demand with diesel generation, whereas the case of Los Angeles is due to the high wind resource in the zone, allowing at the same time Minimizing the purchase of energy and reducing payment for power purchase.

Table 1-8:
MG Energy Consumption under CNM business model: Energy produced during Horizon Time and its percentage regarding demand in each location



Energy	LOAD				GRID				ERNC								CONV			
Locations	**Shed**		**DR**		**Purchased**		**Sold**		**Solar PV**		**Wind**		**ERNC Self-consumption**		**BESS**		**DG1EFF**		**DG2FLEX**	
	MWh	**%**	**MWh**	**%**	**MWh**	**%**	**MWh**	**%**	**MWh**	**%**	**MWh**	**%**	**MWh**	**%**	**MWh**	**%**	**MWh**	**%**	**MWh**	**%**
Putre	0.0	0%	0.4	2.0%	0.0	0.03%	-5.6	31%	12.9	71%	0.0	0%	7.3	41%	0.005	0.03%	6.6	37%	4.2	23%
PozoAlmonte	0.0	0%	0.0	0.0%	11.5	63%	-5.9	33%	12.6	69%	0.0	0%	6.6	37%	0.0	0%	0.0	0%	0.0	0%
Calama	0.0	0%	0.2	0.9%	9.4	52%	-6.6	37%	13.1	73%	0.8	4%	7.3	40%	0.0	0%	1.4	8%	0.0	0%
Antofagasta	0.0	0%	0.1	0.5%	9.7	53%	-4.6	26%	11.1	61%	0.0	0%	6.4	36%	0.0	0%	1.2	7%	0.8	5%
Diego de Almagro	0.0	0%	0.0	0.0%	11.5	63%	-6.4	36%	13.1	72%	0.0	0%	6.6	37%	0.0	0%	0.0	0%	0.0	0%
MontePatria	0.0	0%	0.3	1.8%	0.0	0%	-4.3	24%	11.2	62%	0.0	0%	6.9	38%	0.0	0%	6.8	37%	4.4	25%
LosAndes	0.0	0%	0.1	0.4%	10.3	57%	-5.3	29%	11.9	66%	0.0	0%	6.6	37%	0.0	0%	0.6	3%	0.6	3%
Santiago	0.0	0%	0.1	0.4%	10.6	58%	-3.8	21%	10.2	57%	0.0	0%	6.4	36%	0.0	0%	0.6	3%	0.6	3%
Pichilemu	0.0	0%	0.2	1.3%	0.0	0%	-3.8	21%	10.0	55%	0.8	4%	6.9	38%	0.0	0%	7.4	41%	3.8	21%
Linares	0.0	0%	0.2	1.1%	0.0	0%	-3.8	21%	10.1	56%	0.0	0%	6.4	35%	0.0	0%	7.7	43%	4.0	22%
Concepcion	0.0	0%	0.1	0.4%	10.6	58%	-3.9	21%	10.3	57%	0.0	0%	6.4	36%	0.0	0%	0.6	3%	0.6	3%
LosAngeles	0.0	0%	0.1	0.8%	0.0	0.03%	-14.3	79%	0.0	0%	26.4	146%	12.0	67%	0.0	0%	3.8	21%	2.3	12%
Temuco	0.0	0%	0.1	0.7%	10.9	60%	-2.3	13%	8.4	47%	0.0	0%	6.1	34%	0.0	0%	0.5	3%	0.6	3%
Valdivia	0.0	0%	0.2	0.9%	0.0	0.03%	-8.7	48%	1.7	9%	17.7	98%	10.7	60%	0.0	0%	4.5	25%	2.9	16%
Osorno	0.0	0%	0.2	1.2%	0.0	0.02%	-1.5	8%	6.4	35%	3.1	17%	7.9	44%	0.0	0%	6.7	37%	3.4	19%
Coyhaique	0.0	0%	0.2	1.0%	0.0	0%	-8.8	49%	1.5	8%	18.0	99%	10.7	59%	0.0	0%	4.7	26%	2.7	15%
PuntaArenas	0.0	0%	0.1	0.8%	8.9	49%	-1.8	10%	0.0	0%	10.6	58%	8.7	48%	0.0	0%	0.2	1%	0.3	1%

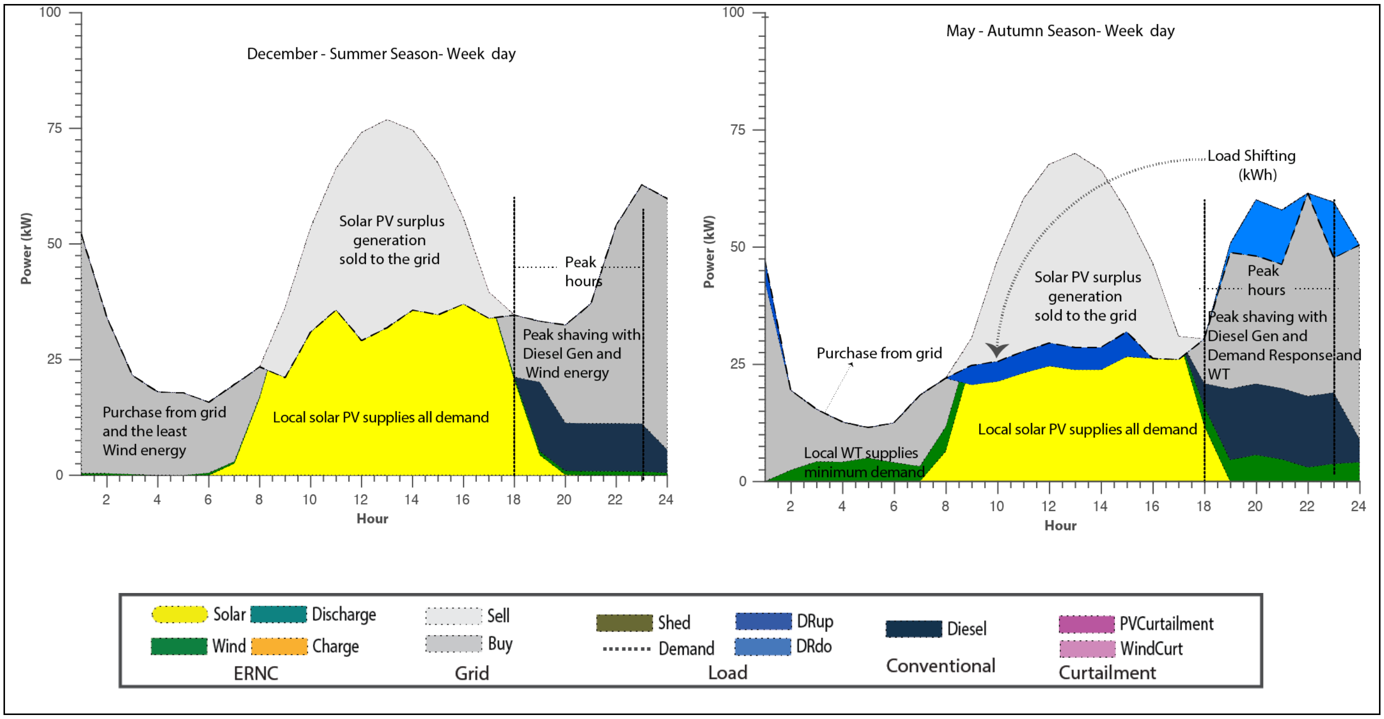


Figure 1-2: Micro Grid Energy Management in Calama under Net-Metering business model: Autumn and Summer week days

Table 1-9:
MG Energy consumption under CNM mode: Energy generated during a typical summer day and autumn day and each percentage regarding demand in the case of Calama

		kWh	%	+%	kWh	%	+%
ERNC	Solar	529	66%	48%	470	63%	44%
	Wind	82	10%		84	11%	
	BESS	0	0%		0	0%	
CONV	Diesel	25	3%	3%	86	12%	12%
GRID	BUY	393	49%	49%	330	44%	44%
	SELL	(232)	29%	-	(228)	31%	-
LOAD	DR	0	0%	0%	37	0.5%	-
	SHED	0	0%		0	0%	
		797	100%		742	100%	100%

i) Detailed daily operational cost for the case of Calama

The community micro grid located in areas where there is a good renewable resource (e.g. solar or wind) as the case of Calama, tends to self-supply the demand as much as possible and in case of peak power purchase rate is relatively high, micro grid will avoid buying energy at peak hours through two technologies: efficiently managing the electrical demand by transferring flexible load (e.g. washing machine, dishwasher, ironing) from peak hours to daytime when there is enough solar generation, and through Diesel generation, which is fast and enough flexible to supply generation ramps due to wind resource intermittency and volatility. Hence, the costs of efficiently managing fuel demand and costs are higher during Autumn - Winter, even though for the SING case, the peak hours are extended for the whole year. Given the above, energy purchase costs are also lower in autumn-winter months. Regarding revenues for energy sales to the grid, these latter are higher in summer-spring months due to the greater renewable production in daytime. Table 6-12 summarizes the costs of fuel, demand management, energy purchases/sales, and power purchase for the Calama case for each week (W) and weekend (WD) of the year.

Table 1-10:
Daily operational costs: fuel, grid exchange costs, demand response, peak power costs and revenues from selling energy to grid for the case of Calama under Net-Metering business model

				Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**12 days**	**Year**
				US	US	US	US	US	US	US	US	US	US	US	US	MUS	MUS
Technology	**Diesel**	DG1Eff	W	5	6	7	11	17	9	17	17	17	14	6	5	129	2803
			WD	8	5	10	17	17	17	17	17	17	15	7	9	155	1356
		DG2Flex	W	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			WD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Grid	BUY	W	42	40	41	33	35	36	33	34	39	34	35	41	444	9619
			WD	43	41	49	34	32	34	32	33	36	40	37	50	462	4044
		SELL	W	-21	-24	-26	-24	-20	-19	-22	-21	-25	-24	-26	-20	-272	-5886
			WD	-20	-20	-25	-25	-23	-21	-23	-24	-25	-25	-24	-24	-278	-2434
		POWER	W - WD	30	34	30	31	30	31	30	30	31	31	30	30	372	11290
	Load	DR	W	0	0	0	0	9	0	0	5	5	0	0	0	18	390
			WD	0	0	0	0	1	1	1	7	1	0	0	0	11	95

d) Levelized costs of Energy of Distributed Energy Resources for every community micro grid under Net-Metering scheme

The economic feasibility of installing distributed energy resources in a Net-Billing regime is based on that the energy costs of these latter technologies are lower than the costs of connection and purchase of energy from the network. The objective of reducing investment and operating costs is translated into shifting the energy purchased from the grid through renewable generation and to inject surpluses in the case of having and using efficient diesel generation to reduce peak demand, thus avoid paying a higher peak rate.

The Net-Metering scheme presents economic viability for self-sufficiency and for injecting surpluses into the grid with a minimum of moderate solar resource (4.2 kWh / m2-day) or a good wind resource. Conversely, in areas where the price of energy purchase or price of injection into the grid is considerably lower than the energy costs of photovoltaic technologies (e.g. Valdivia), the contribution of this type of technology to self-sufficiency and energy surplus injectio. In this way, revenues from solar PV power sales are not enough to pay for investment in this technology even in a Net-Metering regime.

On the other hand, in most cases, the levelized cost of energy purchase and power costs under the regime that the distribution network operator assigns as a peak rate is greater than the levelized cost of energy of a micro grid throughout Chile, except in places (Santiago, Temuco and Concepción) where self-sufficiency is economically viable, but energy and non-peak power costs are still cheaper than diesel and demand management costs.

If Levelized cost of energy and power of the network is equivalent to zero, it means that the micro grid minimized the purchase of energy from the grid, because the price is very high.

In general, the proposed scheme is economically viable throughout Chile, using renewable resources, diesel generation and managing demand efficiently for self-sufficiency and peak shaving.

In turn, the average cost of supply with a micro-grid will always be less than the cost of supplying demand with the grid and without installing distributed energy resources. In general, the proposed scheme is economically viable throughout Chile, using renewable resources (RES), diesel generation and managing demand efficiently for self-sufficiency and peak shaving. The most economically viable micro-grid under the Net-Metering scheme is one that has good wind resource and minimizes the purchase of energy and the payment of peak power (eg Los Angeles: $ 135 / MWh). On the other hand, The least economically feasible micro-grid is where the renewable resources are low (GHI: 4.21 kWh / m2-day and wind speed: 3.99 m / s) and the levelized costs of buying energy and powerr to the grid are high (> 210 US / kWh) as the case of Osorno that has an average supply cost of 206 US / MWh. Table 6-13 shows the levelized cost of energy for DERs and grid and average cost of supply under Net-Metering scheme.

Table 1-11:
Levelized Cost of Energy (LCOE) for micro grid DERs and grid: Investment LCOE, Operation and Maintenance LCOE and total LCOE expressed in USD/MWh. under Net-Metering business model

Locations	DG1			DG2			SolarPV			BESS			Wind			uLCOE	Grid	uGrid
	I	OM	ST	I	OM	ST	I	M	ST	I	M	ST	I	M	ST	O	O	T
Putre	19	206	**225**	18	210	**228**	95	8	**103**	170	21	**191**	0	0	**0**	**187**	**0**	**179**
PozoAlmonte	0	0	**0**	0	0	**0**	97	8	**105**	0	0	**0**	0	0	**0**	**105**	**177**	**147**
Calama	40	203	**243**	0	0	**0**	89	8	**97**	0	0	**0**	108	28	**135**	**158**	**196**	**154**
Antofagasta	35	193	**228**	50	225	**275**	110	9	**119**	0	0	**0**	0	0	**0**	**207**	**188**	**164**
DiegodeAlmagro	0	0	**0**	0	0	**0**	93	8	**101**	0	0	**0**	0	0	**0**	**101**	**175**	**143**
MontePatria	20	215	**235**	19	221	**240**	109	9	**118**	0	0	**0**	0	0	**0**	**198**	**0**	**187**
LosAndes	57	193	**249**	76	225	**301**	102	9	**111**	0	0	**0**	0	0	**0**	**221**	**211**	**166**
Santiago	57	193	**250**	76	226	**302**	119	10	**129**	0	0	**0**	0	0	**0**	**227**	**170**	**157**
Pichilemu	19	197	**216**	21	205	**227**	116	10	**126**	0	0	**0**	138	35	**174**	**186**	**0**	**181**
Linares	18	199	**217**	22	207	**229**	120	10	**130**	0	0	**0**	0	0	**0**	**192**	**0**	**183**
Concepcion	57	198	**255**	76	232	**308**	118	10	**128**	0	0	**0**	0	0	**0**	**230**	**197**	**169**
LosAngeles	32	190	**223**	32	195	**227**	0	0	**0**	0	0	**0**	76	20	**96**	**182**	**0**	**135**
Temuco	67	203	**270**	73	233	**306**	145	12	**157**	0	0	**0**	0	0	**0**	**244**	**149**	**155**
Valdivia	25	215	**241**	26	225	**251**	138	12	**150**	0	0	**0**	97	25	**122**	**191**	**0**	**185**
Osorno	19	215	**234**	24	226	**249**	150	13	**162**	0	0	**0**	144	37	**180**	**207**	**144**	**206**
Coyhaique	28	219	**247**	30	228	**259**	145	12	**158**	0	0	**0**	87	22	**110**	**193**	**0**	**179**
PuntaArenas	117	216	**333**	138	250	**387**	0	0	**0**	0	0	**0**	79	20	**99**	**273**	**179**	**152**

e) Total costs of MG: Net present value and average supply cost

Each optimum configuration of the community micro grid evaluated under the Net-Billing program represents the best economic option to meet demand in a 20-year horizon given the costs of investment, maintenance and operation of technologies and the purchase / sale prices of Energy. The net present cost value of investing in distributed energy resources in CNB micro grids comprised of 15 houses with a peak demand of 69 kW at a capital cost rate of 10% over a time horizon of 20 years varies between 69 M$US (e.g. Punta Arenas) y los 285M$US (e.g. Los Angeles), while operating costs, which include costs of purchase / sale of energy from the grid, demand management, on/off of diesel generators and fuel usage, load shedding and maintenance, vary between 29M $ US (Los Angeles) and 365M $ US (Temuco) totaling a net present cost value of 313 $ MUS (Los Angeles) and 478 M $ US (Osorno), whose average cost of supply varies between 135 USD / MWh And 196 US / MWh. In Los Angeles, the solar resource (5.22 kWh / m2-day) and wind power (5.2 m / s) are used to minimize the purchase of power to the grid and take advantage of self-sufficiency while in Osorno, peak power rates are very high and there is a lack of renewable resources, which implies a higher cost in technological development to supply the demand. In addition, given the high cost of purchasing energy and power from the grid, the micro-grid maximizes diesel generation usage to meet demand

Finally, the return on investment (seen as the year in which the micro-network starts to generate savings) varies between 5 (Linares) and 18 (Pozo Almonte). This depends mainly on energy prices and peak / non-peak power and the availability of renewable resources. In the case of Linares, there is a good solar resource (5.45 kWh / m2-day) and compared to the high monomic energy price (271 US / MWh), PV solar and diesel generation allow short-term savings. In contrast, in Pozo Almonte, the renewable solar resource is good and the monomic price of energy is low. Although it is economically feasible to develop a micro-community network, the differences with the project that consist on supplying the entire demand with energy from the grid are few. Regarding the incremental internal rate of return between the project without micro grid and with micro grid it varies between 11% (Pozo Almonte) and 22% (Osorno). Table 6-14 shows the net present cost values for investment, operation and maintenance, total costs, payback, incremental internal rate of return and monomic prices for community micro grids evaluated under Net-Metering scheme.

Table 1-12:
Micro Grid Net present value and average cost of supply over 20 years under Net-Metering Business model

Locations	INV Total M$US	COMA Total M$US	Total M$US	Average supply Cost $US/MWh	IRR %	PAYBACK Years	Monohmic price $US/MWh
Putre	164	252	416	179	20%	8	222
PozoAlmonte	77	300	376	162	11%	18	166
Calama	154	203	358	154	15%	11	174
Antofagasta	76	309	385	165	12%	16	174
DiegodeAlmagro	72	260	332	143	13%	13	156
MontePatria	161	273	433	186	14%	14	199
LosAndes	140	247	387	166	17%	9	195
Santiago	95	269	363	156	13%	14	167
Pichilemu	170	250	420	181	16%	11	206
Linares	160	264	424	182	28%	5	272
Concepcion	140	254	394	169	15%	11	190
LosAngeles	285	29	313	135	21%	7	234
Temuco	73	365	438	188	14%	12	205
Valdivia	235	191	425	183	13%	15	201
Osorno	189	289	478	205	22%	7	274
Coyhaique	236	177	413	177	16%	10	226
PuntaArenas	69	282	351	151	15%	11	169

1.1.3 Optimal Sizing and energy management for Community Small Distributed Generation

The economic feasibility of developing community micro grids under the SDG scheme depends mainly on the renewable resource availability of the area and on energy purchase prices and peak power tariffs. In this way, the optimum sizing and operation of the micro network is obtained under a scheme that does not allow the injection of surpluses into the network.

a) Scenarios operation and energy management of each MG

The operation of the micro-grid under the self-supply scheme without the possibility of injecting the surplus into the network can be classified into three possible operating scenarios and vary from place to place depending on the available renewable resource (solar or wind), prices of energy and power purchase of the network:

- **Micro grid is a solar and/or wind community that reduce peak demand**: it uses solar and / or wind energy to self-supply and also manages demand efficiently to make load shifting and uses diesel generation for peak shaving due to high energy and power rates. This occurs in Antofagasta, Calama, Los Andes, Santiago, Concepcion, Temuco, Valdivia and Punta Arenas.
- **Micro grid is a self-supplied solar community**: it takes advantage of the solar resource to self-supply demand and the rest of the demand is supplied with energy from the grid since energy and power purchase prices are cheaper. This occurs in Diego de Almagro and Monte Patria.
- **Micro grid is a community of distributed energy resources that minimizes the purchase of energy to the grid**: it uses solar or wind resource, demand management, diesel generation and/or energy storage systems to supply most of the demand. In this way it minimizes the purchase of energy to the grid given the high prices of energy and power purchase. Cases of Putre, Los Angeles, Osorno, Coyhaique, Pichilemu and Linares.

b) MG size and annualized cost of Investment, Operation, Maintenance and total costs of DERs

Regarding installed capacity in the community micro grid evaluated under SDG scheme, solar PV is installed in much of the central-south, central and north (Concepción al Norte) zone with power factors between 18% and 24% , being the maximum the case of Calama that has a high irradiance (7.44 kWh / m2-day). In some cases in the south where the available solar resource is lower (Osorno and Temuco) it is economically feasible to supply demand with PV solar generation with average power factors of 14-15%. Finally, in other cases where the irradiance and production is even lower (e.g. Coyhaique: 4.18 kWh / m2-day and Valdivia: 4.12 kWh / m2-day) self-sufficiency with power factors of 14% is still economically feasible.

Regarding installed capacity of wind turbines, wind energy is mainly generated in the south of Chile (e.g. from Valdivia to the south) and in Los Angeles, Pichilemu and Calama. In most of these places there is a good wind resource allowing supply demand most of the day. It installs enough to reduce peak demand and self-supply a percentage of demand. Its power factors range from 25% (e.g. Osorno) to 49% (e.g. Punta Arenas). In addition, there is a negative correlation between high energy purchase prices and grid power, and the installation of wind turbines. That is to say, if there is a moderate wind resource in a given area (average> 4.5 m / s) and the regulated prices paid to the distribution network operator for energy and power are relatively high, the system will include wind power in its long planning Term, since it allows to minimize the purchase from the network and / or to reduce peak demand, diminishing the average costs of supply.

Regarding BESS installed capacity, 52 kWh / 13 kW are installed in the Putre area, mainly to minimize the purchase of power to the grid, given the high power purchase prices ([41.6 US / kW-month , 44.66 US / kW-month]), 25 kWh / 6.25 KW in Pichilemu, 19 kWh / 4.8 KW in Linares, 13 kWh / 3.25 KW in Los Angeles and 27 kWh / 8.3 KW in Coyhaique. In this way, it is economically viable to store energy in daytime with PV solar generation and discharge it at times of greater system load. Thus, the BESS allow peak shaving dermand, being a complementary technology to diesel generation.

Regarding diesel generation, it is installed in all evaluated areas except in communities that pay cheap energy and power prices (e.g. Diego de Almagro). It is the most economical technology to reduce peak demand at times that there is no available solar resource and to meet demand in case of reducing peak power to the maximum. For cases of good solar resource, but where energy and power purchase rates are not relatively high, it is sufficient to reduce peak demand with diesel generation.

Of course, in places with higher energy purchase rates and power payments (e.g. Putre, Pichilemu, Los Angeles, Linares, Valdivia, Osorno and Coyhaique), overburdened energy resources are over-installed to minimize energy purchase from grid. On the other hand, in places with cheaper energy and power purchase tariffs (e.g. Los Andes, Pozo Almonte, Santiago, Antofagasta, Calama, Temuco, Concepción and Punta Arenas), RES installed capacity is needed for self-supply demand, and diesel generation to reduce peak demand but the rest of the demand is supplied from the network. Finally, in places with even cheaper energy and power purchase rates (e.g. Diego de Almagro), the most expensive power tariff is paid and the available solar resource in the area is used to install PV solar consumption. Table 6-15 summarizes the power factors, optimal installed capacity (S) for each location and the annualized costs ($ MUSD / year) of investment (I), operation and maintenance (OM), total costs of the micro- The average cost of supply using Solar PV, Wind, BESS and Diesel Gs.

Table 1-13:
Community Small Distributed Generation MG Size: Power factors, Installed capacity, Investment, operation and maintenance and total annualized costs of SPV, WTs, BESS, DG1EFF, DG2FLEX and average cost of supply.

	Solar PV					Wind					BESS					DG1Eff					DG2Flex					MG DGs Total					
	f	S	I	M	T	f	S	I	M	T	f	S	I	M	T	f	S	I	OM	T	f	S	I	OM	T	f	S	I	OM	MG	u
Locations	%	kW	$	$	$	%	kW	$	$	$	%	kWh	$	$	$	%	kW	$	$	$	%	kW	$	$	$	%	kW	$	$	$	$/E
Putre	22	57	9	1	10	0	0	0	0	0	14	52	3	0	3	32	37	2	21	22	30	24	1	13	14	25	132	15	35	50	**0.18**
PozoAlmonte	22	37	6	0	6	0	0	0	0	0	0	0	0	0	0	15	19	1	5	6	0	0	0	0	0	19	57	7	6	12	**0.04**
Calama	24	33	5	0	5	33	17	5	1	6	0	0	0	0	0	11	6	0	1	1	0	0	0	0	0	22	55	10	3	13	**0.05**
Antofagasta	19	38	6	1	6	0	0	0	0	0	0	0	0	0	0	15	20	1	5	6	0	0	0	0	0	17	58	7	6	13	**0.05**
DiegodeAlmagro	23	34	5	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	34	5	0	6	**0.02**
MontePatria	19	41	6	1	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	41	6	1	7	**0.03**
LosAndes	21	43	7	1	7	0	0	0	0	0	0	0	0	0	0	9	11	1	2	2	8	13	1	2	2	12	67	8	4	12	**0.04**
Santiago	18	39	6	1	7	0	0	0	0	0	0	0	0	0	0	10	10	0	2	2	8	13	1	2	2	12	62	7	4	11	**0.04**
Pichilemu	18	58	9	1	10	27	9	3	1	4	16	25	1	0	2	31	38	2	20	22	29	24	1	12	14	24	135	16	34	50	**0.18**
Linares	18	60	9	1	10	0	0	0	0	0	16	19	1	0	1	33	40	2	22	23	32	26	1	15	16	25	130	14	37	51	**0.19**
Concepcion	18	47	7	1	8	0	0	0	0	0	0	0	0	0	0	9	10	0	2	2	8	13	1	2	2	12	69	8	4	12	**0.05**
LosAngeles	18	20	3	0	3	46	31	10	2	12	16	13	1	0	1	27	35	2	15	17	27	23	1	10	11	27	112	16	28	44	**0.16**
Temuco	15	39	6	1	7	0	0	0	0	0	0	0	0	0	0	10	10	0	2	2	7	13	1	2	2	11	62	7	4	11	**0.04**
Valdivia	15	8	1	0	1	38	19	6	1	7	0	0	0	0	0	7	9	0	1	2	0	0	0	0	0	20	36	7	3	10	**0.04**
Osorno	14	60	9	1	10	25	15	5	1	6	16	9	0	0	1	32	39	2	23	25	28	25	1	13	15	23	141	18	38	56	**0.20**
Coyhaique	15	31	5	0	5	38	32	10	3	13	16	27	1	0	2	27	36	2	17	19	28	23	1	12	13	25	129	19	32	51	**0.19**
PuntaArenas	0	0	0	0	0	49	15	5	1	6	0	0	0	0	0	6	14	1	2	2	0	0	0	0	0	28	29	5	3	8	**0.03**

c) MG energy generation to supply community demand consumption

The energy production of renewable technologies that comprise each micro grid depends mainly on the availability of the solar and wind resource of the area. If you have a low-resource renewable scenario, you can supply the demand by purchasing energy and power from the grid or by using diesel generators.

In a community micro grid located in Concepción evaluated under SDG scheme, the production of energa is mainly provided by solar PV ranging between 20% on a typical weekday of August (winter season) and 33% on a typical weekday of January (summer Season). Moreover, the purchase of energy from the grid represents 68% of the energy demanded in the summer case, and 67% in the case of Winter. This slight difference is due to the need of reducing peak demand and avoid a higher payment related to peak power, since this zone is within the SIC. In the case of diesel generation, it is used during the peak months in SIC (April - September) and its use corresponds to 13% of the demand. Also demand management programs (7% of demand) are used, taking advantage of the solar resource of the zone, moving flexible loads to daytime schedule. Figure 6-22 shows the energy management for the case of Concepción and the table 6-17 summarizes the energy generated and the representation of the energy demanded in the case of Concepción for a summer month and a month of Winter. Then, the same is done for the 12 months of the year and the percentages can be seen in table 6-16, which summarizes the total generation by technology for each location and the percentage that represents regarding demand.

In places with very expensive power purchase prices (eg Putre, Linares, Osorno, Los Angeles, Coyhaique and Valdivia), the diesel generation comes from both the economic generator and the flexible generator and contributes to supply demand by 49% (eg Los Angeles) and 67% (eg Linares). In these same places, the purchase of energy and power is low ranging from 0.02% to 0.03% of demand. In places with cheaper power purchase prices than the aforementioned places, the diesel generation comes from the most economic but less flexible generator, which contributes from 2% (Calama) to 10% (Antofagasta) of demand and the most flexible generator that contributes with 3% (Temuco, Los Andes, Santiago and Concepción).
On the other hand, in places where power purchase prices are cheaper, most of the demand is supplied by the grid reaching 76% (e.g. Diego de Almagro).

The total energy demanded in the 24 days of evaluation corresponds to 18 MWh with a peak of 69 kW. In areas with good solar resources (Santiago to the north), community demand is mainly supplied by PV solar generation during daytime hours. While in areas with a good wind resource (Los Angeles to the south) demand is mainly supplied by wind generation throughout the day, given its high volatility and intermittency. Finally, self-consumption from RES under SDG varies throughout the evaluated zones between 18% (e.g. Temuco, Linares) and 57% (e.g. Los Angeles). The case of Temuco and

Linares is due to lack of renewable resources in the zone, supplying the most of the demand with diesel generation, whereas the case of Los Angeles is due to the high wind resource in the zone, allowing at the same time minimizing the purchase of energy and reducing payment for power purchase.

Table 1-14:
MG Energy Consumption under SLG business model: Energy produced during Horizon Time and its percentage regarding demand in each location

Energy	LOAD				GRID				ERNC								CONV			
Locations	Shed		DR		Purchased		Sold		Solar PV		Wind		ERNC Self-consumption		BESS		DG1EFF		DG2FLEX	
	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%
Putre	0.0	0.04%	0.4	2.4%	0.0	0.04%	0.0	0%	7.4	41%	0.0	0%	7.4	41%	0.007	0.04%	6.8	38%	4.2	23%
PozoAlmonte	0.0	0.00%	0.2	1.0%	11.7	65%	0.0	0%	4.7	26%	0.0	0%	4.7	26%	0.0	0%	1.7	10%	0.0	0%
Calama	0.0	0.00%	0.3	1.9%	10.3	57%	0.0	0%	4.5	25%	3.2	17%	7.6	42%	0.0	0%	0.4	2%	0.0	0%
Antofagasta	0.0	0.00%	0.2	0.9%	12.2	67%	0.0	0%	4.2	23%	0.0	0%	4.2	24%	0.0	0%	1.7	10%	0.0	0%
Diego de Almagro	0.0	0.00%	0.0	0.0%	13.7	76%	0.0	0%	4.4	25%	0.0	0%	4.4	25%	0.0	0%	0.0	0%	0.0	0%
MontePatria	0.0	0.00%	0.0	0.0%	13.5	75%	0.0	0%	4.6	26%	0.0	0%	4.6	26%	0.0	0%	0.0	0%	0.0	0%
LosAndes	0.0	0.00%	0.1	0.4%	12.0	66%	0.0	0%	5.1	28%	0.0	0%	5.1	28%	0.0	0%	0.6	3%	0.5	3%
Santiago	0.0	0.00%	0.1	0.5%	13.0	72%	0.0	0%	4.0	22%	0.0	0%	4.0	22%	0.0	0%	0.6	3%	0.6	3%
Pichilemu	0.0	0.00%	0.3	1.5%	0.0	0%	0.0	0%	6.0	33%	1.4	8%	7.5	42%	0.0	0%	6.8	38%	4.0	22%
Linares	0.0	0.02%	0.4	2.1%	0.0	0%	0.0	0%	6.1	34%	0.0	0%	6.1	34%	0.0	0%	7.5	41%	4.8	26%
Concepcion	0.0	0.00%	0.1	0.5%	12.3	68%	0.0	0%	4.8	27%	0.0	0%	4.8	27%	0.0	0%	0.5	3%	0.6	3%
LosAngeles	0.0	0.02%	0.2	1.0%	0.0	0.02%	0.0	0%	2.1	12%	8.3	46%	10.3	57%	0.0	0%	5.5	30%	3.5	19%
Temuco	0.0	0.00%	0.1	0.5%	13.7	76%	0.0	0%	3.3	18%	0.0	0%	3.3	18%	0.0	0%	0.6	3%	0.5	3%
Valdivia	0.0	0.00%	0.3	1.4%	13.0	0.00%	0.0	0%	0.7	4%	4.1	23%	4.8	27%	0.0	0%	0.4	2%	0.0	0%
Osorno	0.0	0.02%	0.3	1.9%	0.0	0.02%	0.0	0%	4.9	27%	2.2	12%	7.0	39%	0.0	0%	7.2	40%	4.0	22%
Coyhaique	0.0	0.00%	0.3	1.8%	0.0	0%	0.0	0%	2.6	14%	7.1	40%	9.7	54%	0.0	0%	5.6	31%	3.6	20%
PuntaArenas	0.0	0.00%	0.2	1.1%	13.4	74%	0.0	0%	0.0	0%	4.2	23%	4.2	23%	0.0	0%	0.5	3%	0.0	0%

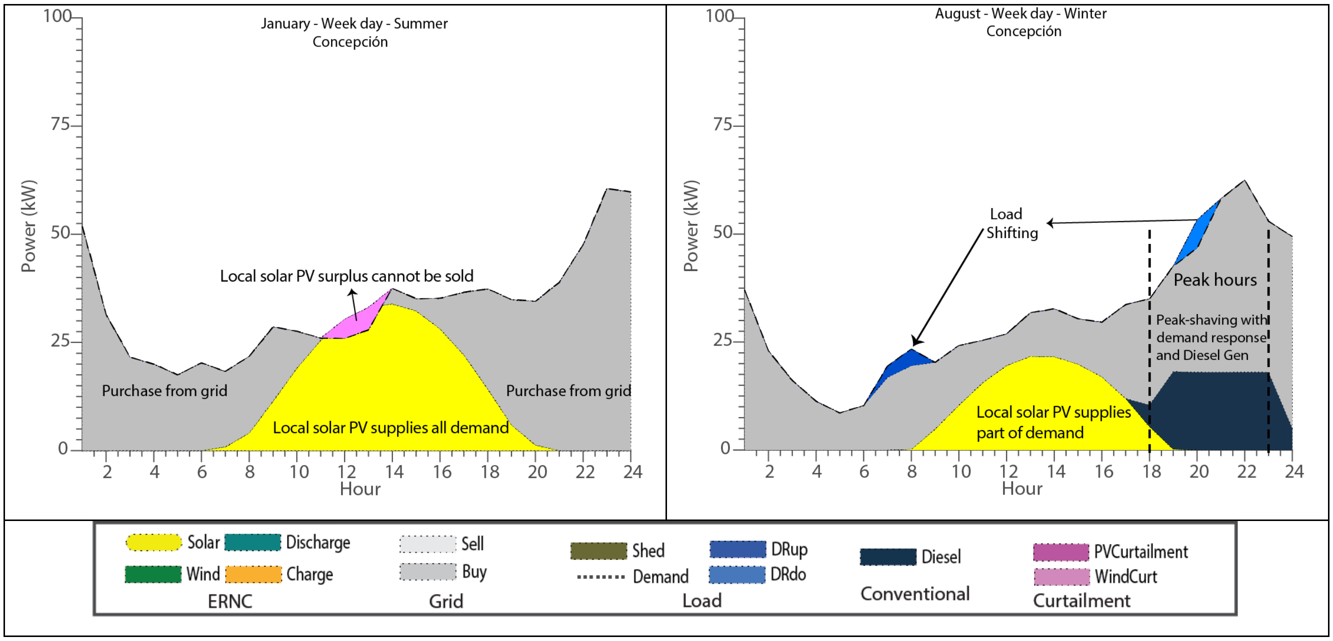


Figure 1-3: Micro Grid Energy Management in Concepción under Net SDG business model: Autumn and Summer week day

Table 1-15:
MG Energy consumption under SDG mode: Energy generated during a typical week summer day and winter day and each percentage regarding demand in the case of Concepción

		kWh	**%**	**+%**	**kWh**	**%**	**+%**
ERNC	Solar	262	32.9%		148	20%	
	Curt PV	9.5	1.1%	40%	0		40%
	Wind	0	0%		0	0%	
	BESS	0	0%		0	0%	
CONV	Diesel	0	0%	0%	100	13%	4%
GRID	BUY	544	68%	4%	503	67%	4%
	SELL	0	0%		0	0%	
LOAD	DR	0	0%	6%	6.54	0.8%	5%
	SHED	0	0%		0	0%	
		797	100%		751	100%	

i) Detailed daily operational cost for the case of Concepción

The community micro grid located in areas where there is limited renewable resource (e.g. solar and wind) as the case of Concepción, tends to minimize the average cost of supplying as much as possible through self-sufficiency and in the case that peak power purchase is relatively high, it will avoid buying power from the grid at peak hours through two technologies: efficiently managing the electricity demand by transferring flexible load at peak times (eg washing machine, dishwasher, ironing) to daytime when there is not necessarily enough solar generation but peak power prices are lower, and through diesel generation, which is fast and flexible enough to supply demand ramps. In this way, the costs of efficiently managing demand and fuel costs are higher during fall - winter. Given the above, energy purchase costs are also lower in the fall-winter months given the peak hours for the SIC. On the contrary, power purchase costs are the same for all months of the year. The table 6-18 summarizes the costs of fuel, demand management, energy purchases/sales, and power purchase for Concepción case for each week (W) and weekend (WD) of the year.

Table 1-16:
Daily operational costs: fuel, grid exchange costs, demand response, peak power costs and purchasing energy costs for the case of Concepción under SDG model

				Jan US	**Feb** US	**Mar** US	**Apr** US	**May** US	**Jun** US	**Jul** US	**Aug** US	**Sep** US	**Oct** US	**Nov** US	**Dec** US	**12 days** MUS	**Year** MUS
Technology	**Diesel**	DG1Eff	W	0	0	0	8	9	9	7	9	9	0	0	0	51	1113
			WD	0	0	0	6	7	9	9	9	6	0	0	0	46	406
		DG2Flex	W	0	0	0	4	10	8	8	10	10	0	0	0	52	1133
			WD	0	0	0	10	10	10	10	10	10	0	0	0	62	543
	Grid	BUY	W	74	69	72	58	68	68	64	68	64	73	64	75	818	17733
			WD	78	75	84	61	62	66	63	61	64	80	67	85	846	7402
		SELL	W	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			WD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		POWER	W - WD	27	29	27	27	27	27	27	27	27	27	27	27	326	9893
	Load	DR	W	0	0	0	1	6	0	0	2	3	0	0	0	12	251
			WD	0	0	0	1	0	0	0	6	0	0	0	0	7	65

d) Levelized costs of Energy of Distributed Energy Resources for every community micro grid under small distributed generation scheme

The economic feasibility of installing distributed energy resources in a SDG regime is based on that the energy costs of these latter technologies are lower than the costs of connection and purchase of energy from the network. The objective of reducing investment and operating costs is translated into shifting the energy purchased from the grid through renewable generation and using efficient diesel generation to reduce peak demand, thus avoid paying a higher peak rate.

The SDG scheme presents economic viability for self-sufficiency with a minimum of moderate solar resource (4.2 kWh / m2-day) or a good wind resource. In contrast, in areas where the energy purchase price is significantly lower than the energy costs of photovoltaic technologies (eg Valdivia), the contribution of this type of technology to self-sufficiency is lower.

Conversely, in areas where the price of energy purchase or price of injection into the grid is considerably lower than the energy costs of photovoltaic technologies (e.g. Valdivia), the contribution of this type of technology to self-sufficiency and energy surplus injectio. In this way, revenues from solar PV power sales are not enough to pay for investment in this technology even in a Net-Metering regime.

On the other hand, in most cases, the levelized cost of energy purchase and power costs under the regime that the distribution network operator assigns as a peak rate is greater than the levelized cost of energy of a micro grid throughout Chile, except in places (Santiago, Temuco and Concepción) where self-sufficiency is economically viable, but energy and non-peak power costs are still cheaper than diesel and demand management costs.

If Levelized cost of energy and power of the network is equivalent to zero, it means that the micro grid minimized the purchase of energy from the grid, because the price is very high.

In general, the proposed scheme is economically viable throughout Chile, using renewable resources, diesel generation and managing demand efficiently for self-sufficiency and peak shaving.

In turn, the average cost of supply with a micro-grid will always be less than the cost of supplying demand with the grid and without installing distributed energy resources. In general, the proposed scheme is economically viable throughout Chile, using renewable resources (RES), diesel generation and managing demand efficiently for self-sufficiency and peak shaving.

The most economically feasible micro-grid under the SDG scheme is the one which has a good wind resource and minimizes the purchase of energy and power from the grid (e.g. Los Angeles: USD 164 / MWh). On the other hand, the least economically feasible micro-grid is where the renewable resources are low (GHI: 4.21 kWh / m2-day and wind speed: 3.99 m / s) and the levelized costs of buying energy and power from the grid are high (> 210 US / kWh) as the case of Osorno that has an average supply cost of 206 US / MWh. Table 6-13 shows the levelized cost of energy for DERs and grid and average cost of supply under SDG scheme.

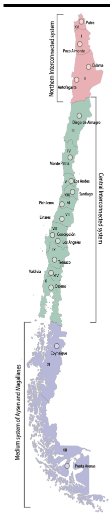
Table 1-17:
Levelized Cost of Energy (LCOE) for micro grid DERs and grid: Investment LCOE, Operation and Maintenance LCOE and total LCOE expressed in USD/MWh. under Net-Metering business model

Locations	DG1			DG2			SolarPV			BESS			Wind			LCOE mean	Grid	uGrid
	I	OM	ST	I	OM	ST	I	M	ST	I	M	ST	I	M	ST	O	O	T
Putre	18	200	**218**	19	208	**227**	95	8	**103**	208	26	**233**	0	0	**0**	**195**	**0**	**187**
PozoAlmonte	37	199	**236**	0	0	**0**	97	8	**105**	0	0	**0**	0	0	**0**	**171**	**178**	**162**
Calama	57	199	**255**	0	0	**0**	89	8	**97**	0	0	**0**	108	28	**135**	**162**	**188**	**159**
Antofagasta	38	201	**240**	0	0	**0**	110	9	**119**	0	0	**0**	0	0	**0**	**180**	**175**	**166**
DiegodeAlmagro	0	0	**0**	0	0	**0**	93	8	**101**	0	0	**0**	0	0	**0**	**101**	**162**	**143**
MontePatria	0	0	**0**	0	0	**0**	109	9	**118**	0	0	**0**	0	0	**0**	**118**	**0**	**182**
LosAndes	62	195	**257**	77	226	**302**	102	9	**111**	0	0	**0**	0	0	**0**	**224**	**199**	**176**
Santiago	58	193	**252**	72	224	**296**	119	10	**129**	0	0	**0**	0	0	**0**	**226**	**161**	**157**
Pichilemu	18	192	**210**	19	200	**220**	116	10	**126**	183	22	**205**	138	35	**174**	**187**	**0**	**187**
Linares	17	193	**211**	17	200	**217**	120	10	**130**	180	22	**202**	0	0	**0**	**190**	**0**	**190**
Concepcion	58	199	**257**	76	232	**308**	118	10	**128**	0	0	**0**	0	0	**0**	**231**	**188**	**175**
LosAngeles	21	185	**206**	21	192	**213**	118	10	**128**	188	23	**211**	76	20	**96**	**171**	**0**	**164**
Temuco	57	201	**258**	80	237	**317**	145	12	**157**	0	0	**0**	0	0	**0**	**244**	**193**	**188**
Valdivia	85	216	**301**	0	0	**0**	138	12	**150**	0	0	**0**	97	25	**122**	**191**	**0**	**187**
Osorno	18	212	**229**	20	222	**242**	150	13	**162**	184	23	**207**	144	37	**180**	**204**	**144**	**209**
Coyhaique	22	213	**234**	21	222	**243**	145	12	**158**	154	19	**173**	87	22	**110**	**183**	**0**	**192**
PuntaArenas	81	212	**293**	0	0	**0**	0	0	**0**	0	0	**0**	79	20	**99**	**196**	**159**	**154**

e) Total costs of MG: Net present value and average supply cost

Each optimum configuration of the community micro grid evaluated under the Net-Billing program represents the best economic option to meet demand in a 20-year horizon given the costs of investment, maintenance and operation of technologies and the purchase / sale prices of Energy. The net present cost value of investing in distributed energy resources in CNB micro grids comprised of 15 houses with a peak demand of 69 kW at a capital cost rate of 10% over a time horizon of 20 years varies between 45 M$US (e.g. Punta Arenas) y and 164M$US (e.g. Coyhaique), while operating costs, which include costs of purchase of energy from the grid, demand management, on/off of diesel generators and fuel usage, load shedding and maintenance, vary between 242M $ US (Los Angeles) and 348M $ US (Temuco) totaling a net present cost value of $ 334 MUS (Diego de Almagro) and 486 M $ US (Osorno), whose average costs vary from 143 USD / MWh to 209 US / MWh. In Diego de Almagro, MG takes advantage of the solar resource to minimize the purchase of energy from the network and low energy purchase prices while in Osorno, the peak and non-peak power rates are very high and there is a lack of renewable resources, which implies a higher cost in technological development to supply the demand. In addition, given the high cost of energy and power purchases, the micro-grid has to maximize diesel generation capacity supply demand. Finally, the return on investment (seen as the year in which the micro-network starts to generate savings) varies between 5 years (Los Angeles) and 14 years (Pozo Almonte). This depends mainly on energy prices and peak / non-peak power and the availability of renewable resources. In the case of Los Angeles, there is a good wind resource and compared to the high monomic price of energy (234 US / MWh), installing wind and diesel generation allows savings in the short term. In contrast, in Pozo Almonte, the renewable solar resource is good and the monomic price of energy is low. Regarding the incremental internal rate of return between the project without micro grid and with micro grid it varies between 13% (Pozo Almonte) and 34% (Linares). Table 6-20 shows the net present cost values for investment, operation and maintenance, total costs, payback, incremental internal rate of return and monomic prices for community micro grids evaluated under SDG scheme.

Table 1-18:
Micro Grid Net present value and average cost of supply over 20 years under SDG Business model



Locations	INV Total	COMA Total	Total	Average supply Cost	IRR	PAYBACK	Monohmic price
	M$US	M$US	M$US	$US/MWh	%	Years	$US/MWh
Putre	125	310	435	187	22%	7	222
PozoAlmonte	57	321	378	162	13%	14	166
Calama	89	282	371	159	16%	10	174
Antofagasta	58	327	385	166	15%	11	174
DiegodeAlmagro	44	289	334	143	20%	8	156
MontePatria	54	370	424	182	20%	8	199
LosAndes	66	344	411	176	20%	8	195
Santiago	61	305	366	157	17%	9	167
Pichilemu	138	297	434	187	16%	11	206
Linares	115	328	443	190	34%	4	272
Concepcion	70	336	407	175	18%	8	190
LosAngeles	140	242	381	164	27%	5	234
Temuco	61	378	439	188	20%	7	205
Valdivia	64	372	436	187	18%	9	201
Osorno	149	337	486	209	25%	6	274
Coyhaique	164	284	447	192	18%	8	226
PuntaArenas	45	313	358	154	21%	7	169

1.1.4 Optimal sizing and energy management for community Large Distributed generation

The economic viability of developing community micro grids under LDG scheme depends mainly on the renewable resource availability in the area and the prices of energy purchase / sale (stabilized price) and peak power tariffs. In this way, the optimum sizing and operation of the micro-grid is obtained under a scheme that remunerates the short-term nodal price adjusted to market price band plus power node price.

a) Scenarios operation and energy management of each MG

The operation of the micro-grid under LDG scheme can be classified into four possible operating scenarios and vary from place to place depending on the available renewable resource (solar or wind), the energy and power purchase prices power and prices of energy sales to the grid:

- **Micro grid is a solar and / or wind community that reduces peak demand demand**: it uses solar and / or wind energy to supply demand and also manages demand efficiently to make load shifting and uses diesel generation for peak shaving because energy and power rates are expensive. This occurs in Antofagasta, Calama, Los Andes, Santiago, Concepcion, Temuco and Valdivia.
- **Micro grid is a self-sufficient solar community**: it takes advantage of the good solar resource to self-supply demand and the rest of the demand is supplied with energy from the grid since energy and power purchase prices are cheaper. This happens in Diego de Almagro.
- **Micro grid is a community of distributed energy resources that minimizes the purchase of energy from the grid**: it uses solar or wind resource, demand management, diesel generation and energy storage systems to supply most of the demand. In this way it minimizes the purchase of energy to the grid given the high prices of energy and power rates. Cases of Putre, Los Angeles, Osorno, Coyhaique, Pichilemu and Linares.
- **Micro grid is a community without renewable energy resources that reduce peak demand**: given the low purchase and injection energy prices of the grid and the high costs of wind investment, renewable sources are not installed instead diesel generation is used to reduce peak demand.

b) MG size and annualized cost of Investment, Operation, Maintenance and total costs of DERs

Regarding installed capacity in community micro grid evaluated under LDG (PMGD), solar PV is installed in much of the central-south, central and north (Concepción al Norte) zone with power factors between 18% and 24 %, the maximum being the case of

Calama which has a high irradiance (7.44 kWh / m2-day). In some cases in the south where the available solar resource is smaller (Osorno and Temuco) it is economically feasible to supply demand with PV solar generation with average power factors of 14-15%. Finally, in other cases where the irradiance and production is even lower (e.g. Coyhaique: 3.22 kWh / m2-day and Valdivia: 3.55 kWh / m2-day) self-supply with power factors of 14% is still economically feasible. The case of Los Andes, where 772 kW of solar generation is installed, is worthy of note given the high stabilized price of the area (78.4 US / MWh) and the good available solar resource.

Regarding installed capacity of wind turbines, energy is generated from the wind in Los Angeles and Coyhaique. The low installed capacity is due to the low wind resource of the zones evaluated and the low injection price. In the case of Coyhaique, the stabilized price is very high, which allows to install 330 kW of wind generation. Power factors range from 26% (e.g. Coyhaique) to 28% (e.g. Los Angeles).

Regarding BESS installed capacity, 48 kWh / 12 kW are installed in the Putre area, mainly to minimize the purchase of power to the grid, given the high power purchase prices ([41.6 US / kW-month , 44.66 US / kW-month]) and due to low prices of energy injection to the grid (65.3 US / kWh). In the same way, 46 kWh / 11.5 kW are installed in Monte Patria, 23 kWh / 5.6 KW in Pichilemu, 21 kWh in Linares and 18 kWh in Osorno. In this way, it is economically viable to store energy in daytime with PV solar generation and discharge it at times of greater system load. Thus, the BESS allow peak shaving the demand, being a technology complementary to diesel generation. This occurs only in places with high peak / non-peak power rates.

Regarding diesel generation, it is installed in all evaluated areas except in communities that pay cheap energy and power prices (e.g. Diego de Almagro). It is the most economical technology to reduce peak demand at times that there is no available solar resource and to meet demand in case of reducing peak power to the maximum. For cases of good solar resource, but where energy and power purchase rates are not relatively high, it is sufficient to reduce peak demand with diesel generation.

Of course, in places with higher energy purchase rates and power payments (e.g. Putre, Monte Patria, Pichilemu, Los Angeles, Linares, Valdivia, Osorno and Coyhaique), overburdened energy resources are over-installed to reduce peak power payment. On the other hand, in places with cheaper purchase tariffs (e.g. Pozo Almonte, Los Andes, Santiago, Antofagasta, Calama, Temuco, Concepción), RES installed capacity is needed to supply a part of demand and to inject surpluses into the grid. Also, diesel generation is used to reduce peak demand. Finally, in places with even cheaper energy and power purchase rates (e.g. Diego de Almagro), the most expensive power tariff is paid and the available solar resource of the area is used to install solar PV and inject the surplus to the grid. Table 6-21 summarizes the power factors, optimal installed capacity (S) for each location and the annualized costs ($ MUSD / year) of investment (I), operation and maintenance (OM), total costs of the micro- The average cost of supply using Solar PV, Wind, BESS and Diesel Gs.

Table 1-19:
Community LDG MG Size: Power factors, Installed capacity, Investment, operation and maintenance and total annualized costs of SPV, WTs, BESS, DG1EFF, DG2FLEX and average cost of supply.

	Solar PV					**Wind**					**BESS**					**DG1Eff**					**DG2Flex**					**MG DGs Total**					
	f	S	I	M	T	f	S	I	M	T	f	S	I	M	T	f	S	I	OM	T	f	S	I	OM	T	f	S	I	OM	MG	u
Locations	%	kW	$	$	$	%	kW	$	$	$	%	kWh	$	$	$	%	kW	$	$	$	%	kW	$	$	$	%	kW	$	$	$	$/E
Putre	22	109	14	1	16	0	0	0	0	0	16	48	3	0	3	28	38	2	18	20	31	24	1	14	15	24	183	20	34	54	0.20
PozoAlmonte	22	100	13	1	14	0	0	0	0	0	0	0	0	0	0	16	11	1	3	4	9	13	1	2	3	16	124	14	7	21	0.08
Calama	24	100	13	1	14	0	0	0	0	0	15	2	0	0	0	15	11	1	3	3	10	13	1	2	3	16	124	14	7	21	0.08
Antofagasta	19	100	13	1	14	0	0	0	0	0	0	0	0	0	0	15	13	1	3	4	9	13	1	2	3	14	125	14	7	21	0.08
DiegodeAlmagro	23	100	13	1	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	100	13	1	14	0.05
MontePatria	19	119	15	2	17	0	0	0	0	0	16	46	3	0	3	27	38	2	19	21	29	24	1	14	15	23	192	21	35	55	0.20
LosAndes	21	772	100	10	110	0	0	0	0	0	0	0	0	0	0	8	10	0	1	2	7	13	1	2	2	12	794	101	13	114	0.42
Santiago	18	100	13	1	14	0	0	0	0	0	0	0	0	0	0	9	21	1	3	4	0	0	0	0	0	13	121	14	5	19	0.07
Pichilemu	18	106	14	1	15	0	0	0	0	0	17	23	1	0	1	29	39	2	19	21	31	25	1	14	15	24	176	18	34	52	0.19
Linares	18	103	13	1	15	0	0	0	0	0	17	21	1	0	1	29	39	2	19	21	31	25	1	14	15	24	172	18	35	52	0.19
Concepcion	18	100	13	1	14	0	0	0	0	0	0	0	0	0	0	9	10	1	2	2	8	13	1	2	3	11	123	14	5	19	0.07
LosAngeles	18	100	13	1	14	28	100	19	8	27	0	0	0	0	0	16	36	2	9	11	14	23	1	5	7	19	258	35	24	59	0.21
Temuco	15	100	13	1	14	0	0	0	0	0	0	0	0	0	0	9	11	1	2	2	8	13	1	2	3	10	124	14	5	19	0.07
Valdivia	15	100	13	1	14	25	0	0	0	0	0	0	0	0	0	9	20	1	3	4	0	0	0	0	0	16	120	14	5	19	0.07
Osorno	14	101	13	1	14	0	0	0	0	0	17	18	1	0	1	30	39	2	22	24	32	25	1	16	17	23	171	17	39	57	0.21
Coyhaique	15	115	15	2	16	26	330	62	26	89	0	0	0	0	0	13	43	2	11	13	8	21	1	4	5	15	511	81	43	123	0.45
PuntaArenas	0	0	0	0	0	33	0	0	0	0	0	0	0	0	0	7	8	0	1	1	6	13	1	2	2	15	21	1	3	4	0.01

c) MG energy generation to supply community demand consumption

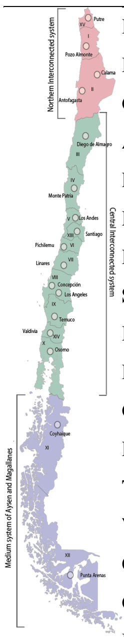
The energy production of renewable technologies that comprise each micro grid depends mainly on the availability of the solar and wind resource of the area. If you have a low-resource renewable scenario, you can supply the demand by purchasing energy and power from the grid or by using diesel generators.

When there is a good wind resource (eg Coyhaique), the production of energy comes mainly from the wind turbine, varying from 0.1% on a typical weekday of july (winter) to 275% on a typical weekday of january (summer). In addition, the installation of 100 kW of solar PV is economically viable and generates 69% of the demand for a typical weekday of january and 37% of the demand for a typical weekday of july. Moreover, the purchase of energy from the grid is minimized for the whole year. In the case of diesel generation, it is used throughout the year in Coyhaique, given the high purchase prices of peak / non-peak power. However, in Autumn and Winter the usage is greater (71% more) and also demand response programs are used, taking advantage of the good solar resource of the area, moving flexible loads to daytime. Figure 6-23 shows the energy management for the case of Coyhaique and Table 6-23 summarizes the energy generated and the number of energy demanded in the case of Coyhaique for a typical weekday of january and a typical weekday of july. Then, the same is done for the 12 months of the year and the percentages can be seen in table 6-22, which summarizes the total generation by technology for each location and the percentage that represents regarding demand.

In places with very expensive power purchase prices (e.g. Putre, Monte Patria, Linares, Osorno, Los Angeles, Coyhaique and Valdivia) the diesel generation comes from both the economic generator and the flexible generator and contributes to supply demand between 29% (i.e. Los Angeles) and 61% (i.e. Linares). In these same places, the purchase of energy and power is low ranging from 0.02% to 0.03% of energy to meet demand. Finally, in areas with cheaper energy purchase prices and power payments (Santiago, Los Andes, Punta Arenas, Calama, Antofagasta, Temuco and Pozo Almonte), the economic generator supplies the annual demand between 2% and 6%. Most of the demand is supplied by the purchasing of energy from the grid between 52% (eg Los Andes) and 96% (eg Punta Arenas).

Finally, self-consumption from RES under PMGD varies throughout the evaluated zones between 34% (e.g. Temuco) and 76% (e.g. Coyhaique). The case of Temuco is due to the low solar and wind resource of the area, supplying most of the demand with diesel generation, while the case of Coyhaique is due to the high wind resource in the area and the high injection price (stabilized price).

Table 1-20:
MG Energy Consumption under LDG business model: Energy produced during Horizon Time and its percentage regarding demand in each location



Energy	LOAD				GRID				ERNC								CONV			
Locations	Shed		DR		Purchased		Sold		Solar PV		Wind		ERNC Self-consumption		BESS		DG1EFF		DG2FLEX	
	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%
Putre	0.0	0%	0.1	0.8%	0.0	0%	-6.0	33%	14.0	78%	0.0	0%	8.0	45%	1.1	6%	6.1	33%	4.3	24%
PozoAlmonte	0.0	0%	0.1	0.5%	9.7	54%	-5.9	32%	12.6	69%	0.0	0%	6.7	37%	0.0	0%	1.0	6%	0.7	4%
Calama	0.0	0%	0.1	0.4%	9.6	53%	-6.9	38%	13.7	76%	0.0	0%	6.8	38%	0.0	0%	1.0	5%	0.7	4%
Antofagasta	0.0	0%	0.0	0.3%	9.9	55%	-4.6	26%	11.1	61%	0.0	0%	6.4	36%	0.0	0%	1.1	6%	0.7	4%
Diego de Almagro	0.0	0%	0.0	0.0%	11.5	63%	-6.4	36%	13.1	72%	0.0	0%	6.6	37%	0.0	0%	0.0	0%	0.0	0%
MontePatria	0.0	0%	0.2	0.9%	0.0	0%	-5.0	28%	13.3	74%	0.0	0%	8.3	46%	1.0	6%	6.0	33%	4.1	23%
LosAndes	0.0	0%	0.1	0.6%	9.4	52%	-84.2	465%	91.9	508%	0.0	0%	7.8	43%	0.0	0%	0.5	3%	0.5	3%
Santiago	0.0	0%	0.1	0.7%	10.5	58%	-3.7	21%	10.2	57%	0.0	0%	6.5	36%	0.0	0%	1.1	6%	0.0	0%
Pichilemu	0.0	0%	0.2	1.3%	0.0	0%	-3.8	21%	11.1	61%	0.0	0%	7.3	41%	0.6	3%	6.5	36%	4.4	25%
Linares	0.0	0%	0.3	1.4%	0.0	0%	-3.2	18%	10.4	58%	0.0	0%	7.2	40%	0.5	3%	6.5	36%	4.5	25%
Concepcion	0.0	0%	0.1	0.4%	10.5	58%	-3.8	21%	10.3	57%	0.0	0%	6.5	36%	0.0	0%	0.5	3%	0.6	3%
LosAngeles	0.0	0%	0.2	1.1%	0.0	0%	-13.6	75%	10.3	57%	16.2	90%	13.0	72%	0.0	0%	3.2	18%	1.9	11%
Temuco	0.0	0%	0.1	0.4%	10.8	60%	-2.2	12%	8.4	47%	0.0	0%	6.2	34%	0.0	0%	0.5	3%	0.6	3%
Valdivia	0.0	0%	0.2	0.9%	10.8	0%	-2.5	14%	8.8	49%	0.0	0%	6.3	35%	0.0	0%	1.0	6%	0.0	0%
Osorno	0.0	0%	0.3	1.4%	0.0	0.00%	-1.5	8%	8.3	46%	0.0	0%	6.7	37%	0.4	2%	6.8	38%	4.6	26%
Coyhaique	0.0	0%	0.2	1.2%	0.0	0%	-45.1	250%	9.7	53%	49.2	272%	13.8	76%	0.0	0%	3.3	18%	1.0	6%
PuntaArenas	0.0	0%	0.2	1.3%	17.4	96%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.3	2%	0.4	2%

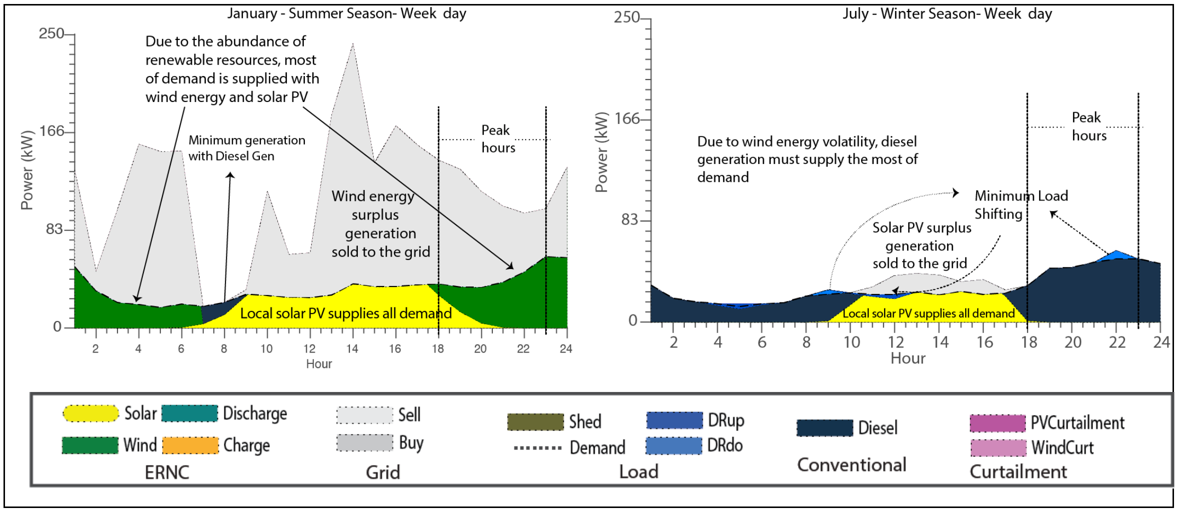


Figure 1-4: Micro Grid Energy Management in Coyhaique under LDG business model: winter and Summer week days

Table 1-21:
MG Energy consumption under LDG mode: Energy generated during a typical summer day and autumn day and each percentage regarding demand in the case of Coyhaique

		kWh	%	+%	kWh	%	+%
ERNC	Solar	550	69%	344%	250	37%	
	Wind	2190	275%		1	0.14%	40%
	BESS	0	0%		0	5%	
CONV	Diesel	35	4%	4.4%	504	74%	4%
GRID	BUY	0	0%	4%	0	0%	0%
	SELL	-1978	-248%		-76	-11.14%	
LOAD	DR	0	0%	6%	11	1.6%	5%
	SHED	0	0%		0	0%	
		797	100%		679	100%	

i) Detailed daily operational cost for the case of Coyhaique

The community micro grid located in areas where there is a moderate wind resource as the case of Coyhaique, tends to minimize the average cost of supplying the network as much as possible through renewable self-sufficiency and in case the peak power purchase rate is relatively high, it will avoid buying power from the grid at peak hours through two technologies: efficiently managing a minimum of the electricity demand by transferring flexible load from peak hours (e.g. washing machine, dishwasher, ironing) to daytime when there is sufficient solar generation, and through diesel generation, which is fast enough and flexible enough to supply generation ramps due to the intermittent wind resource. In this way, the costs of efficiently managing demand and fuel costs are higher during Autumn - Winter. Regarding revenues for energy sales to the grid, these latter are higher in the months of greater wind production. Table 6-24 summarizes the costs of fuel, demand management, energy purchase / sale, and power purchase for the Coyhaique case for each week (W) and weekend (WD) of the year.

Table 1-22:
Daily operational costs: fuel, grid exchange costs, demand response, peak power costs and revenues from selling energy to grid for the case of Coyhaique under LDG model

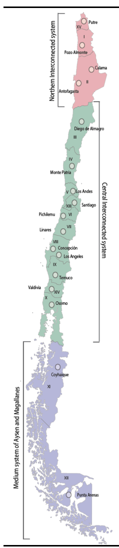
				Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**12 days**	**Year**
				US	US	US	US	US	US	US	US	US	US	US	US	MUS	MUS
Technology	**Diesel**	DG1Eff	W	7	7	0	1	73	26	62	75	50	0	10	0	311	6740
			WD	7	22	38	32	38	46	48	54	45	42	33	0	404	3539
		DG2Flex	W	0	0	0	3	25	12	48	27	25	0	0	0	140	3030
			WD	0	0	23	3	10	0	28	20	2	2	2	0	90	788
	Grid	BUY	W	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			WD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		SELL	W	-183	-528	-233	-299	-23	-164	-7	-11	-55	-578	-65	-352	-2498	-54123
			WD	-294	-155	-54	-87	-72	-16	-45	-43	-142	-108	-74	-596	-1686	-14756
		POWER	W - WD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Load	DR	W	0	0	0	0	7	2	2	3	8	0	2	0	26	570
			WD	0	1	0	1	1	2	4	7	3	4	0	0	23	199

d) Levelized costs of Energy Distributed Energy Resources for every community Large DG

The economic feasibility of installing distributed energy resources in a LDG regime is based on that the energy costs of these latter technologies are lower than the costs of connection and purchase of energy from the network. The objective of reducing investment and operating costs is translated into injecting energy in case of high stabilized price and shifting the energy purchased from the grid through renewable and using efficient diesel generation to reduce peak demand, thus avoid paying a higher peak rate.

The most economically feasible micro grid under the LDG scheme is the one which has a good solar resource, the stabilized price is relatively high and energy and power purchase prices are relatively cheap (i.e. Los Andes: 12 USD / MWh).

Table 1-23:
Levelized Cost of Energy (LCOE) for micro grid DERs and grid: Investment LCOE, Operation and Maintenance LCOE and total LCOE expressed in USD/MWh. under LDG model



Locations	DG1			DG2			SolarPV			BESS			Wind			LCOE mean	Grid	uGrid
	I	OM	ST	I	OM	ST	I	M	ST	I	M	ST	I	M	ST	O	O	T
Putre	20	204	**224**	18	209	**227**	79	8	**87**	182	22	**205**	0	0	**0**	**186**	**0**	**169**
PozoAlmonte	36	191	**227**	63	228	**291**	81	8	**90**	0	0	**0**	0	0	**0**	**203**	**194**	**155**
Calama	37	197	**234**	60	234	**294**	75	8	**82**	198	24	**223**	0	0	**0**	**208**	**194**	**145**
Antofagasta	37	194	**231**	66	231	**297**	92	9	**102**	0	0	**0**	0	0	**0**	**210**	**191**	**159**
DiegodeAlmagro	0	0	**0**	0	0	**0**	78	8	**86**	0	0	**0**	0	0	**0**	**86**	**175**	**134**
MontePatria	21	212	**233**	19	218	**237**	91	9	**100**	182	22	**204**	0	0	**0**	**194**	**0**	**175**
LosAndes	66	195	**261**	80	229	**309**	86	9	**95**	0	0	**0**	0	0	**0**	**221**	**220**	**12**
Santiago	63	206	**269**	0	0	**0**	100	10	**110**	0	0	**0**	0	0	**0**	**190**	**171**	**148**
Pichilemu	20	196	**216**	18	202	**220**	98	10	**108**	170	21	**191**	0	0	**0**	**184**	**0**	**172**
Linares	19	197	**216**	18	202	**220**	101	10	**111**	166	20	**186**	0	0	**0**	**183**	**0**	**173**
Concepcion	65	201	**266**	72	230	**302**	99	10	**109**	0	0	**0**	0	0	**0**	**226**	**197**	**160**
LosAngeles	36	191	**227**	42	203	**245**	99	10	**109**	0	0	**0**	74	31	**104**	**172**	**0**	**136**
Temuco	65	204	**269**	75	234	**309**	121	12	**134**	0	0	**0**	0	0	**0**	**237**	**209**	**181**
Valdivia	63	222	**285**	0	0	**0**	116	12	**128**	0	0	**0**	92	39	**131**	**181**	**0**	**185**
Osorno	19	216	**235**	17	222	**239**	126	13	**138**	173	21	**194**	0	0	**0**	**202**	**144**	**200**
Coyhaique	45	231	**276**	61	242	**303**	122	12	**134**	0	0	**0**	78	33	**110**	**206**	**0**	**202**
PuntaArenas	84	207	**291**	93	242	**335**	0	0	**0**	0	0	**0**	74	31	**105**	**244**	**146**	**156**

e) Total costs of MG: Net present value and average supply cost

Community micro grid deployment planning evaluated under LDG scheme ssuggests installing solar PV in most of Chile in places with average radiation of at least 4.18 kWh

/ m2-day (e.g. Coyhaique). Each optimum configuration of the community micro grid with the LDG program represents the best economic option to meet demand in a 20-year horizon given the costs of investment, maintenance and operation of technologies and energy purchase / sale prices. The net present cost value of investing in distributed energy resources for communities of 15 houses with a peak demand of 69 kW at a capital cost rate of 10% over a 20 year time horizon varies between M$US 110 (i.e. Diego de Almagro) and M$ US858 (i.e. Los Andes), while the present net cost value of operating costs, which include costs of energy purchase / sale to the grid, demand management, On / off of diesel generators and fuel, load shedding and maintenance, vary between M $ US -830 (i.e. Los Andes) because it supplies most of the demand with solar generation and sells a large part ff this energy to the grid, given the high stabilized price. Although it replenishes the remaining demand with diesel generation, energy injection revenues amortize the cost of operating the fuel, and M $ US 318 (i.e. Osorno) because it supplies most of the demand with diesel generation, minimizing the purchase of energy from the grid, and energy sales are much lower than Los Andes case. Finally, the net present cost value of developing micro grids varies between M$US 29 (i.e. Los Andes) and M $ US 465 (i.e. Osorno). Finally, the return on investment (seen as the year in which the micro-network starts to generate savings) varies between 2 years (Punta Arenas) and 17 years (Coyhaique). This mainly depends on the purchase / sale prices of energy and peak / non-peak power and the availability of renewable resources. In the case of Punta Arenas, the monomic price is relatively low and only diesel generation is installed to avoid that the consumption is rated as peak present under Chilean regulation which allows savings in the short term but only a few in the long term. In contrast, in Coyhaique, the renewable solar resource is moderate, as is the wind resource that is very volatile, and the monomic price of energy is high, which implies an extra cost in diesel generation. Regarding the incremental internal rate of return between the project without micro grid and with micro grid it varies between 11% (Coyhaique) and 73% (Punta Arenas).

Table 6-26 shows the net present cost values for investment, operation and maintenance, total costs, payback, incremental internal rate of return and monomic prices for community micro grids evaluated under LDG scheme.

Table 1-24:
Micro Grid Net present value and average cost of supply over 20 years under LDG Business model

D =2.32 GWh	**Locations**	**INV Total** M$US	**COMA Total** M$US	**Total** M$US	**Average supply Cost** $US/MWh	**IRR** %	**PAYBACK** Years	**Monohmic price** $US/MWh
	**Putre**	168	225	394	169	22%	7	222
	PozoAlmonte	120	241	361	155	14%	13	166
	Calama	121	218	338	145	18%	9	174
	Antofagasta	120	249	370	159	15%	12	174
	DiegodeAlmagro	110	203	313	134	17%	9	156
	MontePatria	178	230	408	175	16%	11	199
	LosAndes	858	-830	29	12	17%	9	195
	Santiago	119	225	344	148	16%	10	167
	Pichilemu	154	246	401	172	19%	8	206
	Linares	150	254	404	173	32%	4	272
	Concepcion	120	254	373	160	19%	8	190
	LosAngeles	295	22	317	136	21%	7	234
	Temuco	120	303	422	181	17%	9	205
	Valdivia	118	312	430	185	15%	11	201
	Osorno	147	318	465	200	27%	5	274
	Coyhaique	686	-215	471	202	11%	17	226
	PuntaArenas	9	354	363	156	73%	2	169

1.1.5 Optimal sizing and energy management for community Isolated Micro Grid

The economic viability of developing community micro grids under the IMG scheme depends mainly on the renewable resource available in the area. In this way, the optimum sizing and operation of the micro grid is obtained by being disconnected from the network.

a) Scenarios operation and energy management of each MG

The operation of the micro grid under the self-supply scheme without centralized local supply can be classified in an operating scenario and varies from place to place depending on the available renewable resource (solar or wind):

- **Micro grid is a community of distributed energy resources**: it uses solar or wind resource, demand management, diesel generation and energy storage systems to meet demand.

b) MG size and annualized cost of Investment, Operation, Maintenance and total costs of DERs

Regarding installed capacity of the community micro grid evaluated under IMG, solar PV is installed in much of Chile (Coyhaique to Putre) with power factors between 14% and 24%.

Regarding wind turbines installed capacity, wind energy is mainly generated in the south of Chile (e.g. from Los Angeles to the south) and Pozo Almonte, Calama, Diego de Almagro and Pichilemu. In these last localities, the wind resource is not good, but given that the micro-grid is disconnected from the grid, even if there is a moderate resource, wind generation will be installed capable of supplying demand. Its power factors range from 23% (e.g. Pozo Almonte) to 49% (e.g. Punta Arenas).

Regarding BESS installed capacity, it is deployed in all sites, from 7 kWh/2 kW (i.e. Temuco) to 51 kWh / 13 kW (i.e. Putre and Calama). In this way, it is economically viable to store energy in daytime with solar PV generation and discharge it in hours of greater load of the system.

Moreover, diesel generation is also installed in all sites and it is the most economical technology to reduce peak demand at times that there is a lack of solar resource.

Table 6-27 summarizes the power factors, optimal installed capacity (S) for each location and the annualized costs ($ MUSD / year) of investment (I), operation and maintenance (OM), total costs of the micro- The average cost of supply using Solar PV, Wind, BESS and Diesel Generators.

Table 1-25:
Community Isolated MG Size: Power factors, Installed capacity, Investment, operation and maintenance and total annualized costs of SPV, WTs, BESS, DG1EFF, DG2FLEX and average cost of supply.

	Solar PV					Wind					BESS					DG1Eff					DG2Flex					MG DGs Total					
	f	S	I	M	T	f	S	I	M	T	f	S	I	M	T	f	S	I	OM	T	f	S	I	OM	T	f	S	I	OM	MG	u
Locations	%	kW	$	$	$	%	kW	$	$	$	%	kWh	$	$	$	%	kW	$	$	$	%	kW	$	$	$	%	kW	$	$	$	$/E
Putre	22	57	9	1	10	0	0	0	0	0	14	51	3	0	3	32	38	2	22	23	28	25	1	12	13	24	133	15	35	50	0.18
PozoAlmonte	22	56	9	1	9	23	38	12	3	15	15	38	2	0	2	28	28	1	13	14	20	18	1	6	7	22	149	25	23	48	0.18
Calama	24	43	7	1	7	33	38	12	3	15	16	51	3	0	3	19	38	2	13	15	22	13	1	5	6	23	144	24	22	46	0.17
Antofagasta	19	68	10	1	11	0	0	0	0	0	15	49	3	0	3	32	38	2	22	23	28	25	1	13	14	24	143	16	36	52	0.19
DiegodeAlmagro	23	52	8	1	9	24	20	6	2	8	15	33	2	0	2	28	36	2	18	20	24	23	1	10	11	23	139	19	30	49	0.18
MontePatria	19	63	10	1	10	0	0	0	0	0	15	35	2	0	2	33	38	2	23	25	29	25	1	13	15	24	134	15	37	52	0.19
LosAndes	21	62	10	1	10	0	0	0	0	0	16	41	2	0	3	33	38	2	22	24	28	25	1	12	13	24	135	15	35	50	0.18
Santiago	18	63	10	1	10	0	0	0	0	0	16	24	1	0	1	33	40	2	23	25	30	26	1	14	15	24	134	14	38	52	0.19
Pichilemu	18	57	9	1	10	27	9	3	1	3	16	24	1	0	1	32	38	2	21	23	27	25	1	12	13	24	135	16	34	50	0.18
Linares	18	59	9	1	10	0	0	0	0	0	16	14	1	0	1	33	42	2	24	26	28	27	1	13	15	24	131	13	38	51	0.19
Concepcion	18	65	10	1	11	0	0	0	0	0	15	30	2	0	2	33	39	2	24	25	29	25	1	13	15	24	136	15	38	53	0.19
LosAngeles	18	21	3	0	4	46	32	10	3	12	17	10	1	0	1	25	37	2	15	17	25	24	1	10	11	26	116	17	28	44	0.16
Temuco	15	63	10	1	11	20	10	3	1	4	16	7	0	0	0	34	39	2	24	26	28	25	1	13	14	23	139	16	39	55	0.20
Valdivia	15	50	8	1	8	38	23	7	2	9	16	16	1	0	1	28	37	2	19	21	24	24	1	12	13	24	137	19	34	52	0.19
Osorno	14	60	9	1	10	25	16	5	1	6	16	9	1	0	1	32	40	2	23	25	26	26	1	13	14	22	143	18	38	56	0.20
Coyhaique	15	32	5	0	5	38	30	9	2	12	16	21	1	0	1	27	37	2	18	20	26	24	1	12	13	24	129	19	33	51	0.19
PuntaArenas	0	0	0	0	0	49	41	13	3	16	16	43	2	0	3	24	38	2	17	19	22	24	1	11	12	28	113	18	31	49	0.18

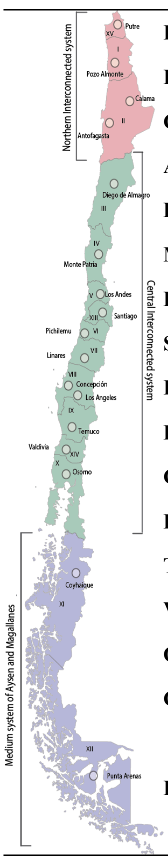
c) MG energy generation to supply community demand consumption

When there is a moderate solar resource (e.g. in Santiago) the production of energy mainly comes from solar PV ranging from 26.5% in a typical weekday of may (autumn) and 44.7% in a typical weekday of january (summer). In the case of diesel generation, it is used throughout the year in Santiago. However, in Autumn and Winter the use is greater (16% more) and also demand response programs are used taking advantage of the solar resource of the area, moving flexible loads to daytime. Figure 6-24 shows the energy management for the case of Santiago and Table 6-29 summarizes the energy management in the case of Santiago for january and may. Then, the same is done for the 12 months of the year and the percentages can be seen in table 6-28, which summarizes the total generation by technology for each location and the percentage that represents regarding demand. The most economical diesel generates between 23% (e.g. Calama) and 44% (e.g. Linares) of the annual energy demand, while the more flexible generator supplies between 9% and 24% (e.g. Santiago and Linares).

The total energy demanded in the 24 days of evaluation corresponds to 18 MWh with a peak of 69 kW. In areas with good solar resources (Santiago to the north), community demand is mainly supplied by PV solar generation during daytime hours. While in areas with a good wind resource (Los Angeles to the south) demand is mainly supplied by wind generation throughout the day, given its high volatility and intermittency.

Table 1-26:

MG Energy Consumption under IMG business model: Energy produced during Horizon Time and its percentage regarding demand in each location



Energy	LOAD				GRID				ERNC								CONV			
Locations	Shed		DR		Purchased		Sold		Solar PV		Wind		ERNC Self-consumption		BESS		DG1EFF		DG2FLEX	
	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%	MWh	%
Putre	0.0	0.03%	0.4	2.4%	0.0	0%	0.0	0%	7.4	41%	0.0	0%	7.4	41%	1.0	6%	7.1	39%	4.0	22%
PozoAlmonte	0.0	0.01%	0.1	0.7%	0.0	0%	0.0	0%	7.0	39%	5.0	28%	12.1	67%	0.8	5%	4.4	25%	2.1	11%
Calama	0.0	0.02%	0.4	2.3%	0.0	0%	0.0	0%	5.8	32%	7.2	40%	13.1	73%	1.2	6%	4.2	23%	1.6	9%
Antofagasta	0.0	0.03%	0.3	1.9%	0.0	0%	0.0	0%	7.5	41%	0.0	0%	7.5	42%	1.1	6%	6.9	38%	4.0	22%
Diego de Almagro	0.0	0.02%	0.4	2.2%	0.0	0%	0.0	0%	6.8	38%	2.7	15%	9.5	53%	0.7	4%	5.8	32%	3.1	17%
MontePatria	0.0	0.03%	0.4	2.4%	0.0	0%	0.0	0%	7.0	39%	0.0	0%	7.0	39%	0.8	4%	7.3	40%	4.1	23%
LosAndes	0.0	0.03%	0.4	2.2%	0.0	0%	0.0	0%	7.4	41%	0.0	0%	7.4	41%	0.9	5%	7.1	40%	3.9	22%
Santiago	0.0	0.02%	0.3	1.9%	0.0	0%	0.0	0%	6.4	36%	0.0	0%	6.4	36%	0.5	3%	7.5	42%	4.4	24%
Pichilemu	0.0	0.00%	0.3	1.5%	0.0	0%	0.0	0%	6.0	33%	1.4	8%	7.4	41%	0.5	3%	7.1	39%	3.9	21%
Linares	0.0	0.00%	0.3	1.8%	0.0	0%	0.0	0%	6.0	33%	0.0	0%	6.0	33%	0.3	2%	8.0	44%	4.3	24%
Concepcion	0.0	0.02%	0.4	2.0%	0.0	0%	0.0	0%	6.7	37%	0.0	0%	6.7	37%	0.7	4%	7.5	42%	4.2	23%
LosAngeles	0.0	0.01%	0.2	0.9%	0.0	0.00%	0.0	0%	2.2	12%	8.3	46%	10.5	58%	0.2	1%	5.4	30%	3.5	19%
Temuco	0.0	0.00%	0.4	2.0%	0.0	0%	0.0	0%	5.3	29%	1.1	6%	6.4	35%	0.2	1%	7.8	43%	4.1	22%
Valdivia	0.0	0.01%	0.6	3.1%	0.0	0.01%	0.0	0%	4.4	24%	5.0	28%	9.4	52%	0.4	2%	6.0	33%	3.3	18%
Osorno	0.0	0.02%	0.3	1.6%	0.0	0.02%	0.0	0%	4.9	27%	2.2	12%	7.1	39%	0.2	1%	7.3	41%	3.8	21%
Coyhaique	0.0	0.00%	0.3	1.7%	0.0	0%	0.0	0%	2.7	15%	6.7	37%	9.4	52%	0.5	3%	5.9	33%	3.6	20%
PuntaArenas	0.0	0.00%	0.2	1.3%	0.0	0%	0.0	0%	0.0	0%	11.5	63%	11.5	64%	1.0	6%	5.1	28%	3.0	17%

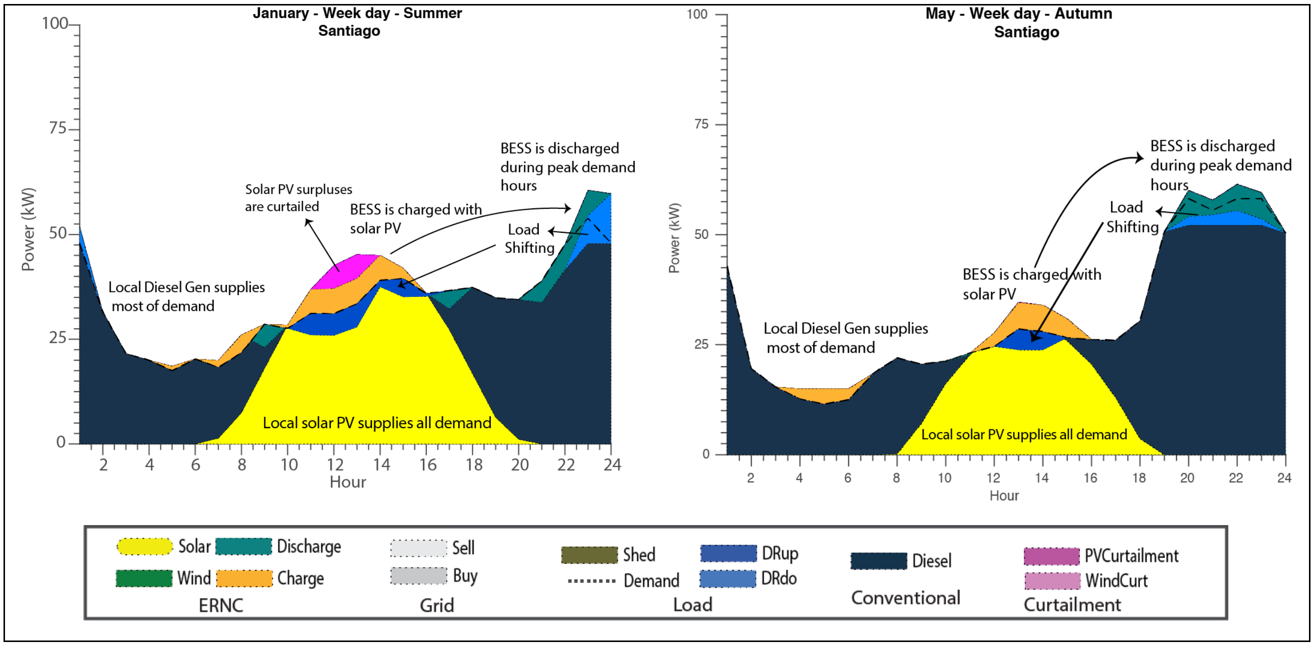


Figure 1-5: Micro Grid Energy Management in Santiago under IMG business model: Autumn and Summer week days

Table 1-27:
MG Energy consumption under IMG mode: Energy generated during a typical week summer day and autumn day and each percentage regarding demand in the case of Santiago

		kWh	%	+%	kWh	%	+%
ERNC	Solar	355	44.7%		196	26.5%	
	PV curt	-11	-1.5%	42%	0	0%	25.7%
	Wind	0	0%		0	0%	
	BESS	-8	-1.2%		-6	-0.8%	
CONV	Diesel	461	58%	58%	551	74.3%	74.3%
GRID	BUY	0	0%	0%	0	0%	0%
	SELL	0	0%		0	0%	
LOAD	DR	23	2.8%	0%	9	1.2%	1.2%
	SHED	0	0%		0	0%	
		797	100%		741	100%	

i) Detailed daily operational cost for the case of Santiago

The community micro grid located in areas where there is a good removable resource (solar or wind) as the case of Santiago tends to minimize the average cost of supply of the network as much as possible by efficiently managing the electrical demand by transferring flexible load (e.g. washing machine, dishwasher, ironing) from peak hours to daytime when there is sufficient solar generation, and through diesel generation, which is fast and flexible enough to supply generation ramps due to the intermittent wind resource, mainly. The table 6-30 summarizes the costs of fuel, demand management, energy purchase / sale, and power purchase for the Coyhaique case for each week (W) and weekend (WD) of the year.

Table 1-28:
Daily operational costs: fuel, grid exchange costs, demand response, peak power costs and revenues from selling energy to grid for the case of Santiago under IMG business model

				Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**12 days**	**Year**
				US	US	US	US	US	US	US	US	US	US	US	US	MUS	MUS
Technology	**Diesel**	DG1Eff	W	52	48	49	58	66	60	70	67	66	62	56	59	714	15467
			WD	57	55	66	59	67	71	65	67	67	65	51	65	757	6621
		DG2Flex	W	38	36	42	26	45	49	31	45	42	35	22	34	445	9649
			WD	41	37	44	35	32	36	37	35	37	43	31	44	453	3963
	Grid	BUY	W	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			WD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		SELL	W	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			WD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		POWER	W - WD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Load	DR	W	5	7	8	2	2	1	0	1	4	1	6	3	41	885
			WD	6	2	7	2	1	0	1	4	2	2	5	7	39	344
		Shed	W	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			WD	0	0	0	0	0	0	0	0	0	0	0	5	5	41

d) Levelized Cost of energy for Distributed Energy Resources for every community MG under Isolated business model

The economic viability of installing distributed energy resources in an IMG regime is based on that energy costs of these same technologies are less than the levelized costs of energy of using diesel generation to supply the entire demand.

The objective of reducing costs of investment and operation translates into displacing the supply from diesel generation by renewable supply.

The IMG scheme presents economic viability for self-sufficiency with a minimum of moderate solar resource (4.12 kWh / m2-day) and a moderate wind resource. Furthermore, the average cost of supply with a micro-grid will always be less than the cost of supplying demand with diesel generation. In general, the proposed scheme is economically viable throughout Chile, using renewable resources (RES), diesel generation and managing demand efficiently for self-sufficiency. The most economically viable micro-grid under the IMG scheme is the one which has a good wind resource (i.e. Los Angeles: US $ 164 / MWh). On the other hand, the least economically viable micro-grid is where there is a lack of renewable resources (GHI: 4.21 kWh / m2-day and wind speed: 3.99 m / s) as the case of Osorno which has an average supply cost of 209 US/MWh.

Table 1-29:
Levelized Cost of Energy (LCOE) for micro grid DERs: Investment LCOE, Operation and Maintenance LCOE and total LCOE expressed in USD/MWh. under IMG business model

Locations	DG1			DG2			SolarPV			BESS			Wind			LCOE mean	Grid	uGrid
	I	OM	ST	I	OM	ST	I	M	ST	I	M	ST	I	M	ST	O	O	T
Putre	17	201	**218**	20	210	**230**	95	8	**103**	209	26	**234**	0	0	**0**	**196**	**0**	**187**
PozoAlmonte	20	195	**215**	28	209	**237**	97	8	**105**	189	23	**212**	155	40	**195**	**193**	**0**	**178**
Calama	29	209	**238**	27	216	**243**	89	8	**97**	184	23	**206**	108	28	**135**	**184**	**0**	**173**
Antofagasta	17	205	**223**	20	215	**235**	110	9	**119**	192	23	**215**	0	0	**0**	**198**	**0**	**194**
DiegodeAlmagro	20	201	**221**	25	213	**238**	93	8	**101**	194	24	**218**	149	38	**187**	**193**	**0**	**185**
MontePatria	17	208	**225**	20	218	**238**	109	9	**118**	193	24	**217**	0	0	**0**	**199**	**0**	**196**
LosAndes	17	199	**217**	21	209	**230**	102	9	**111**	186	23	**209**	0	0	**0**	**192**	**0**	**188**
Santiago	17	201	**218**	19	209	**228**	119	10	**129**	185	23	**207**	0	0	**0**	**196**	**0**	**194**
Pichilemu	17	192	**209**	21	202	**224**	116	10	**126**	194	24	**218**	138	35	**174**	**190**	**0**	**187**
Linares	17	194	**211**	20	204	**224**	120	10	**130**	177	22	**199**	0	0	**0**	**191**	**0**	**191**
Concepcion	17	206	**223**	19	215	**234**	118	10	**128**	189	23	**212**	0	0	**0**	**199**	**0**	**198**
LosAngeles	23	186	**209**	23	193	**215**	118	10	**128**	165	20	**185**	76	20	**96**	**167**	**0**	**164**
Temuco	16	209	**225**	20	220	**240**	145	12	**157**	192	24	**216**	169	43	**213**	**210**	**0**	**207**
Valdivia	20	215	**235**	23	226	**248**	138	12	**150**	177	22	**199**	97	25	**122**	**191**	**0**	**198**
Osorno	18	212	**230**	22	224	**245**	150	13	**162**	180	22	**202**	144	37	**180**	**204**	**0**	**209**
Coyhaique	21	214	**235**	23	223	**246**	145	12	**158**	158	19	**177**	87	22	**110**	**185**	**0**	**192**
PuntaArenas	22	206	**229**	24	214	**238**	0	0	**0**	164	20	**184**	79	20	**99**	**187**	**0**	**183**

e) Total costs of MG: Net present value and average supply cost

Each optimum configuration of the community micro grids with IMG represents the best economic option to supply the demand in a 20-year horizon given the costs of investment, maintenance and operation of the technologies. The net present cost value of investing in distributed energy resources for communities comprised of 15 houses with a peak demand of 69 kW at a capital cost rate of 10% over a 20 year time horizon varies between the M$ US 112 (i.e. Linares) and M$US211 (i.e. Pozo Almonte), while the net present cost value of operating costs, including demand management, on / off diesel generators and fuel, load shedding and maintenance, vary between M $ US 201 (i.e. Calama) because it supplies most of the demand with solar and wind generation, and M$US 335 (i.e. Osorno) because it supplies most of Demand with diesel generation. Finally, the net present cost value of developing community micro grids under IMG varies between M$US 382 (i.e. Los Angeles) and M$US 486 (i.e. Osorno). Table 6-32 shows the costs of investment, operation, total and average costs of supply for IMG in Chile.

Table 1-30:
Micro Grid Net present value and average cost of supply over 20 years under IMG Business model

Locations	INV Total M$US	COMA Total M$US	Total M$US	Average supply Cost $US/MWh
Putre	125	311	436	187
PozoAlmonte	211	204	415	178
Calama	201	201	402	173
Antofagasta	138	315	453	194
DiegodeAlmagro	160	270	430	185
MontePatria	125	333	457	196
LosAndes	127	310	437	188
Santiago	121	331	452	194
Pichilemu	136	299	435	187
Linares	112	331	444	191
Concepcion	126	335	460	198
LosAngeles	141	240	382	164
Temuco	138	345	483	207
Valdivia	158	304	462	198
Osorno	151	335	486	209
Coyhaique	158	290	448	192
PuntaArenas	154	273	427	183

1.1.6 Optimal sizing and energy management for residential Net-Billing scheme

The economic feasibility of developing residential micro grid under the RNB scheme mainly depends on the renewable resource availability in the area and energy purchase / sale prices. In this way, the optimum sizing and operation of the micro grid is obtained under a scheme that only remunerates the energy component of the retail rate.

a) Scenarios operation and energy management of each MG

The operation of the micro-grid under the RNB scheme can be classified into five possible operating scenarios and vary from place to place depending on the available renewable resource (solar or wind), energy purchase and sale prices:

- **Micro grid is a solar and / or wind residence that reduce peak demand**: it takes advantage of the solar and / or wind energy to supply a part of demand and uses diesel generation for peak shaving due to high energy purchase prices. This occurs in Pozo Almonte, Valdivia, Monte Patria, Los Andes and Punta Arenas.
- **Micro grid is a self-sufficient solar residence**: it takes advantage of the good solar resource to self-supply demand and the rest of the demand is supplied with energy from the grid since energy and power purchase prices are cheaper. This occurs in Diego de Almagro, Santiago, Calama, Antofagasta.
- **Micro grid is a residence of distributed energy resources that minimizes the purchase of energy from the grid**: it uses solar or wind resource and diesel generation to supply most of the demand. In this way it minimizes the purchase of energy to the grid given the high prices of energy purchase. Cases of Putre, Los Angeles, Osorno, Coyhaique, Pichilemu and Linares.
- **Micro network is a residence without renewable resources that minimizes the purchase of energy to the network**: it uses diesel generation to minimize the purchase of energy from the grid. Case of Osorno.
- **Micro network is a residence without renewable resources that reduce peak demand**: it uses diesel generation to reduce peak demand grid. Case of Temuco.

b) MG size and annualized cost of Investment, Operation, Maintenance and total costs of DERs

Regarding micro grid installed capacity under residential Net-Billing scheme, solar PV is installed in much of the central-south, central and north (Concepción al Norte) zone with power factors between 18% and 24%, being the maximum the case of Calama that has a high irradiance (7.44 kWh / m2-day). In most places where PV solar capacity is installed, Net-Billing is used, exporting surplus to the grid.

Regarding installed capacity of wind turbines, wind energy is mainly generated in southern Chile (e.g. Los Angeles, Valdivia, Coyhaique and Punta Arenas) and in Calama. In most of these places there is a good wind resource allowing supply of demand most of the day. However, due to its high volatility and intermittency, the maximum capacity limit (10 kW) is not installed in any of these places, but enough capacity is installed to reduce peak demand and self-supply a percentage of the demand. Its power factors range from 33% (e.g. Calama) to 49% (e.g. Punta Arenas).
Regarding energy storage systems, they are not installed anywhere and in the case of diesel generation, it is installed in most places except in communities that pay their distribution network operators relatively cheap energy prices as in the case of Diego de Almagro, Santiago, Calam and Antofagasta.

Table 6-33 summarizes the power factors, optimal installed capacity (S) for each location and the annualized costs ($ MUSD / year) of investment (I), operation and maintenance (OM), total costs of the micro- The average cost of supply using Solar PV, Wind, BESS and Diesel Generatorss.

Table 1-31:
Residential Net-Billing MG Size: Power factors, Installed capacity, Investment, operation and maintenance and total annualized costs of SPV, WTs, BESS, DG1EFF, DG2FLEX and average cost of supply.

	Solar PV					Wind					BESS					DG1Eff					DG2Flex					MG DGs Total					
	f	S	I	M	T	f	S	I	M	T	f	S	I	M	T	f	S	I	OM	T	f	S	I	OM	T	f	S	I	OM	MG	u
Locations	%	kW	$	$	$	%	kW	$	$	$	%	kWh	$	$	$	%	kW	$	$	$	%	kW	$	$	$	%	kW	$	$	$	$/E
Putre	22	3	1	0	1	0	0	0	0	0	26	0.02	0	0	0	32	5	0	3	3	0	0	0	0	0	27	9	1	3	4	0.17
PozoAlmonte	22	3	1	0	1	0	0	0	0	0	0	0	0	0	0	37	2	0	1	1	0	0	0	0	0	29	5	1	1	2	0.10
Calama	24	3	1	0	1	33	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	4	1	0	1	0.05
Antofagasta	19	2	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	2	1	0	1	0.03
DiegodeAlmagro	23	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	3	1	0	1	0.03
MontePatria	19	3	1	0	1	0	0	0	0	0	0	0	0	0	0	34	4	0	2	3	0	0	0	0	0	27	7	1	2	3	0.15
LosAndes	21	4	1	0	1	0	0	0	0	0	0	0	0	0	0	33	5	0	2	3	0	0	0	0	0	27	9	1	2	4	0.17
Santiago	18	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	2	0	0	0	0.02
Pichilemu	18	2	0	0	1	0	0	0	0	0	0	0	0	0	0	39	5	0	3	3	0	0	0	0	0	28	7	1	3	3	0.16
Linares	18	2	1	0	1	0	0	0	0	0	0	0	0	0	0	36	6	0	3	3	0	0	0	0	0	27	8	1	3	4	0.18
Concepcion	18	3	1	0	1	0	0	0	0	0	0	0	0	0	0	37	4	0	2	3	0	0	0	0	0	27	7	1	2	3	0.15
LosAngeles	0	0	0	0	0	46	5	2	0	2	0	0	0	0	0	25	5	0	1	2	0	0	0	0	0	35	9	2	2	4	0.19
Temuco	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	45	5	0	3	3	0	0	0	0	0	45	5	0	3	3	0.16
Valdivia	0	0	0	0	0	38	3	1	0	1	0	0	0	0	0	34	3	0	2	2	0	0	0	0	0	36	6	1	2	3	0.15
Osorno	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43	6	0	4	4	0	0	0	0	0	43	6	0	4	4	0.19
Coyhaique	0	0	0	0	0	38	3	1	0	1	0	0	0	0	0	34	4	0	2	2	0	0	0	0	0	36	7	1	2	4	0.17
PuntaArenas	0	0	0	0	0	49	3	1	0	2	0	0	0	0	0	30	2	0	1	1	0	0	0	0	0	39	5	1	1	3	0.12

c) MG energy generation to supply community demand consumption

When there is good wind resource (e.g. Valdivia), energy production is mainly provided from the wind turbine, varying between 40% on a typical weekday of January and 119% on a typical weekday of June (Autumn-winter season). Moreover, the purchase of energy from the network represents 16% of the energy demanded in the summer case, and 9% in the case of Winter. In the case of diesel generation, it is used throughout the year. However, in summer the use is higher (29% more). Figure 6-25 shows energy management for the case of Valdivia and Table 6-35 summarizes the energy generated in the case of Valdivia for a winter and summer days. Then, the same is done for the 12 months of the year, for a typical weekday and a typical weekend day for every month of the year, and the percentages can be seen on the table 6-34, which summarizes the total generation by technology for each Location and the percentage it represents regarding energy demanded.

The total energy demanded in the 24 days of evaluation corresponds to 1.3 MWh with a peak of 7.5 kW. In areas with good solar resources (Santiago to the north), community demand is mainly supplied by PV solar generation during daytime hours. While in areas with good wind resource (Los Angeles to the south) demand is mainly supplied by wind generation through the day, given its high volatility and intermittency. Finally, self-consumption from RES under the Net-Billing program varies across the evaluated zones between 10% (e.g. Linares) and 52% (e.g. Los Angeles). The Linares case is due to the lack of renewable resources, supplying the most of the demand with diesel generation, whereas the case of Los Angeles is due to the high wind resource in the zone, allowing at the same time minimizing the Purchase of energy from grid.

Table 1-32:
MG Energy Consumption under RNB business model: Energy produced during Horizon Time and its percentage regarding demand in each location

Energy	LOAD				GRID				ERNC								CONV			
Locations	**Shed**		**DR**		**Purchased**		**Sold**		**Solar PV**		**Wind**		**Self-supply**		**BESS**		**DG1EFF**		**DG2FLEX**	
	kWh	**%**	**kWh**	**%**	**kWh**	**%**	**kWh**	**%**	**kWh**	**%**	**kWh**	**%**	**kWh**	**%**	**kWh**	**%**	**kWh**	**%**	**kWh**	**%**
Putre	0.0	0%	0.0	0.0%	98	8%	-137	-11%	420	32%	0	0%	283	22%	0.0	0%	997	77%	0.0	0%
PozoAlmonte	0.0	0%	0.0	0.0%	588	45%	-59	-5%	356	27%	0	0%	297	23%	0.0	0%	490	38%	0.0	0%
Calama	0.0	0%	0.0	0.0%	950	73%	-125	-10%	447	34%	103	8%	425	33%	0.0	0%	0	0%	0.0	0%
Antofagasta	0.0	0%	0.0	0.0%	1140	88%	-17	-1%	252	19%	0	0%	234	18%	0.0	0%	0	0%	0.0	0%
Diego de Almagro	0.0	0%	0.0	0.0%	1091	84%	-45	-3%	328	25%	0	0%	283	22%	0.0	0%	0	0%	0.0	0%
MontePatria	0.0	0%	0.0	0.0%	257	20%	-80	-6%	357	27%	0	0%	277	21%	0.0	0%	841	65%	0.0	0%
LosAndes	0.0	0%	0.0	0.0%	173	13%	-184	-14%	499	38%	0	0%	314	24%	0.0	0%	887	68%	0.0	0%
Santiago	0.0	0%	0.0	0.0%	1172	90%	-6	0%	208	16%	0	0%	202	16%	0.0	0%	0	0%	0.0	0%
Pichilemu	0.0	0%	0.0	0.0%	146	11%	-81	-6%	226	17%	0	0%	145	11%	0.0	0%	1084	83%	0.0	0%
Linares	0.0	0%	0.0	0.1%	35	3%	-113	-9%	243	19%	0	0%	129	10%	0.0	0%	1210	93%	0.0	0%
Concepcion	0.0	0%	0.0	0.0%	239	18%	-60	-5%	285	22%	0	0%	224	17%	0.0	0%	911	70%	0.0	0%
LosAngeles	0.0	0%	0.0	0.0%	65	5%	-539	-41%	0	0%	1212	93%	672	52%	0.0	0%	638	49%	0.0	0%
Temuco	0.0	0%	0.0	0.0%	219	17%	-42	-3%	0	0%	0	0%	0%	0%	0.0	0%	1198	92%	0.0	0%
Valdivia	0.0	0%	0.0	0.0%	333	26%	-155	-12%	0	0%	658	51%	503	39%	0.0	0%	539	41%	0.0	0%
Osorno	0.0	0%	0.0	0.0%	65	5%	-97	-7%	0	0%	0	0%	0%	0%	0.0	0%	1406	108%	0.0	0%
Coyhaique	0.0	0%	0.0	0.0%	171	13%	-173	-13%	0	0%	608	47%	435	33%	0.0	0%	769	59%	0.0	0%
PuntaArenas	0.0	0%	0.0	0.0%	408	31%	-246	-19%	0	0%	888	68%	642	49%	0.0	0%	324	25%	0.0	0%

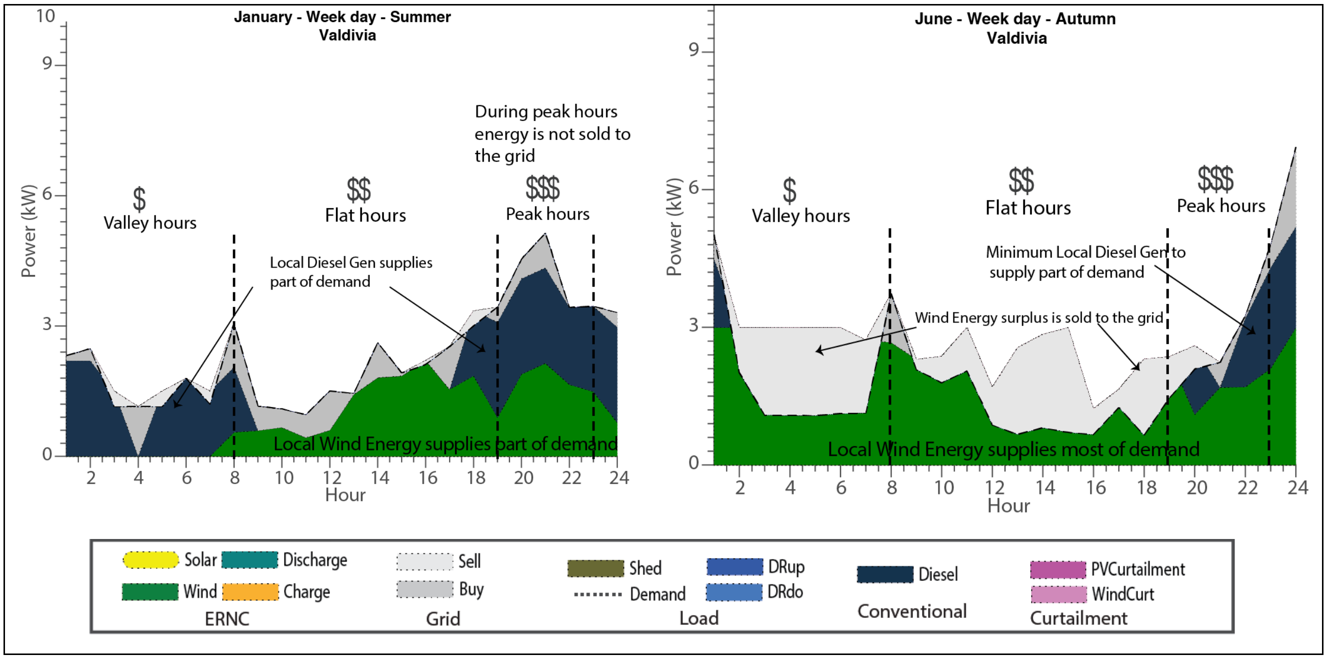


Figure 1-6: Micro Grid Energy Management in Valdivia under Residential Net-Billing business model: Autumn and Summer week days

Table 1-33:
MG Energy consumption under CNM mode: Energy generated during a typical summer week day and autumn week day and each percentage regarding demand in the case of Valdivia

		kWh	%	+%	kWh	%	+%
	Solar	0	0%	40%	0	0%	
ERNC	Wind	22.3	40%		58.5	119%	40%
	BESS	0	0%		0	0%	
CONV	Diesel	26.4	47%	47%	9	18%	4%
GRID	BUY	9	16%	13%	4.5	9%	4%
	SELL	-1.7	-3%		-23	-46%	
LOAD	DR	0	0%	0%	0	0%	0%
	SHED	0	0%		0	0%	
		56	100%		49	100%	

i) Detailed daily operational cost for the case of Valdivia

The residential micro grid located in areas where there is a good renewable resource (solar or wind) as the case of Valdivia, tends to minimize the average cost of supplying the network as much as possible through self-sufficiency and in case the energy rate is expensive through diesel generation, which is fast and enough flexible to supply generation ramps due to intermittent wind power. In this way, fuel costs are higher during summer in Valdivia given the intermittent wind resource. Regarding revenus for energy exports to the main grid, these are higher in the months of greater wind production. The table 6-36 summarizes the costs of fuel, demand management, energy purchase / sale for Valdivia case for each week (W) and weekend (WD) of every month the year.

La micro red residencial ubicada en zonas donde existe buen recurso removable (.e.g solar o viento) como el caso de Valdivia, tiende a minimizar el costo medio de abastecimiento de la red lo más posible a través del autoabastecimiento y en caso de que la tarifa de compra de energía sea, evitará comprar energia de la red en las horas de punta a través de generación diesel, que es lo suficientemente rápida y flexible para suplir rampas de generación debido a la intermitencia del recurso eólico, principalmente. De esta forma, los costos de combustible son mayors durante verano – primera en Valdivia dado la intermitencia del recurso eólico. Con respect a los revenus por venta de energia a la red, estas son mayors en los meses de mayor producción eólica. La table 21 resume los costos de uso de combustible, gestión de demanda, compra/venta de energia y compra de potencia a la red para el caso de Valdivia para cada día tipo de semana y cada día tipo de fin de semana del año bajo un esquema de Net-Billing.

Table 1-34:
Daily operational costs: fuel, grid exchange costs, demand response, peak power costs and revenues from selling energy to grid for the case of Valdivia under Residential Net-Billing business model

				Jan US	**Feb** US	**Mar** US	**Apr** US	**May** US	**Jun** US	**Jul** US	**Aug** US	**Sep** US	**Oct** US	**Nov** US	**Dec** US	**12 days** MUS	**Year** MUS
Technology	**Diesel**	DG1Eff	W	5	3	7	3	2	2	3	6	4	7	7	6	53	1146
			WD	6	2	2	6	6	4	3	3	2	4	6	3	46	401
		DG2Flex	W	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			WD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Grid	BUY	W	2	1	4	2	0	1	1	5	5	2	4	2	29	626
			WD	6	1	0	9	8	3	3	3	3	3	5	3	46	403
		SELL	W	0	-2	0	-1	-2	-2	-2	0	0	0	0	0	-10	-210
			WD	0	-1	-2	0	0	0	0	-1	0	-2	0	0	-7	-58

d) Levelized Cost of energy for Distributed Energy Resources for every residential MG under Net-Billing scheme

The economic feasibility of installing distributed energy resources in a residential Net-Billing regime is based on that the energy costs of these same technologies are lower than the costs of connection and purchase of energy from the grid. The objective of reducing investment and operating costs is translated into shifting the supply from the grid for renewable generation and into injecting surpluses in case of having and using efficient diesel generation to reduce peak demand avoiding a higher payment for energy purchase.

The residential Net-Billing scheme presents economic viability for self-sufficiency and for injecting surpluses into the grid with a minimum of moderate solar resource (5.2 kWh / m2-day) or a good wind resource. However, revenues from solar PV power sales are not enough to pay the investment on DERs.

On the other hand, in most cases, the levelized cost of energy of purchasing from the grid under the BT1 - THR tariff is greater than the cost of supplying the residential micro grid demand with DERs according to the Long-term planning throughout Chile. Also, the average cost of supply demand with a micro grid will always be less than the cost of supplying demand with the grid and without installing distributed energy resources. In general, the proposed scheme is economically viable throughout Chile, using renewable resources (RES) and diesel generation. The micro grid with the highest economic feasibility under the residential Net-Billing scheme is the one that has a good solar resource and low energy purchases from grid (i.e. Diego de Almagro: 155 USD / MWh).

Table 1-35:
Levelized Cost of Energy (LCOE) for micro grid DERs and grid: Investment LCOE, Operation and Maintenance LCOE and total LCOE expressed in USD/MWh. under Residential Net-Billing business model

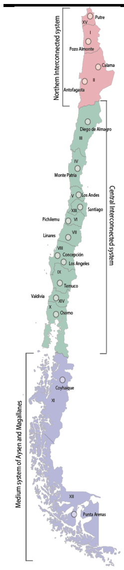
Locations	DG1			DG2			SolarPV			BESS			Wind			LCOE mean	Grid	uGrid
	I	OM	ST	I	OM	ST	I	M	ST	I	M	ST	I	M	ST	O	O	T
Putre	21	175	**196**	0	0	**0**	138	8	**146**	114	14	**128**	0	0	**0**	**157**	**0**	**178**
PozoAlmonte	18	175	**193**	0	0	**0**	141	8	**150**	0	0	**0**	0	0	**0**	**171**	**197**	**170**
Calama	0	0	**0**	0	0	**0**	130	8	**137**	0	0	**0**	142	28	**170**	**154**	**192**	**163**
Antofagasta	0	0	**0**	0	0	**0**	160	9	**170**	0	0	**0**	0	0	**0**	**170**	**190**	**170**
DiegodeAlmagro	0	0	**0**	0	0	**0**	136	8	**144**	0	0	**0**	0	0	**0**	**144**	**176**	**155**
MontePatria	19	182	**201**	0	0	**0**	158	9	**167**	0	0	**0**	0	0	**0**	**184**	**0**	**181**
LosAndes	20	174	**194**	0	168	**168**	149	9	**158**	0	0	**0**	0	0	**0**	**173**	**231**	**174**
Santiago	0	0	**0**	0	0	**0**	174	10	**184**	0	0	**0**	0	0	**0**	**184**	**187**	**170**
Pichilemu	17	167	**184**	0	0	**0**	170	10	**180**	0	0	**0**	0	0	**0**	**182**	**0**	**175**
Linares	19	168	**187**	0	0	**0**	175	10	**186**	0	0	**0**	0	0	**0**	**186**	**0**	**180**
Concepcion	18	179	**197**	0	0	**0**	172	10	**182**	0	0	**0**	0	0	**0**	**189**	**223**	**182**
LosAngeles	28	166	**194**	0	0	**0**	0	0	**0**	0	0	**0**	101	20	**120**	**157**	**0**	**157**
Temuco	15	180	**195**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	**195**	**229**	**189**
Valdivia	19	188	**207**	0	0	**0**	0	0	**0**	0	0	**0**	128	25	**153**	**180**	**0**	**185**
Osorno	16	184	**200**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	**200**	**307**	**196**
Coyhaique	21	189	**209**	0	0	**0**	0	0	**0**	0	0	**0**	115	22	**138**	**174**	**0**	**183**
PuntaArenas	21	180	**201**	0	0	**0**	0	0	**0**	0	0	**0**	105	20	**125**	**163**	**212**	**166**

e) Total costs of MG: Net present value and average supply cost

Residential micro grid planning under Net-Billing scheme suggests installing solar PV in most of Chile in places with average radiation of at least 5.2 kWh / m2-day (i.e. from Concepción to Putre).

Each optimized configuration of the residential micro grid with the Net-Billing program represents the best economic option to meet demand in a 20-year horizon given the costs of investment, maintenance and operation of technologies and the purchase / sale prices of Energy. The net present cost value of investing in distributed energy resources in a house with a peak demand of 7.5 kW at a capital cost rate of 10% over a 20 year time horizon varies between the M$US 3 (i.e. Osorno) and M $ US 18 (i.e. Los Angeles), while the net present cost value of operating costs, which include the costs of buying / selling energy to the grid, on / off Of diesel generators and fuel, and maintenance, vary between M $ US 10 (i.e. Los Angeles) because it supplies most of the demand with wind generation and although it supplies the remaining demand With diesel generation, energy injection revenues amortize the cost of operating the fuel, and the US $ 33 (eg Osorno) because it supplies most of the demand with diesel generation, minimizing the purchase of energy and also energy sales are much lower than the case of Los Angeles. Then, the net present cost value of developing micro grids ranges from M $ US 28 (i.e. Diego de Almagro) to M $ US 36 (e.g. Osorno). Finally, the return on investment (seen as the year in which the micro grid starts to generate savings) varies between 2 years (Osorno) and 16 years (Santiago). This mainly depends on the purchase / sale prices of energy from the grid and the availability of renewable resources. In the case of Santiago, the monomic price is relatively low and the house only invests in diesel generation to reduce peak demand. In contrast, in Osorno, the renewable solar resource is low and also the wind resource, but the monomic price of energy is high, which implies savings in the short term. Regarding the incremental internal rate of return between the project without micro grid and with micro grid it varies between 11% (Santiago) and 96% (Osorno).

Table 1-36:
Micro Grid Net present value and average cost of supply over 20 years under Residential Net-Billing Business model



Locations	INV Total M$US	COMA Total M$US	Total M$US	Average supply Cost $US/MWh	IRR %	PAYBACK Years
Putre	9	24	33	178	30%	5
PozoAlmonte	7	25	31	170	15%	12
Calama	8	22	30	163	14%	12
Antofagasta	4	27	31	170	12%	14
DiegodeAlmagro	5	24	28	155	13%	13
MontePatria	8	25	33	181	19%	8
LosAndes	10	22	32	174	20%	8
Santiago	4	27	31	170	11%	16
Pichilemu	6	26	32	175	26%	6
Linares	7	26	33	180	45%	3
Concepcion	7	26	33	182	19%	8
LosAngeles	18	10	29	157	24%	6
Temuco	2	32	35	189	47%	3
Valdivia	12	22	34	185	16%	11
Osorno	3	33	36	196	96%	2
Coyhaique	12	22	34	183	23%	6
PuntaArenas	12	18	30	166	16%	10

1.1.7 Optimal sizing and energy management for residential Net-Metering scheme

The economic viability of developing residential micro grids under the Net-Metering scheme mainly depends on the renewable resource availability in the area and energy purchase / sale prices. In this way, the optimum sizing and operation of the micro network is obtained under a scheme that remunerates the energy and power component of retail rate.

a) Scenarios operation and energy management of each MG

The operation of the micro-grid under the RNM scheme can be classified into three possible operating scenarios and vary from place to place depending on the available renewable resource (solar or wind), energy purchase and sale prices:

- **Micro grid is a solar and / or wind residence that reduce peak demand**: it takes advantage of the solar and / or wind energy to supply a part of demand and uses diesel generation for peak shaving due to high energy purchase prices. This occurs in Pozo Almonte, Valdivia, Monte Patria, Los Andes, Santiago, Temuco and Punta Arenas.
- **Micro grid is a self-sufficient solar residence**: it takes advantage of the good solar resource to self-supply demand and the rest of the demand is supplied with energy from the grid since energy and power purchase prices are cheaper. This occurs in Diego de Almagro, Calama and Antofagasta.
- **Micro grid is a residence of distributed energy resources that minimizes the purchase of energy from the grid**: it uses solar or wind resource and diesel generation to supply most of the demand. In this way it minimizes the purchase of energy to the grid given the high prices of energy purchase. Cases of Putre, Los Angeles, Osorno, Coyhaique, Pichilemu, Linares and Osorno.

b) MG size and annualized cost of Investment, Operation, Maintenance and total costs of DERs

Regarding residential micro grid installed capacity under Net-Metering business model, solar PV is installed in much of the central-south, central and north (Concepción al Norte) with power factors between 18% and 24%, being the maximum the case of Calama that has a high irradiance (7.44 kWh / m2-day). In some cases in the south where the available solar resource is lower (Osorno and Temuco) it is economically feasible to supply demand with PV solar generation with average power factors of 14-15%. In all the places where PV solar capacity is installed, Net-Metering is used, exporting the surplus to the grid at a price that incorporates the energy and power benefiting from this program.

Regarding installed capacity of wind turbines, energy is mainly generated from the wind in the south of Chile (e.g. Valdivia, Coyhaique and Punta Arenas) and in Los Angeles. In most of these places there is good wind resource allowing to supply demand most of the day. It installs enough wind energy to reduce peak demand with plant factors ranging from 38% (e.g. Coyhaique) to 49% (e.g. Punta Arenas).
Regarding diesel generation, it is installed in most places except in communities that pay their distribution network operators relatively cheap energy prices as in the case of Calama, Antofagasta and Diego de Almagro.

Table 6-39 summarizes the power factors, optimal installed capacity (S) for each location and the annualized costs ($ MUSD / year) of investment (I), operation and maintenance (OM), total costs of the micro grid DERs and The average cost of supply using Solar PV, Wind, BESS and Diesel Generators.

Table 1-37:
Residential Net-Metering MG Size: Power factors, Installed capacity, Investment, operation and maintenance and total annualized costs of SPV, WTs, BESS, DG1EFF, DG2FLEX and average cost of supply.

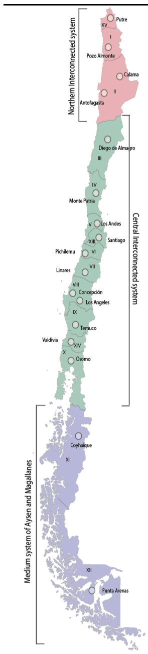
	Solar PV					Wind					BESS					DG1Eff					DG2Flex					MG DGs Total					
	f	S	I	M	T	f	S	I	M	T	f	S	I	M	T	f	S	I	OM	T	f	S	I	OM	T	f	S	I	OM	MG	u
Locations	%	kW	$	$	$	%	kW	$	$	$	%	kWh	$	$	$	%	kW	$	$	$	%	kW	$	$	$	%	kW	$	$	$	$/E
Putre	22	10	2	0	2	0	0	0	0	0	0	0	0	0	0	56	10	1	9	10	58	7	0	7	7	45	28	3	16	19	0.88
PozoAlmonte	22	10	2	0	2	0	0	0	0	0	0	0	0	0	0	50	6	0	5	5	0	0	0	0	0	36	16	3	5	8	0.36
Calama	24	10	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	10	2	0	2	0.11
Antofagasta	19	10	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	10	2	0	2	0.11
DiegodeAlmagro	23	10	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	10	2	0	2	0.11
MontePatria	19	10	2	0	2	0	0	0	0	0	0	0	0	0	0	62	10	1	10	10	69	6	0	6	7	50	25	3	16	19	0.90
LosAndes	21	10	2	0	2	0	0	0	0	0	0	0	0	0	0	58	10	1	9	10	65	6	0	6	7	48	27	3	16	19	0.88
Santiago	18	10	2	0	2	0	0	0	0	0	0	0	0	0	0	46	3	0	2	2	0	0	0	0	0	32	13	2	2	5	0.21
Pichilemu	18	10	2	0	2	0	0	0	0	0	0	0	0	0	0	60	11	1	9	10	64	6	0	6	6	47	27	3	16	19	0.87
Linares	18	10	2	0	2	0	0	0	0	0	0	0	0	0	0	57	11	1	10	10	60	7	0	6	7	45	28	3	16	19	0.89
Concepcion	18	10	2	0	2	0	0	0	0	0	0	0	0	0	0	63	10	1	10	10	68	6	0	6	7	49	26	3	16	20	0.91
LosAngeles	0	0	0	0	0	46	10	4	1	5	0	0	0	0	0	50	11	1	8	9	40	5	0	3	3	45	26	5	12	17	0.78
Temuco	15	10	2	0	2	0	0	0	0	0	0	0	0	0	0	65	10	1	11	11	67	6	0	6	7	49	26	3	17	20	0.95
Valdivia	0	0	0	0	0	38	10	4	1	5	0	0	0	0	0	64	7	0	8	8	59	4	0	4	4	54	21	5	13	17	0.81
Osorno	14	9	2	0	2	0	0	0	0	0	0	0	0	0	0	62	11	1	11	12	62	7	0	7	7	46	26	3	18	21	0.99
Coyhaique	0	0	0	0	0	38	10	4	1	5	0	0	0	0	0	56	10	1	9	9	53	5	0	4	5	49	25	5	14	19	0.89
PuntaArenas	0	0	0	0	0	49	10	4	1	5	0	0	0	0	0	65	7	0	7	7	0	0	0	0	0	57	17	4	8	12	0.57

c) MG energy generation to supply community demand consumption

When there is a good solar resource (e.g. Diego de Almagro), the production of energy is mainly provided by solar PV ranging from 100% on a typical weekday of July (winter season) and 105% on a typical weekday of January (Summer season). Moreover, the purchase of energy from the network represents 64% of the energy demanded in the summer case, and 76% in the case of Winter. In the case of diesel generation, it is not used, since the energy rate is relatively cheap. Figure 6-26 shows energy management for the case of Diego de Almagro and Table 6-41 summarizes the energy in the residential micro grid located in Diego de Almagro for a typical weekday of summer and typical weekday of winter. Then, the same is done for the 12 months of the year and the percentages can be seen in table 6-42, which summarizes the total generation by technology for each Location and the percentage it represents regarding energy demanded.

The total energy demanded in the 24 days of evaluation corresponds to 1.3 MWh with a peak of 7.5 kW. Self-consumption energy provided by RES under the Net-Billing program varies across the evaluated zones between 9% (e.g. Temuco and Osorno) and 52% (e.g. Los Angeles). Cases of Temuco and Osorno are due to a lack of renewable resources, and hence, supplying the most of the demand with diesel generation, whereas the case of Los Angeles is due to the high wind resource in the zone, allowing at the same time Minimizing the purchase of energy from the grid.

Table 1-38:
MG Energy Consumption under RNM business model: Energy produced during Horizon Time and its percentage regarding demand in each location



	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%
Putre	0.0	0%	0.5	0.0%	0	0%	-5684	-437%	1289	99%	0	0%	283	22%	0.0	0%	3346	257%	2425	187%
PozoAlmonte	0.0	0%	0.2	0.0%	68	5%	-1786	-137%	1256	97%	0	0%	297	23%	0.0	0%	1836	141%	0	0%
Calama	0.0	0%	0.0	0.0%	891	69%	-885	-68%	1369	105%	0	0%	425	33%	0.0	0%	0	0%	0	0%
Antofagasta	0.0	0%	0.0	0.0%	922	71%	-654	-50%	1107	85%	0	0%	234	18%	0.0	0%	0	0%	0	0%
Diego de Almagro	0.0	0%	0.0	0.0%	900	69%	-831	-64%	1305	100%	0	0%	283	22%	0.0	0%	0	0%	0	0%
MontePatria	0.0	0%	0.9	0.0%	0	0%	-5465	-420%	1123	86%	0	0%	277	21%	0.0	0%	3474	267%	2244	173%
LosAndes	0.0	0%	1.7	0.0%	0	0%	-5606	-431%	1191	92%	0	0%	314	24%	0.0	0%	3507	270%	2283	176%
Santiago	0.0	0%	1.3	0.0%	446	34%	-796	-61%	1023	79%	0	0%	202	16%	0.0	0%	703	54%	0	0%
Pichilemu	0.0	0%	0.5	0.0%	0	0%	-5627	-433%	1046	80%	0	0%	145	11%	0.0	0%	3663	282%	2293	176%
Linares	0.0	0%	1.4	0.0%	0	0%	-5710	-439%	1013	78%	0	0%	129	10%	0.0	0%	3745	288%	2330	179%
Concepcion	0.0	0%	0.0	0.0%	0	0%	-5511	-424%	1032	79%	0	0%	224	17%	0.0	0%	3579	275%	2274	175%
LosAngeles	0.0	0%	4.0	0.0%	0	0%	-5666	-436%	0	0%	2635	203%	672	52%	0.0	0%	3261	251%	1152	89%
Temuco	0.0	0%	0.0	0.0%	0	0%	-5555	-427%	842	65%	0	0%	120	9%	0.0	0%	3808	293%	2279	175%
Valdivia	0.0	0%	0.8	0.0%	0	0%	-4841	-372%	0	0%	2197	169%	503	39%	0.0	0%	2683	206%	1337	103%
Osorno	0.0	0%	0.0	0.0%	0	0%	-5695	-438%	693	53%	0	0%	115	9%	0.0	0%	4018	309%	2359	181%
Coyhaique	0.0	0%	5.2	0.0%	0	0%	-5542	-426%	0	0%	2201	169%	435	33%	0.0	0%	3137	241%	1589	122%
PuntaArenas	0.0	0%	0.6	0.0%	13	1%	-3896	-300%	0	0%	2799	215%	642	49%	0.0	0%	2458	189%	0	0%

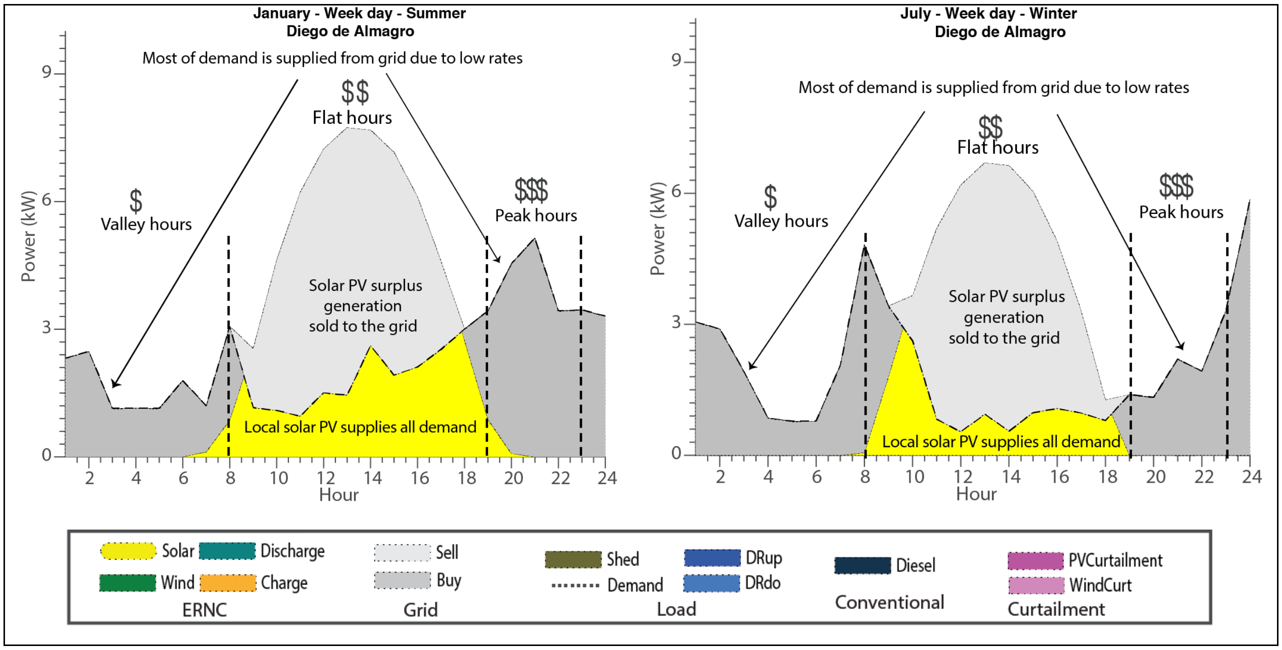


Figure 1-7: Micro Grid Energy Management in Diego de Almagro under Residential Net-Metering business model: Autumn and Summer week days

Table 1-39:
MG Energy consumption under RNM mode: Energy generated during a typical summer day and autumn day and each percentage regarding demand in the case of Diego de Almagro

		kWh	%	+%	kWh	%	+%
ERNC	Solar	59	105%	105%	46	100%	100%
	Wind	0	0%		0	0%	
	BESS	0	0%		0	0%	
CONV	Diesel	0	0%	0%	0	0%	0%
GRID	BUY	36	64%	-5%	35	76%	0%
	SELL	-39	-69%		-35	-76%	
LOAD	DR	0	0%	0%	0	0%	0%
	SHED	0	0%		0	0%	
		56	100%		46	100%	

i) Detailed daily operational cost for the case of Diego de Almagro

The residential micro grid located in areas where there is a good renewable resource (e.g. solar) such as the case of Diego de Almagro tends to minimize the average cost of supplying the network as much as possible through self-supply demand with solar PV and supply the remaining demand from the network . Table 6-42 summarizes the costs of buying / selling power grid for the case of Diego de Almagro for a typical weekday and typical weekend day for every month of the year under a Net-Metering scheme.

Table 1-40:
Daily operational costs: fuel, grid exchange costs,and revenues from selling energy to grid for the case of Diego de Almagro under Residential Net-Metering business model

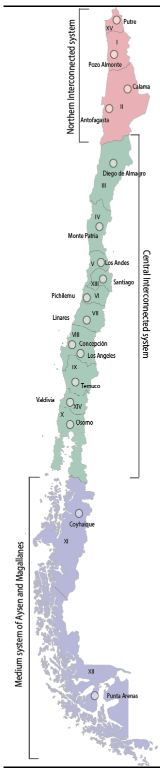
				Jan US	Feb US	Mar US	Apr US	May US	Jun US	Jul US	Aug US	Sep US	Oct US	Nov US	Dec US	12 days MUS	Year MUS
Technology	Diesel	DG1Eff	W	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			WD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		DG2Flex	W	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			WD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Grid	BUY	W	7	6	7	5	6	6	6	8	6	6	7	6	75	1634
			WD	7	8	8	8	8	7	8	8	6	7	8	4	87	764
		SELL	W	-3	-3	-3	-3	-3	-3	-3	-2	-3	-3	-3	-3	-36	-781
			WD	-3	-3	-3	-2	-2	-2	-2	-2	-3	-3	-3	-3	-30	-262

d) Levelized Cost of energy for Distributed Energy Resources for every residential MG under Net-Metering scheme

The residential Net-Metering scheme presents economic viability for self-sufficiency and for injecting surpluses into the grid with a minimum solar resource (4.21 kWh / m2-day) or a good wind resource. In this case, the revenues from sale of solar PV power is sufficient to pay for the investment in this technology.

In general, the proposed scheme is economically viable throughout Chile, using renewable resources and diesel generation to reduce peak demand. The most economically feasible micro grid under the residential Net-Metering scheme is the one which has a high energy injection price (Therefore, the energy purchase rate is expensive) and moderate solar resource (e.g. Linares: -274 USD / MWh). In contrast, the least economically viable micro-grid is where the removable resources are moderate and the purchase energy rate is cheap (150 US / kWh), as in the case of Santiago, which has an average Supply cost of 160 US / MWh.

Table 1-41:
Levelized Cost of Energy (LCOE) for micro grid DERs and grid: Investment LCOE, Operation and Maintenance LCOE and total LCOE expressed in USD/MWh. under Net-Metering business model

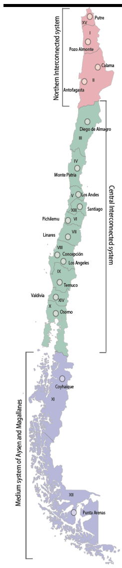


Locations	DG1			DG2			SolarPV			BESS			Wind			LCOE mean	Grid	uGrid
	I	OM	ST	I	OM	ST	I	M	ST	I	M	ST	I	M	ST	O	O	T
Putre	12	179	**191**	11	181	**192**	138	8	**146**	0	0	**0**	0	0	**0**	**176**	**0**	**-135**
PozoAlmonte	13	177	**190**	0	0	**0**	141	8	**150**	0	0	**0**	0	0	**0**	**170**	**189**	**129**
Calama	0	0	**0**	0	0	**0**	130	8	**137**	0	0	**0**	0	0	**0**	**137**	**195**	**120**
Antofagasta	0	0	**0**	0	0	**0**	160	9	**170**	0	0	**0**	0	0	**0**	**170**	**194**	**151**
DiegodeAlmagro	0	0	**0**	0	0	**0**	136	8	**144**	0	0	**0**	0	0	**0**	**144**	**179**	**126**
MontePatria	11	185	**196**	9	187	**196**	158	9	**167**	0	0	**0**	0	0	**0**	**187**	**0**	**75**
LosAndes	11	178	**189**	10	179	**189**	149	9	**158**	0	0	**0**	0	0	**0**	**179**	**0**	**24**
Santiago	12	171	**183**	0	0	**0**	174	10	**184**	0	0	**0**	0	0	**0**	**183**	**192**	**160**
Pichilemu	11	171	**182**	10	173	**183**	170	10	**180**	0	0	**0**	0	0	**0**	**182**	**0**	**8**
Linares	12	172	**183**	11	173	**184**	175	10	**186**	0	0	**0**	0	0	**0**	**184**	**0**	**-274**
Concepcion	10	183	**193**	10	184	**194**	172	10	**182**	0	0	**0**	0	0	**0**	**190**	**0**	**82**
LosAngeles	13	167	**181**	16	170	**186**	0	0	**0**	0	0	**0**	101	20	**120**	**162**	**0**	**-273**
Temuco	10	186	**196**	10	187	**197**	211	12	**223**	0	0	**0**	0	0	**0**	**205**	**0**	**85**
Valdivia	10	191	**201**	11	195	**206**	0	0	**0**	0	0	**0**	128	25	**153**	**187**	**0**	**71**
Osorno	11	189	**200**	11	191	**202**	218	13	**231**	0	0	**0**	0	0	**0**	**211**	**0**	**-132**
Coyhaique	12	193	**205**	13	196	**209**	0	0	**0**	0	0	**0**	115	22	**138**	**184**	**0**	**-84**
PuntaArenas	10	182	**192**	0	0	**0**	0	0	**0**	0	0	**0**	105	20	**125**	**158**	**219**	**38**

e) Total costs of MG: Net present value and average supply cost

Residential Micro grid Planning under Net-Metering scheme suggests installing solar PV in most of Chile in places with average radiation of at least 4.21 kWh / m2-day (eg Osorno). Each optimum configuration of the residential micro-networks with the Net-Metering program represents the best economic option to meet demand in a 20-year horizon given the costs of investment, maintenance and operation of the technologies and the purchase / sale prices of Energy. The net present cost value of investing in distributed energy resources for a house with a peak demand of 7.5 kW at a capital cost rate of 10% over a 20 year time horizon varies between the M $ US 19 (i.e. Calama, Antofagasta and Diego de Almagro) and M $ US 43 (i.e. Los Angeles), while the net present cost value of operating costs, which include costs of energy purchase / sale to the grid, on / off of diesel generators and fuel, and maintenance, vary between M $ US-93 (i.e. Los Angeles) because it supplies most of the demand with wind power generation and Despite supplying the remaining demand with diesel generation, energy injection revenues are very high compared to the cost of operating the diesel generators, and M $ US 9 (i.e. Santiago) because it supplies most of the demand With solar PV and diesel generation. In the same way, injection revenues are high compared to fuel costs. Then, the net present value of developing residential micro grids under Net-Metering scheme varies between M $ US-50 (e.g. Linares) and M $ US 29 (e.g., Santiago). Finally, the return on investment (seen as the year in which the micro grid starts to generate savings) varies between 2 years (Linares) and 16 years (Santiago). This mainly depends on the purchase / sale prices of energy from the grid and the availability of renewable resources. In the case of Santiago, the monomic price is relatively low and only invests in diesel generation to reduce peak demand. In contrast, in Linares, there is a lack of renewable resources but the monomic price of energy is high, which implies savings in the short term. Regarding the incremental internal rate of return between the project without micro grid and the project with micro grid it varies between 12% (Santiago) and 60% (Osorno).

Table 1-42:
Micro Grid Net present value and average cost of supply over 20 years under Net-Metering Business model



Locations	INV Total M$US	COMA Total M$US	Total M$US	Average supply Cost $US/MWh	IRR %	PAYBACK Years
Putre	28	-52	-25	-135	45%	3
PozoAlmonte	22	2	24	129	17%	10
Calama	19	3	22	120	17%	9
Antofagasta	19	9	28	151	13%	13
DiegodeAlmagro	19	4	23	126	15%	11
MontePatria	27	-13	14	75	24%	6
LosAndes	27	-23	4	24	29%	5
Santiago	20	9	29	160	12%	16
Pichilemu	27	-26	1	8	30%	5
Linares	28	-78	-50	-274	60%	2
Concepcion	27	-12	15	82	23%	6
LosAngeles	43	-93	-50	-273	40%	3
Temuco	27	-11	16	85	23%	6
Valdivia	40	-27	13	71	19%	8
Osorno	25	-49	-24	-132	51%	3
Coyhaique	42	-58	-15	-84	29%	5
PuntaArenas	38	-31	7	38	20%	7

1.2 Comparison of MG business models

Each of the previously mentioned and explained micro-grid business models is a long-term planning alternative for a single home or community so they can meet their demand with DERs: RES + BESS + DR + Diesel. In spite of the regulatory differences: price of injection, explicit payment for power, minimum and maximum limits of installed capacity, capacity to buy and sell energy to the grid and dynamic tariffs, among others, it is possible to distinguish common characteristics between Different business models. Therefore, the micro grid defined as a solar community, that is, that installs and operates solar PV, self-supply part of the demand in a daily schedule allowing you to reduce energy purchase costs. The maximum self-supply occurs when the levelized cost of energy of solar PV is equivalent to the cost of purchasing energy from the grid. In this way, the solar community is economically feasible in each of the models presented above, even when the average irradiance of the area is low (e.g. Coyhaique in micro community network: 4.11 kWh / m2-day), except in the case of Punta Arenas, where the irradiance does not exceed 4 kWh / m2-day. Furthermore, the wind community is also economically viable, but a moderate wind resource (4.5 m / s average) is needed to install wind turbines. In this way, the energy generated with the wind is mainly used for self-sufficiency and to reduce peak demand.

On the other hand, diesel generation and demand management are economically feasible resources mainly to supply part of peak demand and are fast enough to respond to variations in demand. However, in the case of demand management, it is necessary to have a good solar resource in the area in order to be able to move flexible load to daytime hours and it is only economically feasible in community micro grids.

Regarding the use of energy storage batteries, these are economically viable in business models where it is not possible to inject energy surpluses into the network (IMG and SLG), since in most areas evaluated, it is more economically feasible to inject surplus provided by solar PV to the grid and supply peak demand with diesel generation. In this sense, the BESSs remain inflexible (charging time of four hours), with a very low lifetime (approximately 3650 cycles assuming that they are charged / unloaded once a day a year) and a high investment cost.

1.3 Tables

Table 1-43: Micro grid dimensions in literature review

Author/ objective	*Window & time horizon*	*Objective function*	*Resource uncertainty*	*Peak shave*	*Places and houses*	*Technology* Wind turbine (WT) Photovoltaic (PV) Diesel Gen (DG) Fuel cell (FC) Micro turbine (MT) Carbon Heat &	*Tariff*	*Psell= Pbuy*
(Tenfen & Finardi, 2015) Measure technical and economic impacts of the uG on the main Grid	1 min – 1 day	Min fuel, maintenance, start-up, shut down, CLD and grid exchange	Forecasted PV & wind	No	1 place – 1 house	Critical, curtailable and reschedulable load demand FC, Gas MT, WT, PV and ESS	ToU 3	Simple
(Kriett & Salani, 2012) Quantify cost reductions in a residential uGrid	15 min – 365 days	Min fuel, start-up, shut-down, grid exchange	No	Yes	1 place – 1 house	Electrical and thermal loads, wind, sun	Tou 2/ RTP	Dual prices
(Holjevac et al., 2015) Quantify the ability of uGrid components to provide flexibility	30 min – 365 days	Min fuel & grid exchange	No	No	1 place - uGrid	Heat and electrical demand, flexible demand, uCHP, WT, PV,	Flat	Dual prices
(Wouters, 2015) Min annualized cost of the system to meet energy demand	1 hour – 1 day	Investment valorization + Min OM, fuel, grid exchange & carbon tax	No	No	Adelaide based neighbourhood	uCHP, WT, PV, space heating and cooling, thermal demand.	Flat	FIT for residential PV export
(D. T. Nguyen & Le, n.d.) Optimal EM framework for cooperative uGrids	1 hour – 1 day	Min grid exchange, startup, shutdown, fuel, shift demand costs	ARMA WT. PDF: normal PV & truncated normal load	No	Community	WT, PV, ESS, DR, Diesel gen	RTP	Simple
(M. Q. Wang & Gooi, 2010) Effect of uncertainty in the optimization results of a spinning reserve problem	1 hour – 1 day	Max profit (reserve, lost load, operational costs)	PDF: Weibull wind, bimodal PV	No	1 Place	WT, PV, FC and MT	RTP	Simple
(Hoke et al., 2013) Min energy cost & max cost savings of uGrid - LP	1 hour – 3 days	Min fuel, DR, battery conversion losses and grid exchange	No	No	uGrid in US	WT,PV,Diesel Gen, ESS, DR	RTP	Can not sell
(Tsikalakis et al., 2011) Economic evaluation of a uGrid in a real-time market	1 hour – 1 day	Min fuel, start-up, grid exchange & curtailment	No	No	Commercial, industrial and residential	WT, PV, FC, MT	RTP	Can not sell
(Quashie & Joos, 2016)Quantify bilevel planning strategy in a urban uGrid	1 hour –7 days	Min investment + Min emission, fuel, maintenance, grid power purchase & CHP costs	No	No	Urban distribution network	WT, CHP, ESS	Flat	-
(H. Wang & Huang, 2015) Propose a theoretical framework for investment and operation of a uGrid	1 hour – 10 years	Min investment + Min fuel cost	No	No	Hong Kong uGrid	WT,PV,ESS,DR, Diesel gen	Day-ahead prices	Can not sell
(J. Zhang et al., 2016) BP to determine the optimal size of distributed generations in a uGrid	1 hour – 6 days by season	Min investment + Min start-up, reserve, compressors, expanders, fuel, emissions costs	No	No	Islanded uGrid	WT, PV, Compressed energy storage (CAES), diesel Gen,	Islanded	-
(R. Palma-Behnke et al., 2011)Show economic sense of uGrid management	15 min – 2 days	Min fuel, start-up, unserved power & unserved water cost	GFS & WRF	No	Community	Diesel Gen, battery bank, WT, PV & water supply	Islanded	-
(Alharbi & Bhattacharya, 2013) Manage high penetration of renewables in islanded uGrids	1 hour – 1 day	Min fuel, start-up, renewable curtailment & shift demand costs	No	No	Benchmark uGrid	WT, PV, ESS, DR, Diesel generators.	Islanded	-
(Morais et al., 2010) Decide the best VPP management strategy to min gen costs	1 hour – 1 day	Min battery, PV, WT, fuel, undelivered energy costs	No	No	Budapest Tech isolated system	WT, PV, ESS, FC	Islanded	.
(Yazdani et al., 2015) Single- objective optimal sizing approach for a uGrid	1 hour – 365 days	Min capital, replenishment, operation, maintenance, fuel and salvage costs	PDF: weibull wind. Normal power-factor	No	Offgrid community	WT,PV, ESS, diesel gen	Islanded	-

Table 1-44: Solar PV module factors

Factors	Value
p	15.39
q	-0.177
r	0.0794
m	-0.009736
s	-0.8998

Table 1-45

Authors	Operational costs							Technology							Programming			
	Fuel	Start-up	Shut-down	Grid purchase	Grid sale	Curtailment	Emission									Mode (Deterministic – Stochastic – Predective)		
								WT	PV	Diesel Gen	ESS	CHP	MT	FC	Bi-level	D	S	P
(Tenfen & Finardi, 2015)	✓	✓	✓	✓	✓	×	×	✓	✓	×	✓	×	✓	✓	×	✓	×	×
(Kriett & Salani, 2012)	✓	✓	✓	✓	✓	×	×	×	✓	×	✓	✓	×	×	×	✓	×	✓
(Holjevac et al., 2015)	✓	×	×	✓	✓	×	×	✓	✓	×	×	✓	×	×	×	×	×	×
(Wouters et al., 2015)	✓	×	×	✓	✓	×	×	✓	✓	×	×	✓	×	×	×	✓	×	✓
(D. T. Nguyen & Le, 2013)	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	×	×	×	×	✓	✓	×
(M. Q. Wang & Gooi, 2010)	✓	×	×	✓	✓	×	×	✓	✓	×	×	×	✓	✓	×	✓	×	×
(Hoke et al., 2013)	✓	×	×	✓	×	✓	×	✓	✓	✓	✓	×	×	×	×	✓	×	×
(Tsikalakis et al., 2011)	✓	✓	×	✓	×	×	×	✓	✓	×	×	×	✓	✓	×	✓	×	×
(Quashie & Joos, 2016)	✓	×	×	✓	×	×	✓	✓	×	×	✓	✓	×	×	✓	✓	×	×
(H. Wang & Huang, 2015)	✓	×	×	✓	×	×	×	✓	✓	✓	✓	×	×	×	✓	✓	×	×
(J. Zhang et al., 2016)	✓	✓	×	×	×	×	✓	✓	✓	✓	✓	×	×	×	✓	✓	×	×
(R. Palma-Behnke et al., 2011)	✓	✓	✓	×	×	×	×	✓	✓	✓	✓	×	×	×	×	✓	×	×
(Alharbi & Bhattacharya, 2013)	✓	✓	×	×	×	✓	×	✓	✓	✓	✓	×	×	×	×	✓	×	×
(Morais et al., 2010)	✓	×	×	×	×	✓	×	✓	✓	✓	✓	×	×	×	×	✓	×	×
(Yazdani et al., 2015)	✓	×	×	×	×	×	×	✓	✓	✓	✓	×	×	×	×	✓	✓	×