UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE
ELECTRIC POWER INDUSTRY

Master’s Thesis

PV DISTRIBUTED GENERATION AND STORAGE IN THE SPANISH ELECTRICITY SYSTEM
ECONOMIC ANALYSIS FOR A REGULATORY PROPOSAL

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Supervisor:	**Pablo Frías**

Madrid, July 2015

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ABSTRACT

Distributed generation, and specifically Solar PV, penetration is exponentially growing based on the cost reduction achieved during the last years.

Grid parity has been achieved in numerous locations, this together with different support frameworks have provided the incentives for an increasing deployment of this technology.

Battery cost has also shown a step decrease in costs in the last year. If this tendency is sustained, energy storage pared with PV rooftop systems will allow for some consumers to go off grid in a profitable way.

This thesis analyzes the effect of those consumers leaving the grid on the total welfare and questions this option as the most efficient. Regulatory schemes and tariff structures are evaluated in order to identify the optimal framework to create thee correct incentives.

Finally the Spanish case is analyzed and specific conclusions are derived for the specific situation.

RESUMEN

La reducción de costes observada por la tecnología de generación Solar Fotovoltaica, está conllevando altos índices de penetración de esta tecnología en forma de generación distribuida.

El coste de generación de esta tecnología ha alcanzado en diversas localizaciones y sistemas la paridad con el precio de consumidor. Esta situación, junto con los marcos regulatorios establecidos, está fomentando la instalación masiva de esta tecnología.

El coste de las baterías también ha mostrado una importante reducción de costes a lo largo del último año. De mantenerse esta tendencia, esta tecnología en combinación con la generación fotovoltaica permitirá a algunos consumidores abandonar la red de forma rentable.

Esta tesis presenta un análisis del efecto de desconexión de algunos consumidores sobre el bien común y evalúa la eficiencia de esta opción. Con el objetivo de identificar el marco regulatorio óptimo que establezca los incentivos correctos para los consumidores, se ha analizado la naturaleza de este problema desde diferentes perspectivas.

Finalmente se ha analizado el caso de España y se han identificado conclusiones concretas acerca de la solución óptima para el caso concreto.

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1 INTRODUCTION

The electric system is facing one of the biggest threats or opportunities of the last decades. Distributed generation and specifically PV penetration is exponentially growing.

Thanks to the cost decrease of the last years, PV generation is reaching grid parity in many regions of the globe. This situation leads to a major change in the structure of the electric power system.

Distributed generation needs from a new framework that takes into account the activities that the distribution companies are supposed to implement in order to deal with the switch form a one way flow to a changing flow system where consumers became prosumers.

On the other hand, energy storage is showing a slow but determined path towards cost reduction and efficiency increase. Commercial use of batteries is increasing in a wide range of appliances. This analysis will focus on the retail level, analyzing the integration of PV generation and the different back-up options. From the prosumers perspective, the back-up service that can be provided by the grid is compared to the different storage and back-up generation technologies.

Grid integration of PV generations is, at a first glance the optimal alternative as distributed generation add RE generated electricity and benefits from the security of supply that the interconnected system provides. Nevertheless, given the cost reduction path for distributed generation and storage, if the cost of the network (regulated cost) impose a high burden on prosumers, other options became profitable. Standalone systems, despite being apparently a second best option, under certain regulatory frameworks may gain economic sense.

The impact of the isolation of a certain number of agents from the existent network might imply serious technical and economic challenges as the cost should be supported by less consumers and therefore the incentives to abandon the grid will increase.

This analysis pretends to identify the optimal system integration in order to propose the proper regulation for the system.

The scope of the analysis is limited to the Spanish system so that the proposed regulation can be properly implemented within the regulatory framework of the country.

2 OBJECTIVES OF THE MASTER THESIS

The central objective of this thesis relies on proposing regulation for the challenges that the electric system will face in the near future. Proper regulation for distributed generation and specifically for PV is fundamental to guarantee correct incentives to the agents.

It is therefore intended to identify the optimal viable alternatives that allow to maximize the social welfare based on the benefits from the cost reduction in renewable energy technologies.

Conclusions from this analysis will be used to analyze current regulatory proposals and propose some guidelines for the optimal regulation.

3 ELECTRICITY GENERATION EVOLUTION

Since the beginning of 1920s, electrification has been developed based on big facilities connected to the load through large transmission lines.

Generation technologies based on thermal Power fueled by fossil fuel, nuclear power plants, together with hydro power allowed to establish a system able to deal with the complexity of the electricity service.

The network interconnection allowed to provide security of supply based on meshed structures where failures of a generation units were managed in real time allowing the system to keep providing the service.

These facilities were dimensioned based on the scale economies shown by those technologies, it was therefore economic rational to dimension those facilities in the range of 5.00 MW-1.000 MW.

First network development and construction of generation facilities was developed by governments through the creation of vertically integrated utilities.

Those public companies were gradually exposed to liberalization in response to concerns about energy security and independence from foreign energy sources as a result of the 1970s oil crisis [1].

Through liberalization, governments intended to incentivize private investment in generation were competition was progressively introduced. Nevertheless high investments that required long terms for investment recovery showed under some regulatory frameworks difficulties to be founded.

Network activities remained aside as the characteristics of natural monopoly required specific regulation and in the majority of the cases competition was not entitled to generate social wealth.

During 1990s Cycle Gas Turbines (CCGT) were introduced as a technology that provided its relatively moderate investment cost and its flexible generation capacity along with its modular nature, presented better conditions for investment. Based on its flexibility, CCGT were able to get back investment costs and profit from prices fluctuations. CCGT facilities are easily located closer to consumers and connected to distribution networks where loads are served. This allows to reduce losses while requires some distribution network management.

Renewable energy technologies (solar PV, CSP, and Wind) have irrupted in the generation market on a first base, relying on concerns of CO2 emissions and climate change effects, this first approach allowed to implement the first systems based of heavy regulatory support as the technologies were immature and required from a regulated scheme to incentive investment.

After the first stage, RES-E technologies have shown a step decrease in costs based on the learning curve that has been undervalued several times.

Specifically wind and solar technologies have shown a shift in installed capacity followed by a decrease in costs and increase in generation capacity. This incentivize new generation to be installed leading to further decrease in costs.

RES-E technologies, can be installed both at a network level as well as at the distribution level, in fact, given the characteristics of solar PV generation units has been taken to the same place where domestic consumption occur. Rooftop generation is increasing taking distributed generation to the extreme.

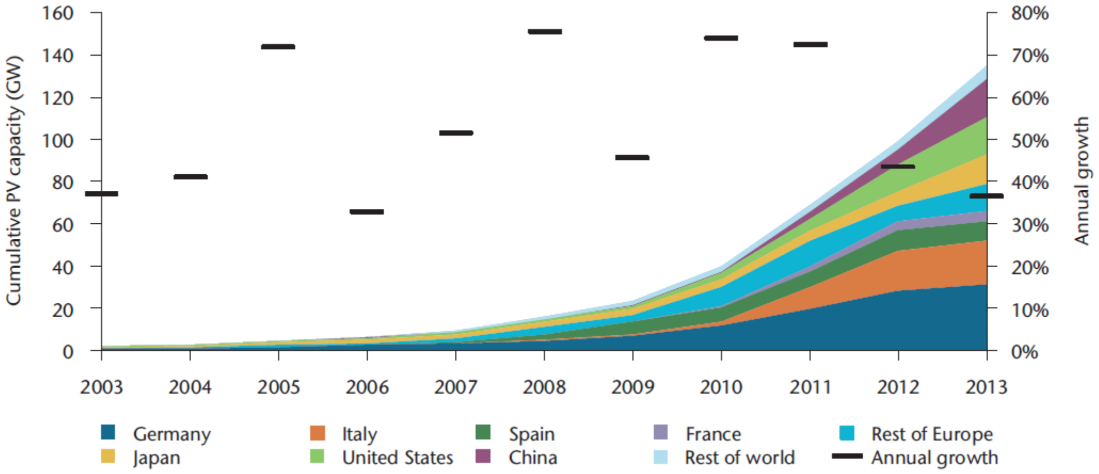
In this document, solar PV distributed generation options are further analyzed in order to identify the challenges that traditional utilities, policy makers and regulatory authorities will face in the incoming years. Other technologies such as batteries and other back-up generation alternatives are analyzed given their interaction in the PV deployment.

4 PHOTOVOLTAIC EVOLUTION AND INTEGRATION OPTIONS

According to the IEA, [2] the cost of PV modules has been divided by five in the last six years and the cost of full PV systems has been divided by almost three. The global rate of annual new-built capacities, which was 7 GW in 2009, reached 35GW in 2013 and is expected to exceed the 54 GW in 2015 [3].

Cumulative installed capacity has grown at an average rate of 49% per year for the last ten years, this path is expected to be sustained based on the current cost reduction achievements [3].

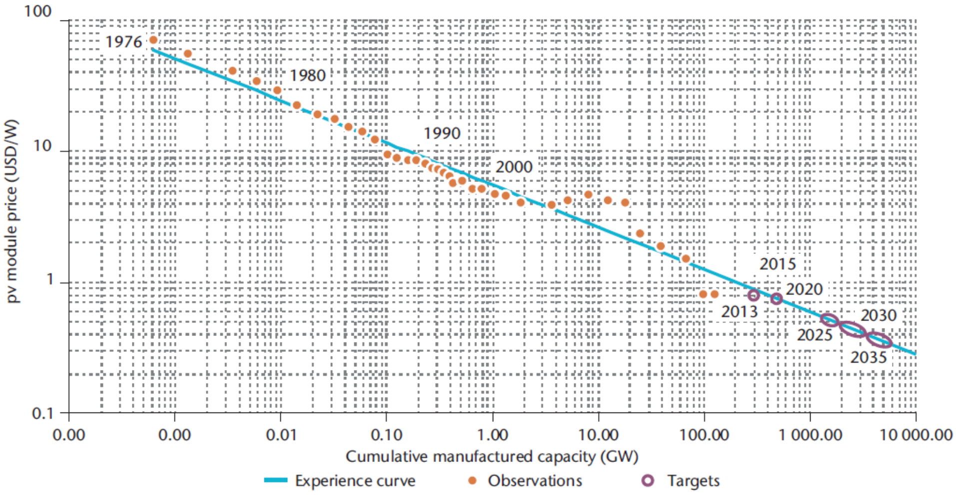
Figure 1: Cumulative installed capacity and growth of PV



Source: [2]

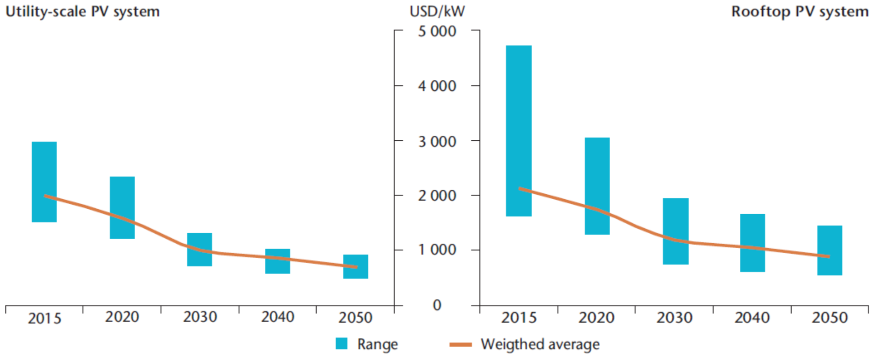
Cost reduction has been fostered by the increase of manufacturing capacities and the geographical relocation of the main factories to Asia.

Figure 2: Past modules prices and projection to 2035



Source: [2]

Figure 3: Investment Costs Projections



Source: [2]

4.1 TECHNOLOGY IMPROVEMENTS

PV technology is based on the semiconductor materials that generate electricity. Silicon is being used as the main material for PV cells construction.

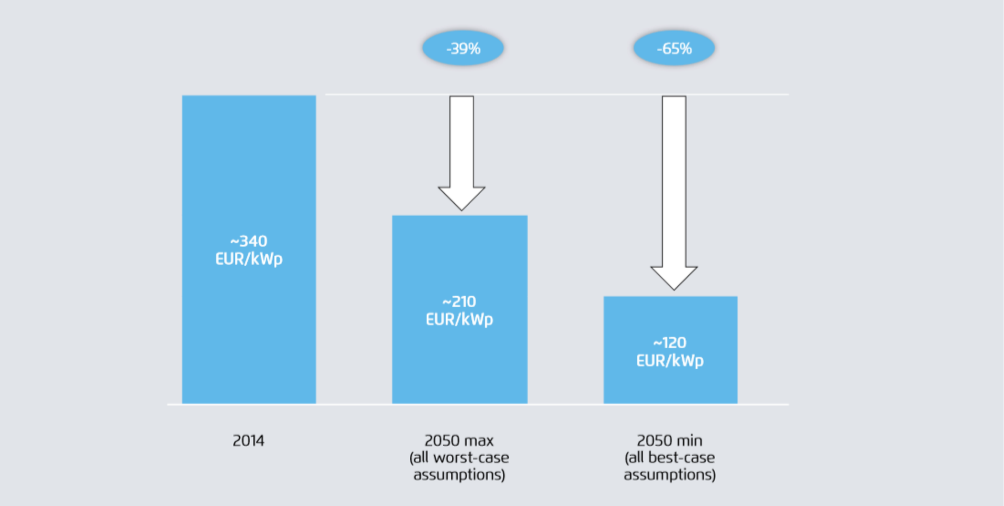
Then modules are created by grouping cells. Protection frame and a front glass are added to guarantee that modules are prepared for outdoors weather conditions. By a combination of modules, strings and arrays are built; those arrays are finally integrated into systems.

System capacity depends on the future use and therefore a wide range of capacities has been observed in the industry from small watt systems to big GW systems.

Systems can be used in different ways:

- Grid connected systems need from inverters to convert DC to AC power. Apart from inverters other equipment is needed to adapt the generated electricity to be transmitted through the network. Integrated equipment (transformers, monitoring equipment, and other structural elements are commercialized).

Figure 4: Projected cost reduction of Integrated equipment



Source: [4]

- Isolated systems that can be CD (as simple load distribution) or hybrids that require the inverter as the connected ones. This option faaces similar cost structure.

Systems can be mounted on fixed or tracking structures tradeoff between both systems have been widely analyzed showing different outcomes based on the geographic location and conditions.

Commercial silicon modules show an average efficient of 16%, nevertheless most advanced modules are reaching 21% efficiency.

PV modules are generally granted with a 25 years guarantee at 80% of their retied output

Manufacturing optimization has shown to be the main source of cost reduction as energy consumption, labor and raw materials required were significantly reduced.

Prices for entire systems differ from big to smaller systems as scale provides cost reduction for the common elements (transformers, structural, monitoring, inverters, etc.)

Differences by countries are also important based on two factors. On one side, Soft costs (permitting, inspection, installation workforce, etc) differ from country to country. On the other, different regulatory schemes leaded to different revealed cost by promoters; when high and fixed incentives are set, prices tend to adapt to this values (REF) whereas where competitive tenders have been established revealed prices (South Africa, Brazil, Saudi Arabia) are much lower showing the effect of competitive pressure. Very low prices assume the capacity of cost reduction in the near future, some of them might show too optimistic and delays are being observed, therefore those prices should not been taken as market prices for current systems as long as they are not installed.

In order to compare the cost of PV energy facilities, the Levelized cost of Energy (LCOE) is calculated. LCOE provides the theoretical constant cost of electricity generation taking into consideration the present value of the total costs associated with the facility.

LCOE is therefore expressed in € per kWh that can be expressed in nominal or real terms, for sake of simplicity and provided that other measures to be compared with (s.a retail electricity prices) are nominal rated, LCOE in this analysis will be reported as nominal.

LC=E calculation

$$\sum_{t=1}^{T}\left(\frac{LCOE_t}{(1+r)^t}\, x\, G_t\right) = I + \sum_{t=1}^{T}\frac{OMC_t}{(1+r)^t}$$

Where:

- LCOE (€/Kwh)
- T Years Economic lifetime of the PV system
- t Year t
- OMC Operation & Maintenance (O&M) costs and insurance costs (€)
- Gt kWh PV electricity generated on year t
- I Initial investment (€)

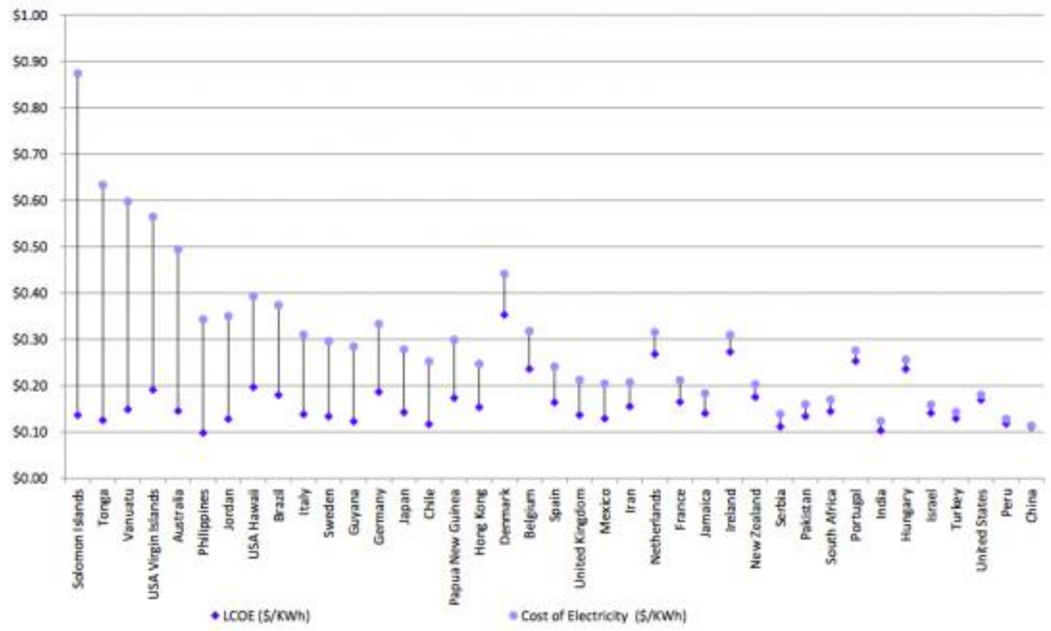
From the LCOE formula, assuming a constant value, LCOE can be rearranged:

$$\sum_{t=1}^{T} LCOE = \frac{I + \sum_{t=1}^{T} \frac{OMC_t}{(1+r)^t}}{\sum_{t=1}^{T} \left(\frac{G_t}{(1+r)^t} \right)}$$

The LCOE of distributed solar PV has fallen below the variable retail electricity price for domestic and commercial users.

For bulk power on grid PV generation is already competitive in certain markets, especially in systems where peak demand is covered by oil generators.

Figure 5: Grid Parity by Country 2015



Source: [5]

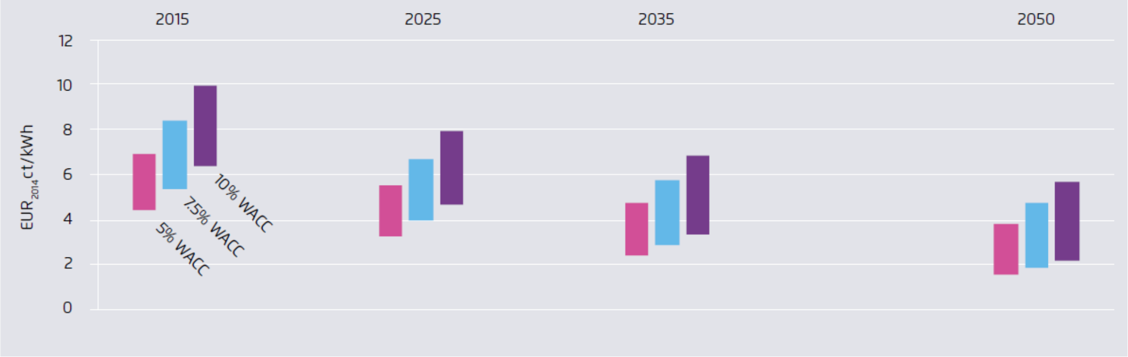
LCOE in Spain utility level PV generation calculated to be around 6 cents/KWh in 2015 [6], while average wholesale electricity price is in a similar range.

Projected LCOE for 2025, 2035, and 2050 follows a cost reduction that is projected to end with a cost range between 2-4 cent/kWh. Under this projected cost, large PV facilities will be far below wholesale price.

As it can be appreciated in the graph 6, final cost will be directly related with the finance cost. Provided that initial investment costs account for the major part of the future LCOE cost, capacity to lower financial cost will allow PV facilities to maximize cost reduction.

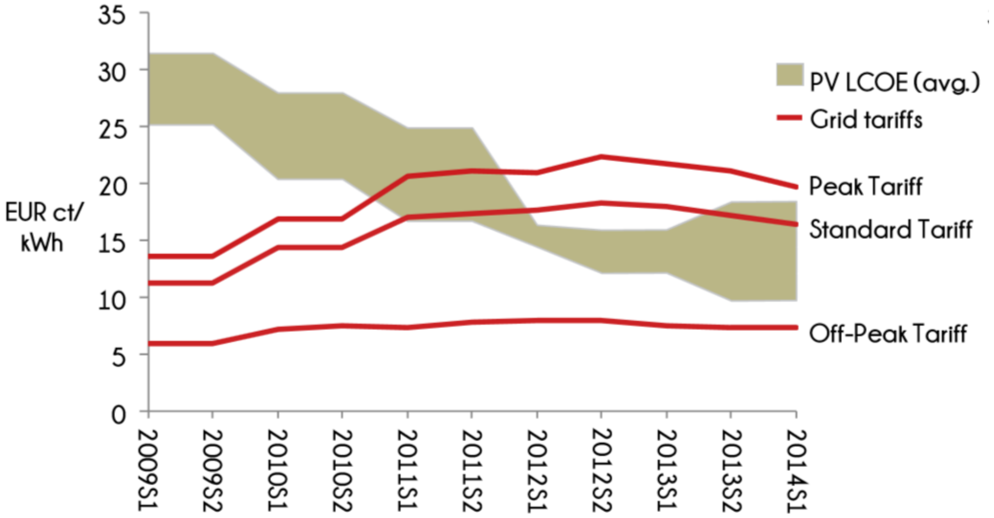
New financial structures and products are allowing reduction in financial costs, provided the impact on the final cost, this is further analyzed in section 10.

Figure 6: LCOE Projected for Spain



Source: [4]

Figure 7: Grid Parity for Spanish market



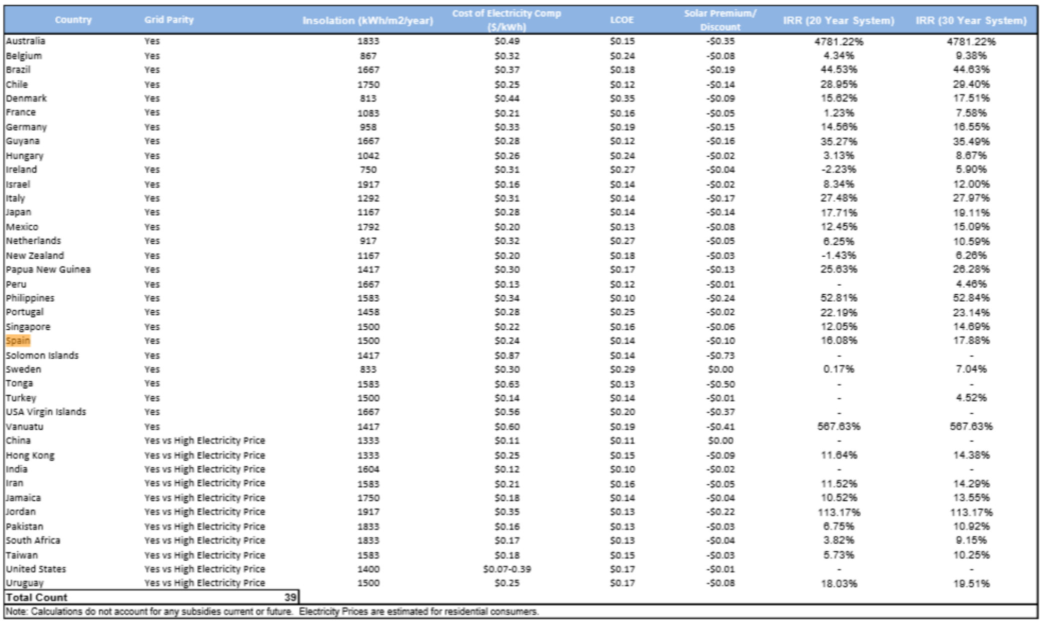
Source: [7]

Cost for distributed generation, specifically rooftop LCOE cost has already reached grid parity according to [7] and [5]. Both argue that grid parity has been achieved.

Grid parity is here considered by comparing LCOE of residential PV facilities with the variable component of retail price. According to calculations provided by the referred reports, LCOE in Spain for residential PV is near 12 cents per kWh, this value is the current approximately value of the variable component of the regulated price for small consumers in Spain. This situation, known as grid parity provides incentives for consumers to install a generation unit in their own roof and became prosumers.

Prosumers will benefit from consuming their own generated electricity, saving retail price for any unit of energy self-consumed and completing their consumption when needed with energy from the network. Despite the simplicity of this structure, multiple implications should be taken into consideration.

Figure 8: Countries with Grid Parity



Country	Grid Parity	Insolation (kWh/m2/year)	Cost of Electricity Comp ($/kWh)	LCOE	Solar Premium/ Discount	IRR (20 Year System)	IRR (30 Year System)
Australia	Yes	1833	$0.49	$0.15	-$0.35	4781.22%	4781.22%
Belgium	Yes	867	$0.32	$0.24	-$0.08	4.34%	9.38%
Brazil	Yes	1667	$0.37	$0.18	-$0.19	44.53%	44.63%
Chile	Yes	1750	$0.25	$0.12	-$0.14	28.95%	29.40%
Denmark	Yes	813	$0.44	$0.35	-$0.09	15.62%	17.51%
France	Yes	1083	$0.21	$0.16	-$0.05	1.23%	7.58%
Germany	Yes	958	$0.33	$0.19	-$0.15	14.56%	16.55%
Guyana	Yes	1667	$0.28	$0.12	-$0.16	35.27%	35.49%
Hungary	Yes	1042	$0.26	$0.24	-$0.02	3.13%	8.67%
Ireland	Yes	750	$0.31	$0.27	-$0.04	-2.23%	5.90%
Israel	Yes	1917	$0.16	$0.14	-$0.02	8.34%	12.00%
Italy	Yes	1292	$0.31	$0.14	-$0.17	27.48%	27.97%
Japan	Yes	1167	$0.28	$0.14	-$0.14	17.71%	19.11%
Mexico	Yes	1792	$0.20	$0.13	-$0.08	12.45%	15.09%
Netherlands	Yes	917	$0.32	$0.27	-$0.05	6.25%	10.59%
New Zealand	Yes	1167	$0.20	$0.18	-$0.03	-1.43%	6.26%
Papua New Guinea	Yes	1417	$0.30	$0.17	-$0.13	25.63%	26.28%
Peru	Yes	1667	$0.13	$0.12	-$0.01	-	4.46%
Philippines	Yes	1583	$0.34	$0.10	-$0.24	52.81%	52.84%
Portugal	Yes	1458	$0.28	$0.25	-$0.02	22.19%	23.14%
Singapore	Yes	1500	$0.22	$0.16	-$0.06	12.05%	14.69%
Spain	Yes	1500	$0.24	$0.14	-$0.10	16.08%	17.88%
Solomon Islands	Yes	1417	$0.87	$0.14	-$0.73	-	-
Sweden	Yes	833	$0.30	$0.29	$0.00	0.17%	7.04%
Tonga	Yes	1583	$0.63	$0.13	-$0.50	-	-
Turkey	Yes	1500	$0.14	$0.14	-$0.01	-	4.52%
USA Virgin Islands	Yes	1667	$0.56	$0.20	-$0.37	-	-
Vanuatu	Yes	1417	$0.60	$0.19	-$0.41	567.63%	567.63%
China	Yes vs High Electricity Price	1333	$0.11	$0.11	$0.00	-	-
Hong Kong	Yes vs High Electricity Price	1333	$0.25	$0.15	-$0.09	11.64%	14.38%
India	Yes vs High Electricity Price	1604	$0.12	$0.10	-$0.02	-	-
Iran	Yes vs High Electricity Price	1583	$0.21	$0.16	-$0.05	11.52%	14.29%
Jamaica	Yes vs High Electricity Price	1750	$0.18	$0.14	-$0.04	10.52%	13.55%
Jordan	Yes vs High Electricity Price	1917	$0.35	$0.13	-$0.22	113.17%	113.17%
Pakistan	Yes vs High Electricity Price	1833	$0.16	$0.13	-$0.03	6.75%	10.92%
South Africa	Yes vs High Electricity Price	1833	$0.17	$0.13	-$0.04	3.82%	9.15%
Taiwan	Yes vs High Electricity Price	1583	$0.18	$0.15	-$0.03	5.73%	10.25%
United States	Yes vs High Electricity Price	1400	$0.07-0.39	$0.17	-$0.01	-	-
Uruguay	Yes vs High Electricity Price	1500	$0.25	$0.17	-$0.08	18.03%	19.51%
Total Count	39						

Note: Calculations do not account for any subsidies current or future. Electricity Prices are estimated for residential consumers.

Source: [5]

In the next section a detailed analysis on different options for prosumers is provided.

5 OPTIONS FOR RESIDENTIAL DISTRIBUTED PV GENERATION

In this chapter different modalities for distributed generation are presented and major characteristics of each one are analyzed. Most common regulatory schemes applied to promote distributed generation are further analyzed.

5.1 PV GENERATION OPTIONS – ON GRID SYSTEM

This option for distributed generation has been promoted by several countries as the preferred option for PV integration.

Taking generation to the place of consumption provides a number of benefits that have been recognized under several regulatory frameworks.

Deploying PV distributed generation reduces net demand from traditional generation and therefore a reduction in losses from transport is acknowledged.

This option is also facilitating small agents to invest in new generation, and more specifically in renewable energy helping to achieve renewable goals in the countries where targets were already set.

New services are being created on the base of distributed on-grid generation and businesses are being developed to provide those services.

Despite the pros previously detailed, distributed pv generation presents some drawbacks have been identified.

It is not clear that the effect on the distribution cost is as positive as the reduction in transmission losses could be, provided that the inverse flows and the generation variability require higher levels of distribution management and therefore the effect on this side is not clear, especially when high penetration rates are observed.

The other concern is related with promotion mechanisms and the effect of those mechanisms on the network cost recovery capacity.

Different support mechanisms are being applied to PV distributed generation but basically two major schemes are being used.

- Feed In tariffs: Under this scheme, generators are awarded with a specific price for the energy generated. This price is normally set on the base of a sufficient profit and is generally higher than the average wholesale market price.
    - Feed in premiums can be considered a variation of feed in tariffs under which generators earn wholesale market price plus a premium that is added on top.

  These schemes were traditionally applied for big facilities in order to incentivize investment and have been applied to this end.
- Net metering: This scheme better recognizes the nature of the distributed generation, under net metering consumers can generate electricity on site to offset their own load and deliver any excess electricity to the grid. Under this structure, the energy offset provide an implicit price for the generated electricity equal to the retail price.

  This scheme has been adapted in different regulatory frameworks, specifically, the way excess electricity is rewarded changes from one system to the other.
    - Credits: Under net metering, prosumers are credited for their excess production, this credit can be used to offset the subsequent electricity bills.
        - Credits can be banked for a specific amount of time, most frequent schemes allow for 1 year banking whereas others don’t set a limit.
    - Net billing and virtual metering: Other options should be considered as a variation of net metering.
        - Virtual metering allows consumers to use the awarded credits from one facility to offset electricity consumption in a different location. Virtual metering allows several customers to aggregate generation credits, fostering community ventures.
        - Under Net Billing, energy sent to the grid from and energy consumed from the grid by the customer are measured

independently. Therefore, different rates can be applied to generation and consumption weighting the intended incentives.

In other cases, prosumers are allowed to produce and consume their own electricity and excess production do not generate any credits nor compensation.

Under this schemes investors are able to gain sufficient profit from their investment in PV generation while contributing to increase the renewable generation mix.

It should be stressed that both, FIT and net metering schemes imply a cost that the system should finance. The cost allocation of both promotion structures has to be implemented based on the appropriated regulatory approach.

It should be observed that if the tariff structure allocates part of the cost of the policy and grid costs on the volumetric parameter, under net metering consumers that are offsetting their energy will -partially- not pay for this amount. This is the case of the Spanish system where a backup fee has been proposed to offset this effect, further detail on this proposal and analysis on the impact of net metering is provided under the specific section.

5.2 PV GENERATION OPTIONS – OFF GRID SYSTEM

As previously showed grid parity has been reached or it is about to in the near future. Under this perspective consumers envisage the possibility of reducing their electricity bills or even earning money.

Off grid system are traditionally used in isolated locations where transmission deployment has not economic sense.

Under certain regulatory frameworks where no specific incentives are provided for on grid PV distributed solutions and when regulated (policy and network) costs are high enough, off grid systems gain economic sense.

5.3 THE NEED FOR BACKUP

Generation form solar PV technology depends on the solar irradiation and therefore this technology shows a natural limitation on the generation hours. Therefore, a backup system is required in order to comply with demand.

In order to defer electricity consumption, storage has to be implemented. In order to do so, batteries are integrated in the system.

Batteries are charged during the day with the exceeding generation and used during the night to provide electricity.

Off grid systems have been used as emergency solutions as the quality and the amount of energy provided by a rational investment level were not able to comply with traditional quality requirements.

Latest technology evolution is allowing to improve off grid systems performance and reduce required investment costs.

6 OFF-GRID: BACK UP OPTION AND COMBINED PROPOSALS

Energy storage can be provided by different technologies that at this moment show different development stages.

Hydro pumping is the most mature technology, its use is widespread and it can be used for large periods of charge or discharge. Pumping is normally connected to the grid in order save excess energy or to arbitrage between pick and valley hours. Despite the rudimentary of the technology it is economically proven. Environmental concern as well as the location needed have been some of the main barriers for this technology.

Several technologies are been developed and tested to increase storage capacity based on a wide range of technologies and materials.

Examples of other emerging storage technologies are:

- compressed air energy storage;
- power to gas;
- flywheels;
- supercapacitors.

Electricity can also be stored in thermal form using:

- boilers;
- heat pumps;
- ice;
- chilled water.

Thermal storage integration with combined heat and power production has been efficiently implemented. Integration with wind generation has also been proved efficient. Achieved storage costs under thermal technologies are normally lower than other technologies, but efficiency is highly reduced when trying to reverse heat into energy. Therefore thermal energy generated under those technologies is normally directly used without further transformation. It should be noted that provided this limitation, those systems are might only have economic sense in places were thermal energy can be directly used.

Despite the wide range of options for energy storage, batteries have shown to be one of the leading technologies to provide storage for distributed generation, under this assumption and recognizing that probably other storage technologies might be able to provide better, more reliable and at lower cost service than batteries, this study will focus on batteries alternatives as the main storage technologies to be integrated with distributed generation.

6.1 BATTERIES

Despite being mainstreamed in the last period, Batteries are not a new technology, in fact Alessandro Volta is considered the inventor of this technology in 1799. Lead-acid batteries provided electricity in New York at night in the 1880s according to EPRI and DOE.

This electrochemical rechargeable batteries are based on different technologies and component materials that define a wide range of electrochemical batteries. The source, scarcity and extraction technologies used to obtain the materials has a direct impact on the final cost of the battery as well as the possibility of reusing or recycling the device.

Battery storage can provide different services to the system as they can be used for long term variability coverage (mainly for renewable generation) as well as for covering short term variations in the energy supply.

Nevertheless, batteries are normally not suitable for long period (seasonal) storage, as other technologies are more efficient in providing this service.

Most common battery technologies used account for Lead-acid and the increasing in popularity Lithium-ion.

Lead-acid batteries are the most commonly used because of the low cost, it is considered to be a mature technology with a high availability. While those batteries have been utilized in the past for grid storage, their lifespan is shortened by the characteristics of the grid and of grid consumption provided that partial discharges and charges reduce the average life of the battery.

Lithium-ion (Li-ion) technology for batteries is becoming widespread since the proliferation of laptops and cell phones, as they are suited to mobile applications.

Increasing demand for small portable appliances with simple charging dynamics and therefore longer lifespan as well as higher storage potential has provided the base for covering the first stages of the learning curve of this technology.

At bigger scales, costs were assumed to be too high to compete with other mature storage technologies, nevertheless latest advances are showing that expected prices might underestimate the capacity of cost reduction based on scale manufacturing.

Flow batteries consist on two electrolytes (tanks of liquids) that are pumped through a membrane held between two electrodes to store and to generate electricity. In contrast with a Li-ion technology, where the energy-storing materials and electrolyte are inside the cell. Flow batteries are expected to be easily escalated, reliable and guarantee long life. Flow batteries can use Zinc-Bromine, Iron-Chromium, and Vanadium Redox.

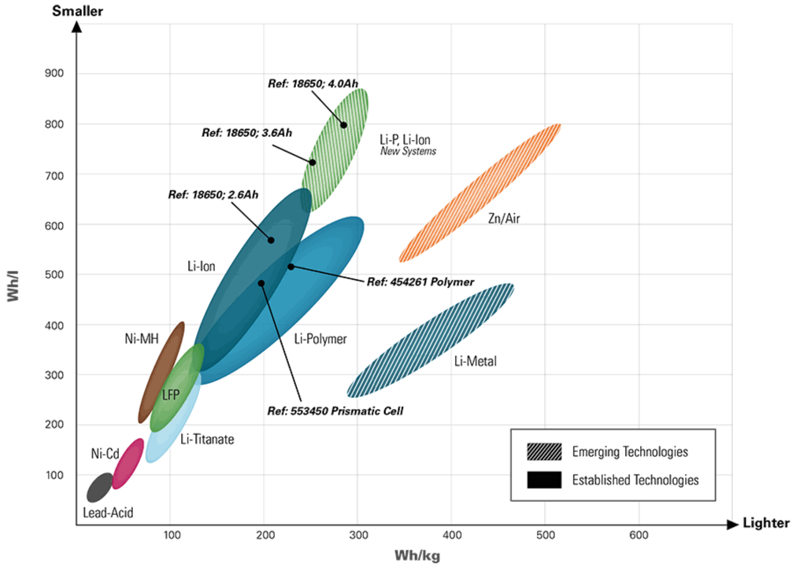
Based on the chemical composition of the batteries, the conditions under which the batteries are used and the manner they are used affect their performance. In fact the depth of discharge (% of battery capacity used) of a battery conditions its life extension and therefore can reduce the number of cycles under which a battery works properly.

Batteries are characterized by the energy they can storage, normally provided in kWh or MWh depending on the scale of the battery.

Power capacity is also provided in kW or MW as the basic reference for commercial batteries.

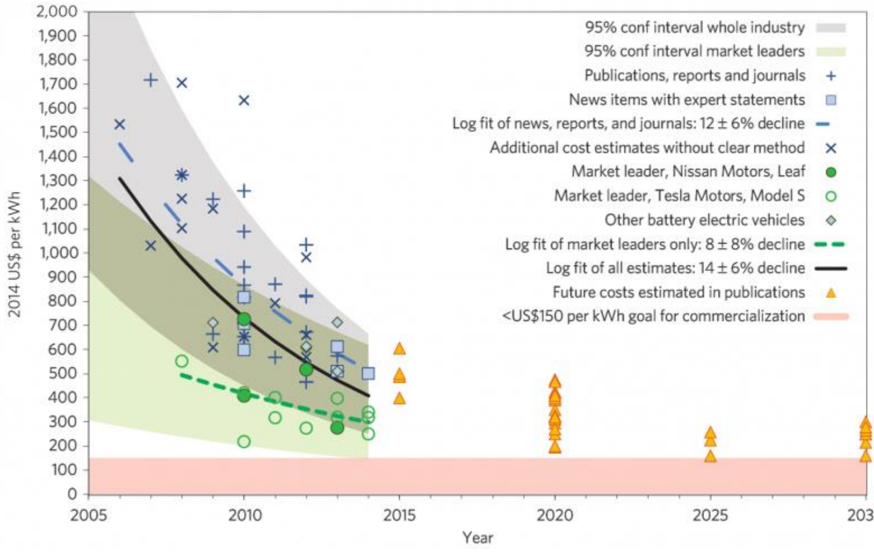
Temperature and other ambient conditions have important effects on the batteries, effects observed vary with the technology and design used.

Figure 9: Density comparison of different battery technologies



Source: Iccexenergy

Figure 10: Battery Cost Projection



Source: Bjorn Stockholm Environment Institute

6.1.1 Calendar and cycle life

The number of charge and discharge cycles a battery can complete without losing performance (80%) is considered the cycle life of the battery. This live cycle is provided by the manufacturer under certain environmental conditions.

Calendar life measure the time (in years) that a battery is capable of operating under certain performance requirements.

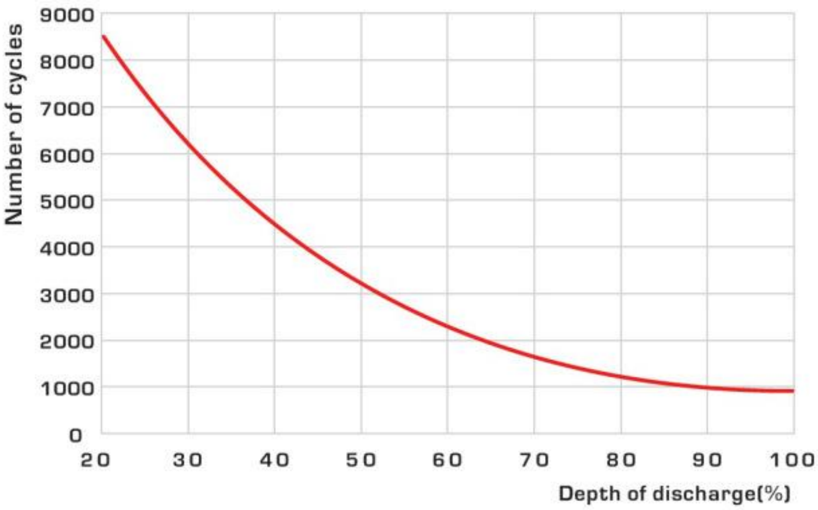
Cycle life, together with battery capacity determine the total amount of energy that the battery will provide, it is therefore a key factor to determine the LCOE of the battery.

6.1.2 Depth of discharge

DoD is defined as the battery capacity that has been used and is expressed as a percentage over the total battery capacity. Expected life will be lower the deeper the battery is discharged.

The effect of DoD depends on the battery type, the chemistry and the environmental conditions.

Figure 11 Life cycle versus DOD



Source: power battery manufacturer

6.1.3 Ambient temperature

Temperature under which the battery is functioning has an important effect on battery performance. High temperatures lead to capacity decrease, corrosion and gases generations that if not properly ventilated might generate further problems.

Batteries can also suffer in extremely cold environments, the electrolyte may freeze and poorer performance are observed.

Therefore, in order to control this variable Some battery types, may require integrated temperature management in the battery installation for optimal performance and safety. However, lithium-ion batteries are generally not as sensitive to temperature as lead-acid batteries.

6.1.4 Service provided

Batteries can be used to supply different services as their technical capacities allow them to provide both: fast short term energy as for instance for frequency regulation. And at the same time be used as a load shading shifting consumption from one hour to other during the same day.

Battery design and selection of chemistry will allow to optimize the use of the battery and increase life cycle.

6.1.5 Barriers for battery integration

6.1.6 Technical barriers

Validated performance and safety are the main barriers for further deployment of batteries. Those barriers are being overcome as higher number of batteries are being manufactured and tested. Industry and utility acceptance are growing as better performance and reliability is being achieved.

6.1.7 Economic barriers

The lack of direct monetary compensation in the majority of the systems, imply the major economic barrier. As cost competitiveness is being achieved, the remining element for higher battery deployment is the availability of structured finance able to adapt to the specific characteristics of the income generation (expense avoidance).

6.1.8 Battery Storage system

Battery storage systems contain a number of primary components including the battery, the power conversion and the monitoring and control systems.

Batteries based on Cells, contain a number of cells connected in modules and those modules connected into packs.

Flow batteries, as previously described contain tanks filled with an electrolyte which flows by a reaction stack.

Monitoring and control systems are the battery management system that is in placed in order to optimize performance and guarantee security conditions through controlling charging and discharging of the battery and avoids cells overcharging.

Especially in lithium-ion battery systems, thermal monitoring is fundamental provided the risk of overheat of this batteries.

New systems are integrating different elements required for battery integration. It is becoming very common to couple the system with an inverter. Additional elements such as power electronics or power conversion systems or bidirectional power inverters are being added in order to adapt the system to the different modalities of battery connection.

Other elements for remote tracking, control and management are being integrated as information availability allows to optimize the system and apply artificial intelligence to the system management, allowing for better performance and improved security control.

6.2 HOUSEHOLD SOLAR PV BATTERY STORAGE

Battery storage at residential level allows higher self-consumption of PV generated electricity. It can also help to relieve the local grid from capacity constraints. Coordination of PV generation and load can be done through batteries.

Coordinating battery charge allows the system to optimize the charging and therefore control the export of electricity generated to the grid. This way, energy will be delivered to the grid during pick demand while pick solar power production is partially storage in order to reduce the energy exported to the network. This coordination will avoid oversupply that would damage the stability of the network and require curtailment of distributed PV generation.

This application might foster solar PV deployment and reduce the cost of the distribution network. In order to integrate such systems correct incentives shall be in place.

Regulatory frameworks are been developed in order to address this and other implementation of distributed generation and storage, different approaches are being placed.

The case of Germany, where storage incentivized to be installed and controlled this way is further analyzed in the regulatory chapter.

6.2.1 COST EVOLUTION

Residential lithium-ion batteries are facing a faster than expected cost reduction. From the 1000€/KWh costs form the end of 2014, Tesla Batteries are being sold at 330€/KWh this cost reduction was expected to happen in around 3 years, it should therefore been showing a faster cost reduction.

Under this tendency, cost estimations in the midterm tend to 100€/kWh bringing to the profitable arena most of the integrated systems with batteries.

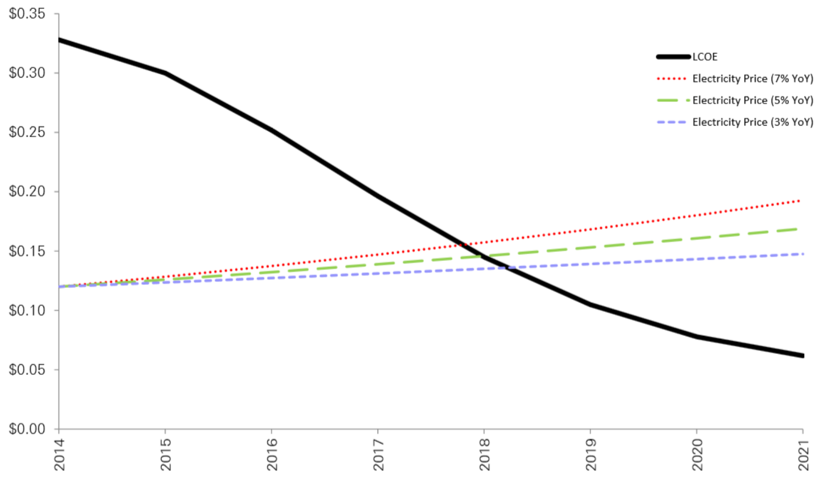
Cost decrease has been caused by increased deployment, economies of scale, higher manufacturing capacity and the slow increase in Electric vehicles penetration.

As batteries reduce costs, Electric Vehicles will turn more competitive, more EV will be sold and increasing numbers in battery manufacturing will allow to a decrease in cost base on the learning curve.

In the next graph an estimation for the evolution is presented based on the calculations provided by Deutsche Bank regarding the LCOE of Off grid system with PV and batteries.

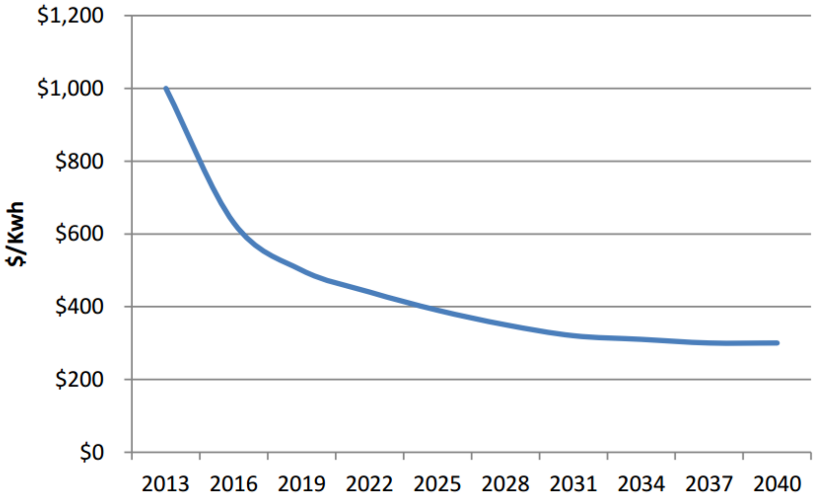
Depending on electricity prices and based on projected battery cost reductions, it is argued that the average price for energy will equal the cost of the alternative system by 2018.

Figure 12: LCOE PV plus Battery



Source: [5]

Figure 13: IEA Lithium-ion Battery Cost projections



Source: IEA

7 ILLUSTRATIVE MODEL: PV STAND-ALONE SYSTEM OPTIMIZATION

In order to better understand PV off grid system requirements and economics, a simplified model is presented.

The model takes the standard load curve provided by Red Electrica and published in (BOE) this load curve is used to calculate the average price applied to consumers under PVPC scheme in Spain.

It should be therefore noted that optimizing this consumption will allow to have a better understanding of the required back-up and the cost of this service.

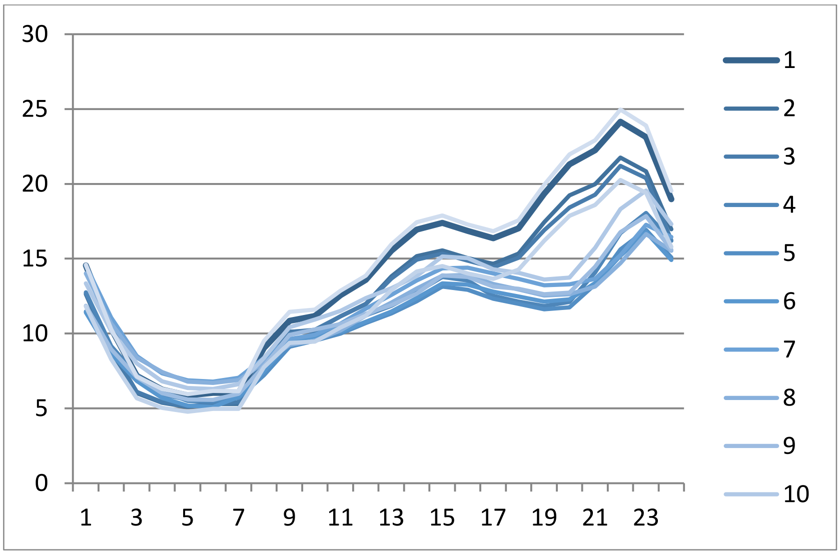
Under the model PV generation is modeled based on Madrid located facility.

Efficiency rate of the PV generation units is taken from SunPower and total yearly consumption is based on the published report by (IDAE).

7.1 THE LOAD CURVE

Consumption profiles depend on social habits as well as geographic conditions, specially light ours. Therefore, a standard load curve would reflect with enough accuracy the average demand in the country.

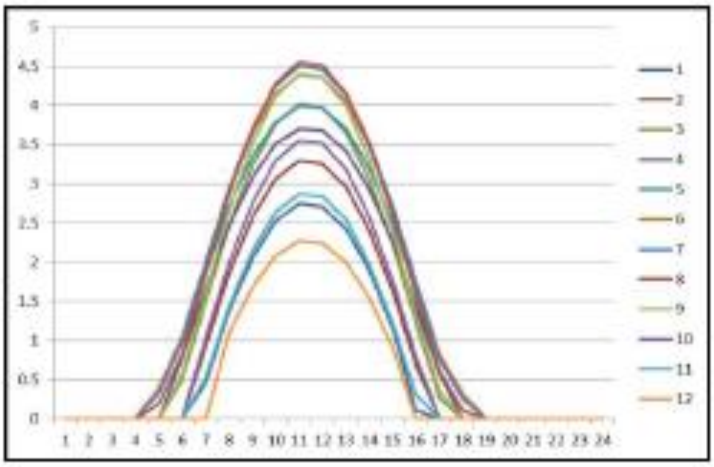
Figure 14: Standard day load for each month



Source: Self elaboration with data from the Oficcial Gacette (BOE)

7.2 THE GENERATION PROFILE

Figure 15: PV generation curve for a standard day in different months



Source: Self elaboration with data from the Joint Research Centre

7.2.1 Instant consumption and Differed consumption

Instant generation provides electricity during the light hours; during those hours electricity can be directly used avoiding the use of battery storage.

Energy exceeding consumption will be stored for the night consumption.

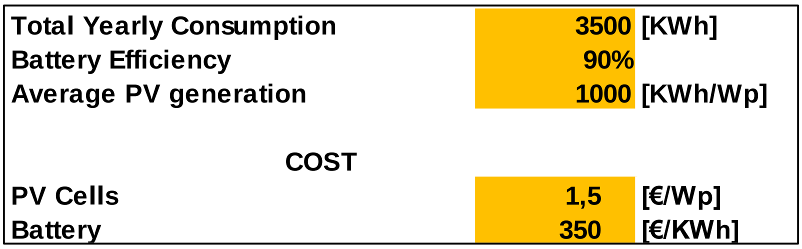
In order to guarantee supply; capacity, both for PV and batteries must be oversized so that the storage capacity not only covers the differences between generation and consumption during the day cycle but exceeding capacity should be stored to avoid energy shortages in case of adverse weather conditions or any other factor that prevents from optimal generation.

7.3 OPTIMIZATION

Total cost of an isolated system depends on two main drivers: PV cells and batteries capacity. Given the tradeoff between both, the optimal combination should be found in order to minimize costs and guarantee a certain quality.

The model tries to reduce the cost of a reliable system, minimizing the cost function subject to some reliability measures. The main characteristics of the model are:

Input data:



Total Yearly Consumption	**3500**	**[KWh]**
Battery Efficiency	**90%**	
Average PV generation	**1000**	**[KWh/Wp]**
COST		
PV Cells	**1,5**	**[€/Wp]**
Battery	**350**	**[€/KWh]**

Objective Function:

$$Min\ (\ PV[Wp]\ *\ price\ [€/Wp]\ +\ Battery\ [Kwh] * price[€/Kwh]\ )$$

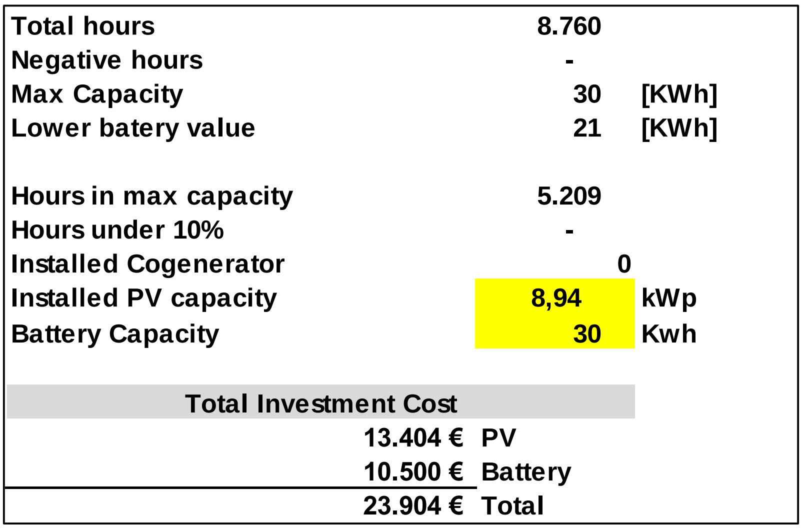
s.t. $BL(t-1) + G(t-1) - D(t-1)\ >\ SL$

Where

- BL stands for Battery Level,
- G for generation,
- D for Consumption
- SL is security level which is set equal to 3 day consumption.

Results from the optimization show how the tradeoff between battery capacity and PV installed capacity is solved.

Under this conditions a standalone system cost are similar to those calculated under LCOE for PV and LCOE for battery as well.



Total hours	**8.760**	
Negative hours	**-**	
Max Capacity	**30**	**[KWh]**
Lower batery value	**21**	**[KWh]**
Hours in max capacity	**5.209**	
Hours under 10%	**-**	
Installed Cogenerator	**0**	
Installed PV capacity	**8,94**	**kWp**
Battery Capacity	**30**	**Kwh**
Total Investment Cost		
13.404 €	**PV**	
10.500 €	**Battery**	
23.904 €	**Total**	

7.3.1 Security of supply

Despite the conditions under which the optimization case have been calculated, where the battery allows for 3 days consumption with no generation, reliability is still lower than network quality standards, it should be therefore noted that a back-up generator might be required to guarantee the conditions provided by the grid.

7.3.2 Model variation

An additional variable was introduced to this model, in order to evaluate the economic feasibility of a micro CHP dual system.

Commercial micro CHP are similar to commercial gas boilers, but this systems use the residual heat to provide an average of 1kWe from Free Piston Stirling Engine achieving efficiency range of 90%.

The optimization formula was updated to incorporate a binary variable to decide whether or not to install the micro CHP generator and how it affected the other capacities.

Taking advantage of this technology will allow generating extra electricity exactly in the moments when higher electricity consumption happens. Especially during winter season provided that heating the house will generate electricity guaranteeing that during cold cloudy day electricity will be sufficiently generated.

The main outcome from this model modification depends on total consumption and price of the CHP system. When it is used, both battery and PV capacities are lowered as condition for battery minimum storage can be relaxed.

Outcome

Total hours	**8.760**	
Negative hours	**-**	
Max Capacity	**18**	**[KWh]**
Lower batery value	**10**	**[KWh]**
Hours in max capacity	**-**	
Hours under 10%	**15**	
Installed Cogenerator	**1**	
Installed PV capacity	**4,17**	**kWp**
Battery Capacity	**18**	**Kwh**
Total Investment Cost		
8.000 €		
6.261 €	**PV**	
6.300 €	**Battery**	
20.561 €	**Total**	

Final outcome shows that relaxing the condition form minimum storage and slightly adding generation, required capacity both for solar PV and battery are lowered, achieving a lower investment cost.

8 GRID DEFLECTION

Grid deflection has been only considered economic rationale for a number of specific cases. In fact, the possibility of economic sense for unplugging a house from the existing network is rarely found under the current costs.

Standalone facilities are common in isolated systems that, compared to the need of network extension investment, standalone PV generation plus batteries are installed. These systems tend to suffer a marked scarcity of energy and therefore the service quality is hardly comparable to the service provided by the network.

Nevertheless, in the lack of a proper regulation, under increasing costs of electricity together with declining cost of generation and storage (batteries) technologies, some consumers might find the incentive to abandon the grid.

8.1 CONSUMER PERSPECTIVE OF GRID DEFLECTION

8.1.1 Economic feasibility for grid deflection

Thanks to latest cost reductions, PV generation is achieving grid parity in Spain, this situation imply that LCOE for PV is lower that retail costs and therefore net metering schemes would represent a clear opportunity for investment.

Nevertheless, given the proposed regulation on distributed generation, net metering is being discouraged.

Under this perspective, grid deflection has been considered as a way to avoid paying for the network costs.

In order to be able to unplug from the network, a trustworthy back-up system is needed as previously argued.

Battery costs are declining but it is still considered to have a great potential for cost cutting.

Provided the current battery costs, in order to maintain the quality of the service, the current cost of the unplugged systems is higher than the regulated price of electricity provision.

Nevertheless, projected battery cost reductions along with PV generation optimization, can show in a shorter term than expected real economic benefits for grid deflection.

It should be noted that positive valuation for off grid deflection might be based not on the most efficient system but on distortions created by the regulatory framework.

Further analysis is developed under different perspectives to understand the sources of the distension as well as the possible consequences that current cost structure can lead to. On this bases, the subsequent sections discuss the social effect of deflection.

8.2 NETWORK PERSPECTIVE OF GRID DEFLECTION

8.2.1 Impact of grid deflection

In order to evaluate grid deflection implications, a number of issues should be addressed.

Penetration level is key for the economic impact, a small number of consumers getting disconnected does not have a high impact on the system.

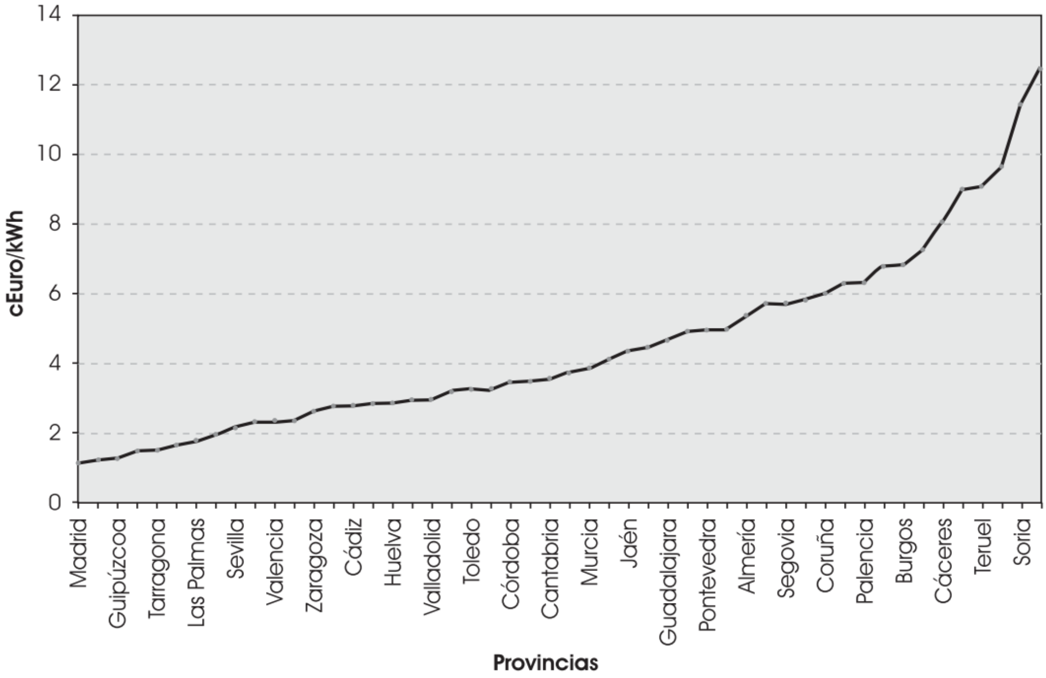
Nevertheless as the number of costumers unplugging increase, the effects can be significantly higher.

As shown in the tariff structure section, distribution, transmission and a number of system costs are recovered through both the fixed and the variable components of the tariff.

When consumers disconnect from the network they stop paying their piece of the cost and therefore this cost should be relocated within the remaining consumers. Therefore, the effect of an increasing number of consumers unplugging would imply an increase in cost for the remaining ones and therefore higher incentives to abandon the network.

The impact of the abandonment of the network depends on the previously cost generated and supported by that consumer. It should be noted that, according to (paper distribution costs IIT Tomás Gomez) depending on the population density as well as the network configuration, some connections imply much higher costs than others, in general terms big cities show low connections cost per user and also per energy consumption (Kwh), while small villages show higher distribution costs as few consumers require large network deployment. It should be therefore noted that grid deflection impact is not linear.

Figure 16: Efficient Unitary Cost by province

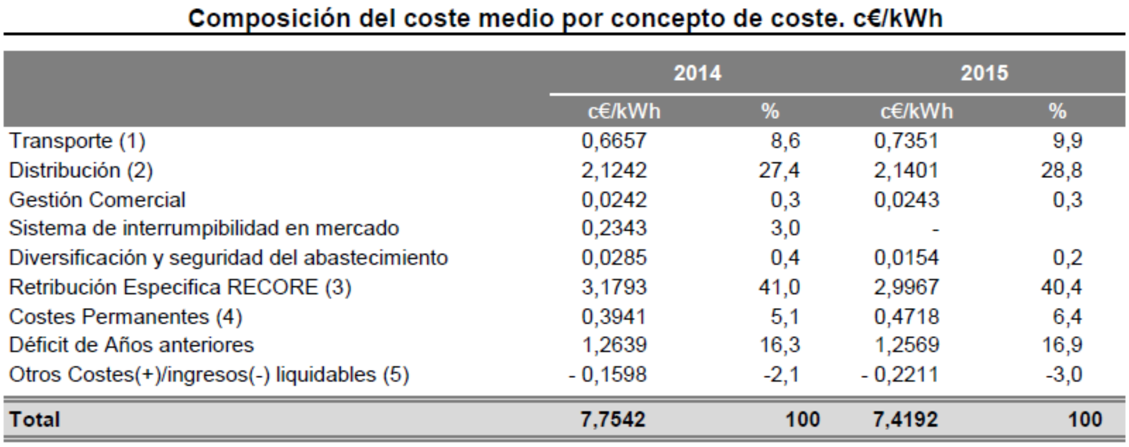


Source: [8]

In the graph the regional average distribution cost per kWh is shown. As it can be observed distribution costs in Soria are almost ten (10) times the costs in Madrid. This information suggests that for specific cases differences can be even higher.

Taking into consideration the average cost of distribution paid by consumers that, according to the CNMC amounts for 2,14 cents€/KWh.

Figure 17: Average regulated cost by concept for retail pricing



Composición del coste medio por concepto de coste. c€/kWh

	2014		2015	
	c€/kWh	%	c€/kWh	%
Transporte (1)	0,6657	8,6	0,7351	9,9
Distribución (2)	2,1242	27,4	2,1401	28,8
Gestión Comercial	0,0242	0,3	0,0243	0,3
Sistema de interrumpibilidad en mercado	0,2343	3,0	-	
Diversificación y seguridad del abastecimiento	0,0285	0,4	0,0154	0,2
Retribución Especifica RECORE (3)	3,1793	41,0	2,9967	40,4
Costes Permanentes (4)	0,3941	5,1	0,4718	6,4
Déficit de Años anteriores	1,2639	16,3	1,2569	16,9
Otros Costes(+)/ingresos(-) liquidables (5)	- 0,1598	-2,1	- 0,2211	-3,0
Total	**7,7542**	**100**	**7,4192**	**100**

Source: CNMC

It can be clearly inferred that most population, living in big cities pays for the cost of distribution in small villages.

When distribution costs are extremely high compared to the average, the impact of unplugging depends on the configuration of the network.

Assuming an extreme case where only two consumers remain connected in a certain substation, if one of them decides to go off grid, the cost for the network will remain the same as the marginal cost can be neglected.

On the other extreme, unplugging of one consumer located in highly populated city will also show small impact on total costs. In fact, as these consumers cross subsidize the high distribution costs from isolated ones; impact on other consumers would be slightly higher.

Nevertheless, if increasing number of consumers decides to go off grid, the impact will be significant and will lead to more incentives to go off grid as the cost of the service increases.

There might be one option were getting some consumers off grid would decrease shared cost. If consumers from those locations where distribution costs are higher move together out from the network allowing cutting the service in this location might imply a cost reduction for the whole system.

This hypothesis should be better tested based on the efficient distribution models that are used as efficiency benchmark for the distribution network.

8.3 SOCIAL WELFARE EFFECT OF GRID DEFLECTION

The analysis provides an insight on the private incentives for grid deflection, as lower cost for PV distributed generation and batteries is provided, households with available space will have economic incentives to go off grid.

It is therefore an opportunity to save money from deflection.

In order to asses if the money saved has a positive impact or not on the whole social welfare. A number of issues have been addressed and other should be taken under consideration.

- It has been shown that for some specific cases, grid deployment might save distribution costs to the system. But for the general case, grid deployment will imply higher distribution costs for the remaining consumers.
- Other costs that are shared within the electricity consumers, provided that the amount of money will not vary with the grid deflection, the same amount will be divided within one less consumer. Those costs are, for some extent network costs that should be charged to those consumers using the network but other costs, under the Spanish tariff regulation, come from policy and regulatory costs that show inefficient as are not charged on the use nor the causality principle (REF Batlle Regulation Book) but simply distributed among consumers.

On the other side, distributed PV generation will reduce electricity generation and losses from a mix that generates CO2 being substituted by renewable energy. This switch shows positive externalities that should be accounted for.

Therefore, a clear effect cannot be derived and further analysis should be conducted to quantify the exact impact of grid deflection.

8.3.1 Welfare distribution effect on deflection

Provided that the effect on social welfare of deflection is not totally clear, what it can be derived from the analysis is that the consumer that is abandoning the grid is doing it based on economic rationality.

As economic sense is granted, companies will be prone provide the required services to capture this profit. Therefore those companies should be addressed for the welfare distribution provided that for many consumers those companies will provide a service similar to the one provided by the traditional utility

8.4 CONCLUSIONS ON GRID DEFLECTION

From the analysis is derived that clear incentives and proper tariff regulation will lead to efficient decisions on distributed generation and grid deflection.

It is also clear that grid deflection will be less likely under appropriated tariff structures.

Provided the optimal regulation, under extremely low costs of PV and batteries, some grid deflections might have both economic sense for the consumer and for the system as a whole. Further analysis should be developed in this way, especially to identify locations with extremely high cost of electricity distribution.

In the next section, a theoretical competition analysis is conducted on the service that the network provides in order to identify the proper regulation that shall be proposed in the last section.

9 COMPETITION ANALYSIS OF THE ENERGY SUPPLY AND BACK-UP SERVICE

The natural monopoly characteristics of network business, and specifically the transmission and distribution of electricity has been deeply analyzed and assumed. [1].

As natural monopoly this activities have been regulated and costumers requested to pay for the cost of this services according to the regulatory fee. Different proposals have been stated for the optimal regulation and remuneration of those activities most of them based on recognizing the efficient level of investment and cost for operation and management of the networks while providing a certain level of supply quality.

When new services are created on the base of technology evolution, the traditional understanding of the preexistent market and economic analysis might change.

According to the European Competition Commission, the definition of relevant market is based on the grade of substitutability of one product or service for other product or service. Specifically the Commission notice on the definition of relevant market for the purposes of Community competition law [9]. Establishes the definition of relevant market as:

“The relevant market combines the product market and the geographic market, defined as follows:

- a relevant product market comprises all those products and/or services which are regarded as interchangeable or substitutable by the consumer by reason of the products' characteristics, their prices and their intended use;
- a relevant geographic market comprises the area in which the firms concerned are involved in the supply of products or services and in which the conditions of competition are sufficiently homogeneous.”

Commission provides basic guidelines for the relevant market identification, both for the on the product or service and on the geographic dimension.

The traditional methodology is based on the substitutability criterion that enables to identify the relevant product market and the geographic market with a greater degree of certainty.

Assessment of substitutability might be based on different approaches, the theoretical methodology based on a Short but Non Transitory Increase in Prices (acknowledge as SNIP test) allows to theoretically asses the relevant market for a certain product or service. Other methods, such as demand elasticity, rely on sufficient information availability.

- Demand-side substitutability analyses if a customer, in response to a small (5-10%) increase in the price of the product is prone to change to other product to satisfy the same need.

- Supply-side substitutability analysis refers to the capacity of the supplier to switch production to the relevant products.

When applying the SNIP test to the retail market a number of consideration should be taken.

Electricity provision shall be analyzed as a relevant market provided that a consumer that needs to satisfy a need of electricity will be served by the grid and the whole electricity system. It is also argued that the market should not only be evaluated for the product and the geography but also time should be taken into account.

Energy can be delivered in different moments of the day, those moments might change the nature of the product and be interpreted of different products as the conditions for energy delivery vary over the day hours.

On geographical dimension, energy provision presents again a rather straightforward nor simple analysis. On one side energy is delivered to each individual location, from this perspective is extremely local as no substitution of location can be assumed for, at least a domestic consumer. Other kind of consumers might have a higher dependence on electricity price and therefore a variation in price might imply a change in the location.

In Spain, flat rates are established for the regulated tariff, it should therefore imply that the same service is delivered in the territory.

For years relevant market for retail consumers was defined on the base of a natural monopoly of distribution and transmission activities and therefore the service identified as the relevant market was retail, under which competition was fully introduced by liberalization in 2003.

Eligible consumers are able to change retail company but distribution and transmission remained invariable to costumer decisions and generation itself depended –for some extent- on the retail option.

Therefore the relevant market until this moment has nothing to do with transmission nor distribution activities and the geographical dimension is considered national as any retailer is able to sell energy to consumers and consumers are able to change from one retailer to another independently of their location.

Despite the initial analysis, energy provision has been showing certain changes that might modify this market definition.

As it has been shown the difference between the costs of electricity provided by the traditional network compared to the energy generated at a standalone rooftop system might imply that, provided the conditions, electricity domestic provision can be obtained directly from a distributed generation facility, specifically rooftop PV systems.

Taking in consideration the time dimension of the analysis, for certain moments of the day this facility will be able to provide energy to the consumer, nevertheless, when generation does not match consumption certain back-up is required.

New options should be therefore taken into consideration when defining the relevant market for domestic electricity supply and, given the expected trends in cost reduction a small increase in the price of the energy supplied by the grid (generation plus regulated costs) may imply a shift of costumers from on grid service to the off grid.

Entrance barriers should be considered when analyzing the capacity for homeowners to switch from an on-grid connected service to stand alone off grid facilities.

The main entrance barrier considered is the initial investment as the stand alone system has to be fully invested by the costumer, this entrance barrier would limit the switching capacity even when economic sense is reached.

This entrance barrier is being overcome on the base of new services provided by financial and service companies that make the upfront investment and offer a financial structure similar to the previous electricity invoice. Those services are analyzed in XX section.

Another market analysis might be undergone from the prosumers perspective, distributed PV generation requires, as showed in previous section, a backup system. This service can be provided by a number of technologies locally or this can be provided by the network. It should be therefore noted that the traditional electricity supply will be competing with the other backup technologies for the provision of electricity when the PV generator fails to cover the instant demand.

Under this perspective the following sections will analyze the competitive situation of the alternative backup system compared to the network.

10 NEW BUSINESS CREATION: LOWERING FINANCIAL COSTS AND RISKS BALANCE

Provided that financial costs are one of the major variables for the transition to grid parity, new financial products have been created to encourage this deployment and profit from relatively stable and secure income.

10.1 NEW SERVICES AT RETAIL LEVEL

Other services and business are being created on the base of grid parity and increasing awareness from consumer side.

Different structures have been set up in order to capture part of the grid party arbitrage.

Under the Individual household mindset, traditional financial analysis cannot be conducted. Upfront investment traditionally deters individuals to install distributed generation and even less to go off grid on the base of economic rationality.

On the other side, other incentives may lead those individuals to make a move on the base of environmental awareness, stability of prices or simply because of personal believes.

A number of companies have identified the need of simplified structures that allow consumers to keep their traditional monthly payment but, instead of paying their traditional utility they pay those new companies.

Risk is therefore assumed by the company that invests in the equipment and charges the client a fee for the service. Different structures have been set adapt to different consumption profiles.

Risk sharing has been structured in a way where consumers that are willing to invest, still receive the Operation and Maintenance service and solely pay for this service.

Other services act as a financial institution and lends the amount required to install the equipment and then collects a periodic fee.

Provided that new business will be created as needs are identified, new business models might be created.

10.2 FINANCE COST REDUCTION: YIELD COMPANIES

YieldCos are vehicles that allow the creation of shareholders value through spinning off projects into those vehicles. IPOs of those YieldCos facilitate financing for further deployment.

Through YieldCos, companies achieve lower cost of capital and are able to restructure their original capital structure, achieving further cost of capital reduction.

This vehicles can be used to integrate different projects that under individual risk analysis valuation would require of much higher financial costs. This situation specifically applies to residential solar and international projects in countries where country risk tend to increase the cost of finance, leading to high electricity costs. Other activities with similar profile risk and stable income might be integrated into the same vehicles.

11 REGULATORY ANALYSIS AND PROPOSALS

11.1 IDENTIFICATION OF BEST PRACTICES

11.1.1 Germany

Germany, launched support for home solar and battery storage in 2013.

The German government has supported the installation of battery storage systems coupled with solar PV panels at the household level. The program aims to encourage further technical development of storage battery systems for solar PV installations.

The program provides low-interest loans and repayment subsidies for new solar PV installations which incorporate a fixed battery storage system. The subsidy amounts to a maximum of 30% of the investment cost for the energy storage system, 25 million euros were assigned to finance the program.

Basic program requirements include:

- PV installations must be smaller than 30 kWp, and batteries must be used for at least five years.
- PV systems must have been installed by 31 December, 2012 to receive the battery incentive.
- The PV installation feed-in to the grid must not exceed 60% of its nominal power rating over its whole lifetime, or at least for 20 years. This encourages optimal charging behavior.
- Total subsidies are capped at EUR 600/kWp for PV systems operating within the previous six months.

11.1.2 JAPAN

In 2014, Japan established a subsidy program to support Li-ion battery-based stationary storage systems installation, covering up to 2/3 of the purchase price of the system. Japan’s Ministry of Economy, Trade and Industry, declared that a budget of JPY10B (~$98M) had been allocated for the program. Subsidy payouts are capped at JPY1M ($10k) for individuals and at JPY100M for businesses, available for the installation of battery systems of 1kWh capacity or more.

11.1.3 United States

California - California's AB 2514 energy storage procurement program requires California Public Utilities Commission (CPUC) to consider creating an energy storage procurement mandate for utilities.

CPUC has ratified a mandate that will require the state's biggest investor-owned utilities to add 1.3GW of storage capacity to their grids by the end of 2020 (SCE – 580MW, PG&E – 580MW, SDG&E – 165MW). Additionally, the state's Self-Generation Incentive Program (SGIP) provides financial incentives for the installation of clean and efficient distributed generation technologies.

Washington - Washington State enacted two laws to enable qualifying utilities to credit renewable sourced energy storage output at 2.5 times the electricity price; and to require electric utilities to define a minimum of energy storage in all integrated resource plans.

New York –

New York Battery and Energy Storage Technology consortium was created in 2010 with a $25M grant from New York State Energy Research and Development Authority (NYSERDA) and to position New York State as a world leader in energy storage technology.

In Jan 2014, Consolidated Edison and NYSERDA announced the intention of reducing the load by 100MW during pick demand, partly based on the use of energy storage systems. Under the program, grants for thermal storage units increased from $600/kW to $2,600/kW, and support for battery storage increased from $600/kW to $2,100/kW.

11.1.4 CANADA

Ontario’s government intends to reduce the regulatory barriers identified under the long term energy plan that were limiting the competitiveness of energy storage in Ontario’s electricity market.

By the end of 2014, the government will include (starting with 50MW) storage in its procurement process. The new procurement Plan states that the new process for large renewable energy projects and will also consider proposals that integrate energy storage with renewable energy generation.

12 THE CASE OF SPAIN

Spanish regulatory framework has not specifically recognized the right to generate and consume under a net metering scheme. For many years this modality fold under general provisions for generation units with self-consumption[1].

Provided the need of a regulation on this issue based on the European Directive 2004/8/CE, the government first drafted a Royal Decree on Self-consumption facilities.

The first draft was highly contested by a relevant proportion of stakeholders and was criticized by the Energy Regulator.

Almost two years later, a new Royal Decree has been drafted in order to address this modality.

Under the new draft Decree, small prosumers are charged a fee for self-consumption that amounts to approximately 5cent€/kWh and a fixed fee (around 9€/kW/year). Under the simplified modality excess generation will not be credited nor compensated.

Again this version has been criticized from different stakeholder’s side.

Provided this situation, and based on the previous analysis on the different implications of PV distributed generation, batteries and the impact of grid deflection a number of considerations are provided.

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[1] Electricity Law 54/1997, 38/1992 Special taxes and the Royal Decree 1955/2000

12.1 REGULATORY FRAMEWORK

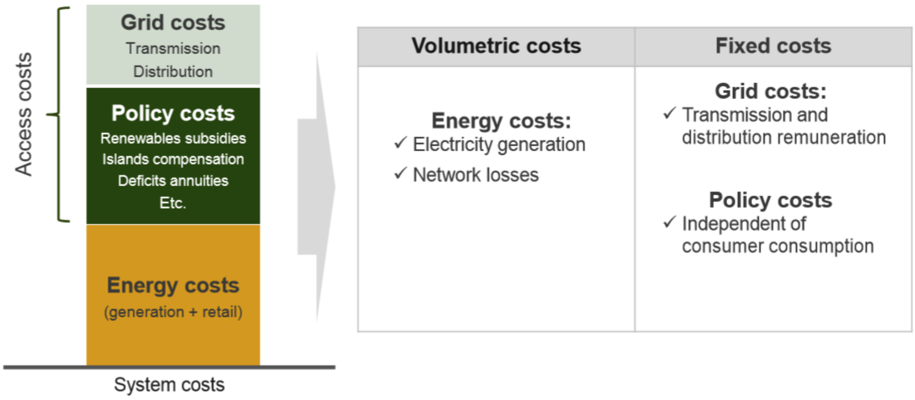
12.1.1 COST ALLOCATION

In order to understand the rationale behind the back-up tariff, some comments should be done on the current tariff structure in Spain.

Consumers are billed based on a volumetric and a fixed charges. Whereas the fixed is based on the contracted capacity (€/kW/days) the volumetric charge is proportional to the energy consumed (€/kWh).

Therefore, according to the figure 18, energy costs should be paid under volumetric charges whereas regulated costs and other policy costs should be addressed under fixed costs. Under this structure correct incentives reflect the nature of each charge.

Figure 18: Nature of System costs according to consumer demand



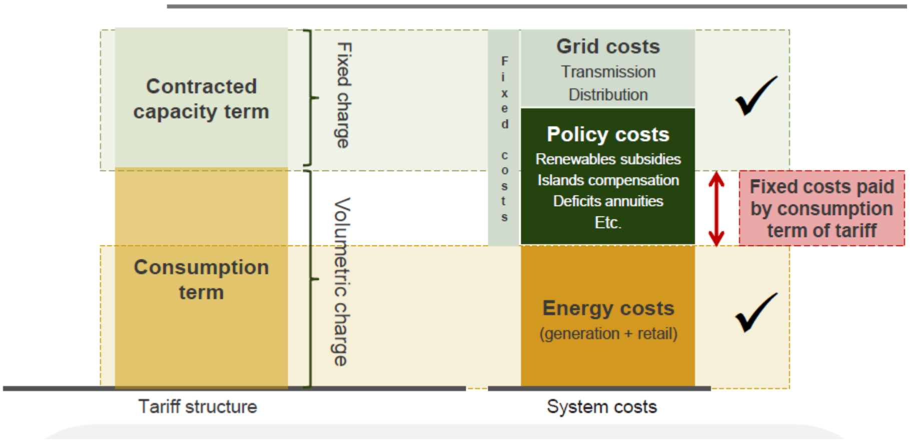
Source: [10]

Under the Spanish regulatory framework, fixed charges do not cover all the fixed and regulatory (that happen to be extremely high) costs and therefore, the volumetric charge includes not only the electricity generation cost but also part of the regulated costs.

Despite an adjustment of the charges, volumetric charges still partially cover fixed costs.

In the next figure it can be observed the structure of costs and charges.

Figure 19: Spanish cost and charges allocation



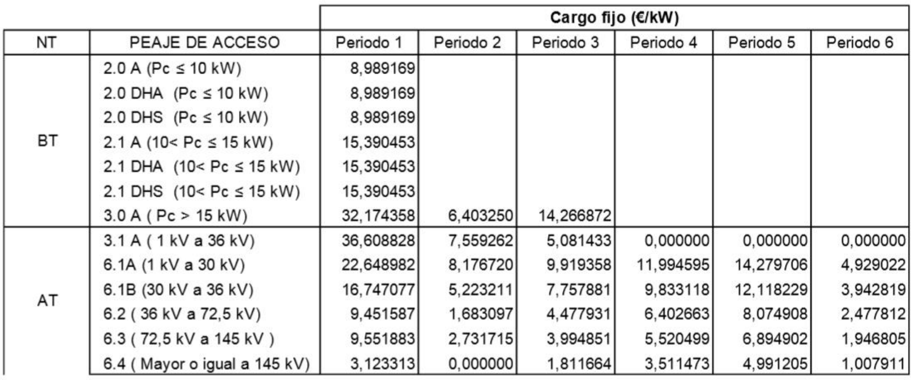
Source: [10]

The fact that the structure does not match with the nature of the charges has several implications as well as a number of interesting discussions that further investigation should address. Especially under high penetration of renewable energy, wholesale prices tend to be lower and so volumetric charges.

The effect of this structure for net metering schemes imply that consumers that are allowed to consume their energy and be compensated for the energy dropped to the distribution network will not cover their share of the network and policy costs.

Under this perspective, the back-up toll was proposed in order to cover this gap and guarantee that prosumers pay for the service the network is providing.

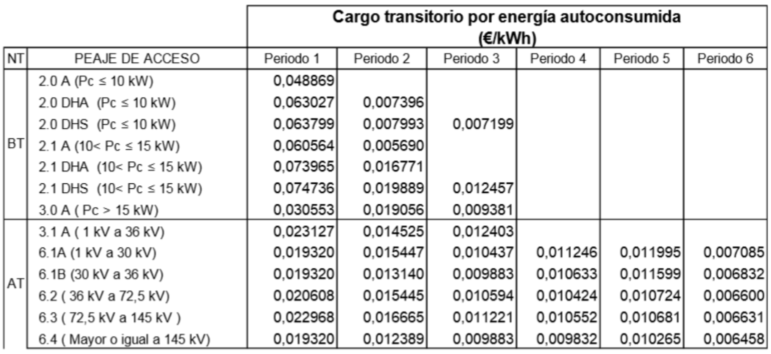
Figure 20: Poposed acces tariff for PV generation connected to the distribution network



		Cargo fijo (€/kW)					
NT	PEAJE DE ACCESO	Periodo 1	Periodo 2	Periodo 3	Periodo 4	Periodo 5	Periodo 6
BT	2.0 A (Pc ≤ 10 kW)	8,989169					
	2.0 DHA (Pc ≤ 10 kW)	8,989169					
	2.0 DHS (Pc ≤ 10 kW)	8,989169					
	2.1 A (10< Pc ≤ 15 kW)	15,390453					
	2.1 DHA (10< Pc ≤ 15 kW)	15,390453					
	2.1 DHS (10< Pc ≤ 15 kW)	15,390453					
	3.0 A (Pc > 15 kW)	32,174358	6,403250	14,266872			
AT	3.1 A (1 kV a 36 kV)	36,608828	7,559262	5,081433	0,000000	0,000000	0,000000
	6.1A (1 kV a 30 kV)	22,648982	8,176720	9,919358	11,994595	14,279706	4,929022
	6.1B (30 kV a 36 kV)	16,747077	5,223211	7,757881	9,833118	12,118229	3,942819
	6.2 (36 kV a 72,5 kV)	9,451587	1,683097	4,477931	6,402663	8,074908	2,477812
	6.3 (72,5 kV a 145 kV)	9,551883	2,731715	3,994851	5,520499	6,894902	1,946805
	6.4 (Mayor o igual a 145 kV)	3,123313	0,000000	1,811664	3,511473	4,991205	1,007911

Source: Draft Royal decree

Figure 21: Proposed Volumetric charge for PV generation connected to distribution network



NT	PEAJE DE ACCESO	Cargo transitorio por energía autoconsumida (€/kWh)					
		Periodo 1	Periodo 2	Periodo 3	Periodo 4	Periodo 5	Periodo 6
BT	2.0 A (Pc ≤ 10 kW)	0,048869					
	2.0 DHA (Pc ≤ 10 kW)	0,063027	0,007396				
	2.0 DHS (Pc ≤ 10 kW)	0,063799	0,007993	0,007199			
	2.1 A (10< Pc ≤ 15 kW)	0,060564	0,005690				
	2.1 DHA (10< Pc ≤ 15 kW)	0,073965	0,016771				
	2.1 DHS (10< Pc ≤ 15 kW)	0,074736	0,019889	0,012457			
	3.0 A (Pc > 15 kW)	0,030553	0,019056	0,009381			
AT	3.1 A (1 kV a 36 kV)	0,023127	0,014525	0,012403			
	6.1A (1 kV a 30 kV)	0,019320	0,015447	0,010437	0,011246	0,011995	0,007085
	6.1B (30 kV a 36 kV)	0,019320	0,013140	0,009883	0,010633	0,011599	0,006832
	6.2 (36 kV a 72,5 kV)	0,020608	0,015445	0,010594	0,010424	0,010724	0,006600
	6.3 (72,5 kV a 145 kV)	0,022968	0,016665	0,011221	0,010552	0,010681	0,006631
	6.4 (Mayor o igual a 145 kV)	0,019320	0,012389	0,009883	0,009832	0,010265	0,006458

Source: Draft Royal decree

12.1.2 Alternative proposals

As stated by the National Energy Commission, imposing volumetric charge for the energy generated is opposed to the regulatory logic, provided that the costs that it is intended to cover have a fixed nature. Therefore fixed access tools shall be stated such as their cover for the fixed regulated costs. On the other side, the NRA proposes to cover the regulatory costs as an annual lump sum for all consumers.

Despite this proposals would cover the costs and avoid cross subsidies, the incentives of this regulation might lead to an inefficient solution.

Assuming the optimistic cost reduction path for both PV and batteries, there is a real chance that in the following years, provided the previously burden on consumers, potential prosumers would be incentivized to go off grid.

Both alternatives, a tariff restructuring and the backup tool would lead to increasing number of consumers willing to go off grid. Under this situation, fixed costs of the system will be redistributed among the remaining consumers, this will imply higher costs and increase the incentives for unplugging.

Therefore, if the cost reduction trends are confirmed, regulatory structure should address this complexity. A number of proposals are further addressed.

13 REGULATORY PROPOSAL

13.1 DISTRIBUTED GENERATION AND BATTERY MANAGEMENT

As previously shown, grid deflection under current costs is not cost efficient for the majority of the cases. Nevertheless, under the current path of cost reduction possible perverse incentives can arise based on the regulatory framework.

Based on the conclusion on the impact of network deflection, proper regulatory framework should prevent from a large residential electricity storage system deployment in the case of those systems being used for self-consumption without providing grid services support.

Incentives should be set in the manner that prosumers support the grid service by integrating distributed generation and storage under the distribution system operator.

13.1.1 Tariff regulation

Tariffs should be regulated regarding the approach of a contestable market where under inefficient (high) tariffs deflection is a real possibility.

Based on that a review of the tariff structure in Spain shall be conducted in order to exclusively include as a fixed charge the concepts that account for the service provided.

Back-up toll should not be necessary once tariffs are properly structured as the fixed part of the tariff will account for the network costs and other required costs to provide the back-up service.

13.1.2 Distribution regulation

Deflection shall be encouraged when the net effect on social welfare is positive. In order to do so, regulation on optimal distribution cost allocation should be developed taking deflection as an alternative for small villages and low density population locations.

As analyzed in chapter 8.2 differences from distribution costs imply an implicit subsidy of isolated consumers. Therefore incentivizing those consumers to go off grid will reduce total cost of the grid.

14 CONCLUSIONS

From the preceding analysis a number of conclusions have been derived.

Cost reduction in distributed generation is leading to a complete change in the traditional way energy provision was understood.

14.1 DISTRIBUTED GENERATION: SOLAR PV IMPACT

14.1.1 On Grid

At the grid level, solar energy generation cost is decreasing and gaining competitiveness. As costs are reduced, larger facilities are installed to provide electricity through the traditional networks. Traditional support mechanisms are being reduced or adjusted as costs decrease. Therefore, under appropriated regulatory frameworks benefits from the technical advances are interiorized by the system.

At the retail level, grid parity is being reached all around the globe. As distributed PV gains competitiveness compared to the retail price paid by consumers, consumers are finding incentives to install this technology and became prosumers.

Nevertheless, the schemes supporting PV distributed generation require an in detail analysis, as they show complex redistribution effects.

Under net metering and similar schemes, if the tariff structure is not efficiently designed and part of the fixed costs are paid through volumetric tariffs, prosumers will not cover the fixed cost of the service and therefore other consumers will be paying their part. Under this situation cross subsidies are being implicitly recognized without a clear analysis on the real rationale of this support.

Further analysis should be therefore developed in order to identify the appropriated incentives for PV distributed generation.

It is also acknowledged that the effect of high penetration of distributed generation imply certain increase in the cost of managing the distribution network. Whereas low penetration allows for loses reduction. Further analysis is proposed on this side, in order to properly address cost allocation of this modality.

14.2 OFF GRID

Despite being the most efficient option, in cases where on grid (distributed PV) is not supported by the regulation or in cases where the cost of the grid is extremely high, alternatives are gaining momentum.

Off grid systems have been considered alternatives for isolated locations where the grid connection was too expensive.

Nevertheless, provided the cost reduction of generation technologies coupled with the incipient cost reduction of batteries this alternative is achieving an impressive cost reduction that will lead in a short period of time to offer a real alternative to the electricity grid connection.

Under this perspective it has been argued that the network will be perceived by prosumers as an option to provide backup, as batteries and other storage technologies can be, and therefore a number of implications have been derived for the regulatory proposals.

The major conclusion is that a regulation should take into consideration this new paradigm and provide a regulatory framework that allows maximizing social welfare.

This social welfare maximization should be achieved by taking into consideration, among others, externalities form renewable energy generation, cost increase or decrease of the distribution networks as well as the location of the generations acknowledging for the different cost for distribution based on the location.

Batteries coordination by the Distribution system operator are also considered a key element in order to reduce losses and costs in the distribution network even under high penetration of distributed generation.

14.3 THE SPANISH CASE

Finally, based on the previous conclusions some considerations are provided for the Spanish regulatory framework.

The main analysis is based on the proposed back-up tariff. The analysis has been based on the perspective of a potential prosumers that has the ability to unplug from the network if it results profitable.

On this side some conclusions have been addressed:

The Spanish Tariff, despite the latest modifications still includes part of the fixed and policy costs on the volumetric side. It is generally argued that an adjusted structure will properly identify the volumetric variable with the generation costs and therefore avoid cross subsidies under net metering. This option also shows a number of disadvantages the main one is the reduction in the incentive for energy efficiency.

Provided that this analysis has been clearly addressed, the conclusion is based on the incentives for the prosumers. From their perspective, a tariff restructure and the back-up tariff lead to similar outcomes as the incentive for unplugging from the network increases under both.

Therefore, despite being correct, from a regulatory perspective, to restructure the tariff, as the effect on the incentives for potential prosumers remain the same, this solution will not reduce the incentives to disconnect from the network.

Therefore, as grid disconnection is considered, under current conditions, an inefficient solution for the system as a whole and from a general perspective the impact on cost distribution is negative. As long as unplugging implies a higher burden on other consumers other regulatory frameworks should be addressed, even if some cross subsides are considered.

15 FURTHER RESEARCH

Based on the conclusions and especially on the limitations to the analysis, a number of relevant issues have been identified for further research.

- Tariff structure under high penetration of renewable energy presents a number of challenges. Provided the cost reduction, a generation mix based on pure renewable energy shall be modeled and further analyzed in order to define proper regulation.
- Distribution network cost analysis shall provide some clear conclusions on the effect of planning grid expansion with the alternative of off grid systems for isolated locations. This would allow to identify the locations where distribution costs are higher than the cost of back-up system provided by batteries along or combined with cogeneration.
- Cost efficiency of domestic micro cogeneration shall be analyzed in detail as new commercial co-generators are available. Further modeling for different heating requirements is envisaged to clearly obtain a conclusion of its profitability.
- Alternative battery technologies and materials shall be analyzed as different characteristics are provided by each technology. Innovation in this field shall be closely followed, facts and general assumed conclusions may be revised on new information.

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