Assessment of the PV Self-Consumption Impact on the Portuguese Scenario within the European Energy Legislative Scheme

Cristina Milagros Herce Villar

Thesis to obtain the Master of Science Degree in

Energy Engineering and Management

Supervisors: Prof. Carlos Augusto Santos Silva

Dra. Maria João Rodrigues

Examination Committee

Chairperson: Prof. Duarte de Mesquita e Sousa

Supervisor: Prof. Carlos Augusto Santos Silva

Member of the Committee: Prof. Luís Filipe Moreira Mendes

July 2016

As a token of appreciation for your time of patience, “service” and inspiration, thank you *Impasible* and thank you Diana.

ABSTRACT

Founded on the emerging new energy paradigm, which places decentralized renewable energy (RE) production as the core and engine of the XXIst century energy revolution, the domain of this work is to explore into how RE decentralization in Portugal would evolve by means of self-consumption (SC). For this study, it has been taken into account current legislative progress, assuming solar photovoltaics (PV) as the most convenient and plausible technology to be applied. Thus, it has been evaluated the adequacy and impact of real demand profiles of residential, retail, hotel and industrial sectors to simulated solar PV production profiles of different locations, orientations and inclinations. In order to assess the optimum *prosumer* (producer and consumer) profile, a techno-economic performance analysis using payback time and interest rate of investment as reference metrics, has been realized. Best economic indicators within each sector vary from a poor 6.85% Internal rate of return (IRR), 9 years payback time (PBT) of a residential profile (Demand1) in Porto (10SW) to an 27.07% IRR and 3 years PBT of a Retail profile (Retail1) in Faro (30SW) reaching a self- consumption of 39.14% (30S).

Furthermore, solar technology has been appraised and the European market and legislative energy strategies evolution has been revised in order to provide a comprehensive framework for the study.

Keywords: renewable energy sources, self-consumption, solar photovoltaics, electricity demand.

RESUMO

Fundada no novo paradigma energético emergente, o qual coloca a produção descentralizada de energia renovável (ER) como o núcleo e o motor da revolução energética no século XXI, o objetivo deste trabalho é explorar como a descentralização da ER em Portugal evoluiria por meio de autoconsumo. Para este estudo, teve-se em conta o actual progresso legislativo, assumindo a energia solar fotovoltaica (PV) como a tecnologia mais conveniente e plausível a ser aplicada. Assim, foi avaliada a adequação e o impacto de perfil de demanda real dos sectores residencial, retalho, hotelaria e industrial para perfis de produção solar PV simulada de diferentes locais, orientações e inclinações. De modo a obter o perfil do prosumidor (produtor e consumidor) óptimo, foi realizada uma análise do rendimento tecno-económico usando o período de recuperação do investimento e a taxa interna de rentabilidade (TIR) como indicadores. Os melhores indicadores econômicos dentro de cada sector podem variar de uma TIR de 6,85% e um tempo de retorno de 9 anos de um perfil residencial (Demand1) no Porto (10SW) a uma TIR de 27,07% e um tempo de retorno de 3 anos de um perfil de retalho (Retail1) em Faro (30SW), alcançando um autoconsumo de 39,14% (30S).

A tecnologia solar e a evolução do mercado europeu energético e legislativo foram também avaliadas para enquadrar o estudo.

Palavras-chave: fontes renováveis de energia, autoconsumo, energia solar fotovoltaica, procura eléctrica.

TABLE OF CONTENTS

LIST OF TABLES

ACRONYMS

µ+: High Efficiency Crystalline Silicon Solar Cell

µc-Si: Microcrystalline Silicon Solar Cell

A-Si: Amorphous Silicon Solar Cell

A-Si:H / A-Si: Hydrogenated Amorphous Silicon Solar Cell

ARC: Anti-Reflection Coating

BCSC: Back Contact Solar Cell

BOS: Balance-Of-System

CCGT: Combined Cycle Gas Turbine

CDM: Clean Development Mechanism

CdTe: Cadmium Telluride Solar Cell

CER: Certified Emission Reduction

CHP: Combined Heat and Power

CIEGS: Costs of Energy Policy, Sustainability and General Economic Interest

CIGS/$CuIn_xGa_{1-X}Se_2$: Copper Indium Gallium Diselenide Solar Cell

CQD: Colloidal Quantum Dot Solar Cell

CPPE: Portuguese Company of Electricity Production

C-Si: Crystalline Silicon Solar Cell

CSP: Concentrated Solar Power

CZTS/Cu_2ZnSnS_4: Copper Zinc Tin Sulfide Solar Cell

DAM: Day-ahead

DSO: Distribution System Operator

DSSCS: Dye-Sensitized Solar Cells

ECSC: European Coal and Steel Community

EEG: Renewable Energy Act

EFG: Edge-defined-film-fed-growth Solar Cell

EPBT: Energy Payback Time

ERSE: Portuguese Electricity Regulatory Agency

ERU: Emission Reduction Unit

ETS: Emissions Trading System / Scheme

EUA: EU Allowance Unit of one ton of CO_2

EWT: Emitter Wrap Through Solar Cell

FF: Fossil Fuel

FIP: Feed-in Premium

FIT: Feed-in Tariff

GaAs: Gallium Arsenide Solar Cell

GDP: Gross Domestic Product

GHG: Greenhouse Gas

HIT: Heterojunction with Intrinsic Thin Layer Solar Cell

IBC: Interdigitated Back-Contact

IDM: Intraday Market

IEA: International Energy Agency

I-MN-TSSC: Ion-implanted N-Type Silicon Solar Cell

IPO: Initial Public Offering

IRR: Internal Rate of Return

ISO: Independent System Operator

ITO: Independent Transmission Operator

JI: Joint Implementation

LCA: Life Cycle Assessment

LCOE: Levelized costs of Energy for Electricity

LGBG: Laser Grooved Buried Grid Solar Cell

Mc-Si: Multicrystalline Silicon

MIBEL: Iberian wholesale Electricity Market

MIBGAS: Iberian Natural Gas Market

MJ: Multijunction Solar Cell

Mono-Si: Single-crystalline Silicon

MWT: Metallization Wrap-through Solar Cell

NEMO: Nominated Electricity Market Operator

NREAP: European Commission National Renewable Action Plans

OMIE: Iberian Spot Market Operator

OMIP: Iberian Forward Market Operator

OPV: Organic Photovoltaics / Organic Solar Cell

OR: Ordinary Regime

OTC: Over the Counter

Pc-Si: Polycristalline Silicon Solar Cell

PERL: Passivated Emitter and Rear Locally Diffused Cell

PERC: Passivated Emitter and Rear cell

PESC: Passivated Emitter Solar Cell

PPA: Power Purchase Agreement

PBT: Payback Time

PCE: Power Conversion Efficiency

POLR: Provider of Last Resort

PSO: Public Service Obligation

PTEL: Portuguese Daily Market

PV: Photovoltaic

QD: Quantum dot Solar Cell

RPC: Rear Point Contact Solar Cell

RE: Renewable Energy

REN: State-owned Enterprise for High Voltage

RES-E: Renewable Energy Sources for Electricity

RGS: Ribbon Growth on Substrate Solar Cell

RNT: National Transmission Grid

SC: Self-consumption

SEI: Independent Electric System

SEN: National Electricity Portuguese System

SENV: Non-Binding System

SEP: Public Service System

Sc-Si: Single-crystalline Silicon

SR: Special Regime

SRM: System of Registration of Microproducers

SRMini: System of Registration of Minigeneration

STR: String Ribbon Solar Cell

TNP: Time-to-net-positive-cash-flow

TPA: Third-party Access

TREC: Tradable Renewable Energy Certificates

TSO: Transmission System Operator

UNFCCC: United Nations Framework Convention on Climate Change

UPAC: Self-consumption Units

UPP: Small Production units

V2G : Vehicle-to grid

WEB: Dentritic Web Solar Cell

1. INTRODUCTION

Today, the world is facing immense environmental threats. Global warming and climate change, loss of biodiversity, ozone depletion, soil erosion, and air and water pollution are global problems with wide-ranging impacts on humankind. As an extension of the ecological problems, there are also serious security issues associated with the large-scale use of fossil and nuclear fuels. Tensions arise from the exhaustion of unsustainable resources, uncertainties in energy prices and energy availability, geopolitical crisis due to the concentration of energy reserves in a few regions of the planet and the risk of nuclear proliferation menacing global security (Saygin and Çetin 2010). The control of energy sources can lead to extreme social adversity, e.g. mostly of the world´s leading oil/gas producing countries politically insecure or at serious conflict with the USA (Gupta and Arora 2015).

Therefore, energy security and climate change are nowadays the most important challenges and the conventional energy paradigm is clearly incapable of solving these significant problems. Therefore, a burgeoning involvement about global environmental and social issues has triggered a quest for a more sustainable approach on how energy is being generated, valued and expended. In such a manner that more environmentally friendly and ethical innovations have been making progress.

This situation has called for a cost-effective sustainable energy policy shift towards new energy strategies aiming to improve energy efficiency and rational use of energy before seeking to meet the remaining demand by the cleanest mean possible. This has been made by either increasing the share of renewable energy sources for electricity (RES-E), moving towards the decentralized paradigm or, as a last resort, exploiting the un-sustainable assets using low-carbon technologies. Yet the transformation to a distributed and dynamic production system has to progress, since the remaining central conception of generation pushes the most promising technologies into large concentrate energy units, having a negative impact on the environment and primarily beneficiating the plant operator, and not to the community that these units are in (Giotitsas, Pazaitis, and Kostakis 2015). A revolutionary alternative of a decentralized, smart energy grid where producers and consumers merge via small-scale energy production is behooved (Giotitsas, Pazaitis, and Kostakis 2015). The milestones that need to be implemented and developed to surmount energy security and climate change challenges in a sustainable way are the following:

- New specific *smart grid* [1] infrastructure, seeing that the existing transmission and distribution one only serves to the traditional centralized generation.

- Deployment of demand side management to shift demand in order to be adjusted to production.

- Production delivered to other districts or stored to be released in periods when is best employed. Authorities

---

[1] "The *smart grid* is a modernized grid that enables bidirectional flows of energy and uses two-way communication and control capabilities that will lead to an array of new functionalities and applications"(US Department of Commerce 2016).

should underpin cross-continental grid connections and reinforce local grids, which would allow energy to flow from Spain to Italy and France during peak generation (Gross 2015).

- New energy storage technologies and grid integration storage alternatives, e.g. vehicle-to grid (V2G) system, where electric and plug-in hybrid cars connect with the power grid by feeding or accepting electricity from the grid to offer regulation services such as keeping voltage and frequency stable, providing sudden demands of power and stabilizing RE intermittency (Yong et al. 2015).

- Major implication of society by a wide number of prosumers or generation participants. Whereas funds dedicated to distributed RE are low, the promotion of large-scale renewable generation or other types of energy infrastructure is subjected to big firms and governmental support ("European Commission - PRESS RELEASES - Press Release - State Aid: Commission Authorises UK Aid Package for Renewable Electricity Production" 2016).

- Appropriate regulation framework and policy to expedite the entrance of new competitors, capital and services as well as to contend with reluctant participants still working under old models.

- Energy efficiency and efficient markets. One of the main purpose of an efficient energy market is to balance and exploit risk, opportunities and competition in the perfect timing to adequately withstand any potential supply scarcity trouble (Christos Papadopoulos 2015). An efficient market and therefore a free competitive market need the presence of:

- Transparency (universal availability and flow of information).
- Liquidity (degree to which a market allows assets to be sold and purchased at steady prices) promoted by well-designed markets.
- Ample number of market participants to avoid price manipulation.

In real scenarios these properties are not fully fulfilled affecting negatively to market parameters being highly uncertain on the long and medium term (Christos Papadopoulos 2015).

Liberalized markets are not unquestionably efficient markets. Major competition and participation of a vast number of members has been developed in only some EU administrations which underwent market privatization. In Germany, generation players have evolved during this century from regular facilities to self-consumers and cooperatives. Whilst other governments or environments have not fostered such real change of model setting aside production to the energy industry oligopoly. This evidence is reflected on electricity prices generated by the whole energy mix (without levies and taxes) as portrayed in the following Figure 1. Spain and UK with a flagrant production oligopoly and therefore an obvious hindrance for new generation competitors, possess one of the highest electricity prices of the Union (David Robinson 2013).

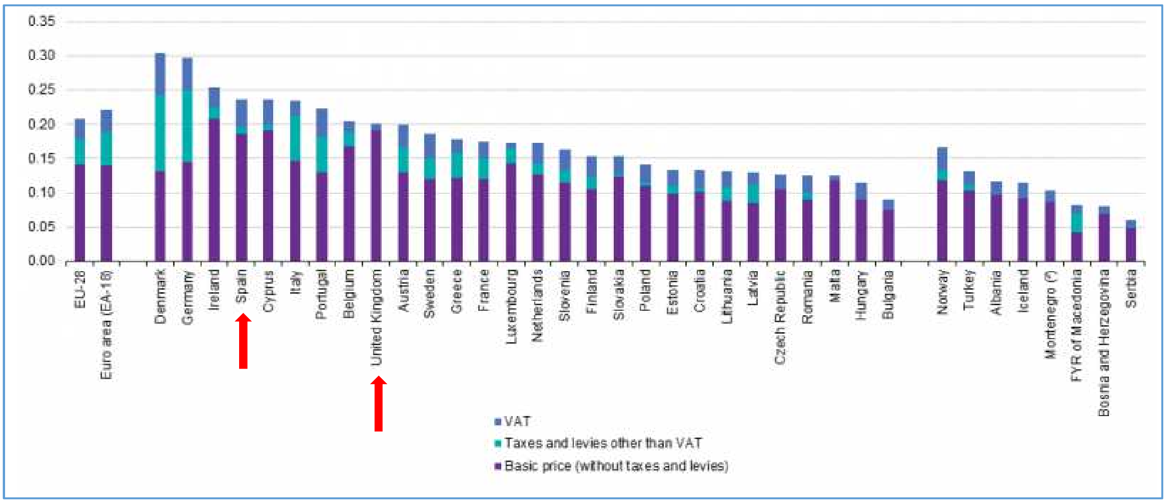


Figure 1. Electricity prices for household consumers, second half 2014. ("File:Electricity Prices for Household Consumers, Second Half 2014 (1) (EUR per kWh) YB15.png - Statistics Explained" 2016)

There is then an opportunity to build a new power system to replace the present failing grid with something more resilient, efficient and egalitarian (Turney and Fthenakis 2011). Distributed generation, particularly undertaken by Photovoltaics (PV) consist of multiple advantages:

- It avoids electricity losses in transmission (about 30% of generation) because most of the time it supplies power directly to where it is needed, barely employing the grid to offload surplus power. Besides, transmission lines and large and unaesthetic transformer stations maintenance could be abruptly reduced.

- It has not a specific point of failure which could abase the whole grid, so decentralization is a securer system than centralized.

- It can be installed on unused spaces such as rooftops avoiding spending more land.

- It provides market space for technologies to compete freely and directly, evading oligopoly environments. In the short term, this can represent more opportunities for small businesses to grow and as a whole, enriches competition producing a more efficient and refined product.

- A decentralized solar strategy does not required governmental financial involvement as the massive energy generation monolithic projects, since owing to small scale production is practically bankable upfront, although it would require an investment in regional and local power storage devices.

- Regarding the welfare of population, distributed energy creates more employment than former units (Kammen, Kapadia, and Fripp 2004) and empowers people with energy generation, producing a useful and a valuable commodity straightforwardly under the control of middle and lower classes who act as producers and consumers simultaneously, "prosumers" and actively manage their loads efficiently as an economic and environmentally responsible answer.

In 2013, Solar Photovoltaic energy represented 0.87% of the global electricity generation worldwide, sustaining a compound annual growth rate in cumulative installed capacity of 43% since 2000 (IEA-PVPS 2014). Between

2000 and 2014, global grid-connected PV capacity grew from 1.3 to 139 GW_p. In fact, it is expected to play a major role in the global energy system by mid-century. In one of the most plausible energy scenarios drew by the International Energy Agency (IEA) (MIT 2016), global demand of electricity rises by 79% between 2011 and 2050, being in 2050, 27% produced by solar (Electricity demand of 33 000TWh and a capacity factor of 15%(Jean et al. 2015)). Within this scenario, 16% of global electricity is projected to be generated by PV and 11% by concentrated solar power (CSP) (REN21 2016).

The singularities that confer PV an added value are its capacity to operate at ambient temperature, with no moving parts and its modularity. This last characteristic grants that its electric power conversion efficiency is not influenced by scale, albeit cost per unit of generating capacity is lower for utility-scale installations than for residential systems as a result of balance-of-system (BOS) costs, contrary to other generation pathways such as thermal generator or wind turbines (MIT 2016).

1.1 Research hypothesis

Consumer's side is being the core of energy systems transition and development, in order to increase energy efficiency and security of supply, with the use of endogenous resources. With that in mind, using REs for Self-consumption (SC) is spreading all over Europe, supported by different national policies, either on small or large scale generation. In this way the consumer is no longer a passive agent, becoming a *prosumer*: an active consumer and producer.

However, besides self-consumption brings economic benefits for the end user (prosumer), the implications of large deployment of self-consumption technologies are yet to be deepen.

Most of energy balances analysis are taken with synthetized profiles or average demand profiles, not representing effectively the natural demand dynamics of a single consumer, either residential or industrial. In this way there is still a lack of knowledge on the balance between production and demand at the consumer's level and its impact, either economic (for the consumer) or energetic (for the grid). While normally optimal tilt and azimuths are considered, in many cases the implementation of these systems are dependent on available area, orientation and angle of roofs. This fact may lead to a different profile of solar production for self-consumption systems. Also the optimum sizing of self-consumption systems can differ according to the energy excess policy or consumer's family typology.

As a result, the scientific contribution of this study deepens the knowledge on the following areas, each of them structured in chapters numbered in order of appearance:

- Chapter 2: History and evolution of the European and Portuguese RE and PV policy introduced by a comparative of the energy generation incentives and costs.

- Chapter 3: Characterization of the technology utilized, complemented with a techno-economic, environmental and scalability assessment of the main commercial PV technologies.

- Chapter 4: SC analysis of the Portuguese study case: by evaluating the adequacy and impact of real demand profiles of residential, retail, hotel and industrial sectors to simulated solar PV production profiles of different locations, orientations and inclinations. This assessment has been accomplished by means of an *ad-hoc* programmed excel tool, which automatizes the prosumer generation and the economic outcome by enabling the free selection of the consumption and demand profiles and the appropriate electric tariff and capacity.

- Chapter 5: Conclusions

- Chapter 6: Possible future work are stated.

This work, is part of a technical consultancy (OTGEN project) commissioned by the Portuguese utility EDP concerning the photovoltaic (PV) and concentrated solar energy (CSP) evolution and impacts on the future of the Portuguese electrical system.

2. LITERATURE REVIEW

2.1 European generation electricity costs

Electricity generation costs are a fundamental part of energy market analysis, and a good understanding of these costs is important when evaluating and designing policy.

2.2.1 ENERGY GENERATION COSTS: BENCHMARKING

Levelized costs of energy for electricity (LCOE)

LCOE represent the real costs of energy production without subsidies and they assess energy production economic viability and market competitiveness.

Figure 2 introduces the European LCOE of 2012 per power generation technology. LCOE range from 20 €/MWh for hydropower at full load to 200 €/MWh for offshore wind and biomass plants at actual full load[2]. Natural gas and hard cold reach at full load 50 €/MWh. In this graph are reflected gas plants current inefficiencies owing to the fact that they are running lower hours because RE rising production and low coal prices. Hence, gas achieves LCOE at realized full load of nuclear and onshore wind. The drop of PV costs is evinced in its LCOE, from 200 €/MWh in 2008 to around 100 €/MWh in 2012. Furthermore, in 2015, LCOE, calculated under certain premises to create a best (min) and worst (max) case optimum were 35 and 180 €/MWh respectively (VGB Powertech 2015).

---

[2] Actual or realized full load are the hours a facility runs on average a year while full load takes in account the hours a plant is meant to run considering technical downtime.

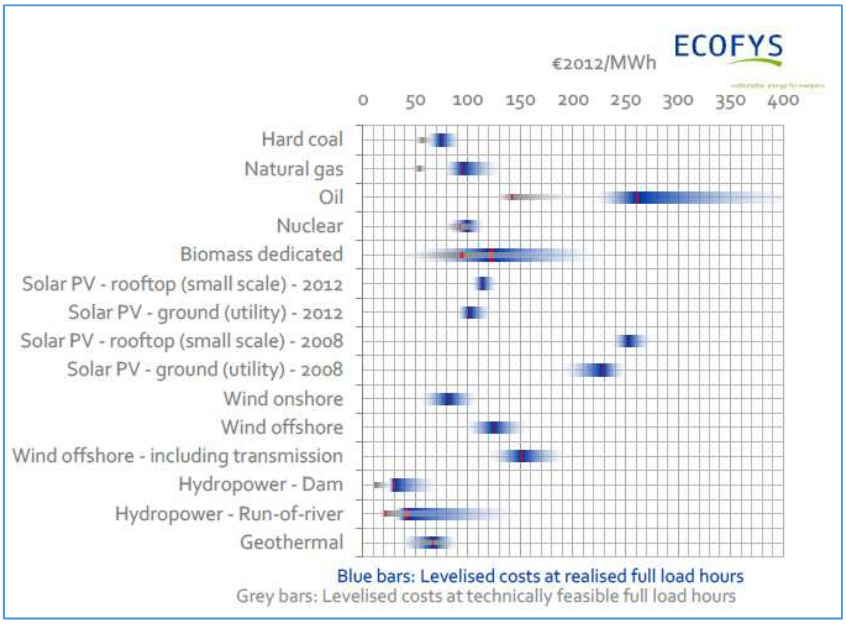


Figure 2. Levelized costs of energy in EU28 for electricity in 2012 (€/MWh)(Sacha Alberici and Pieter van Breevoort et Al. 2014b).

External costs

How fossil fuels and alternative energies affect environment, health and climate change cannot be economically determinate by the deregulated market. So, policy instruments need to be applied to phase out CO_2 emissions through their ability to endorse energetic sustainability. Figure 3 displays the external costs per technology in 2012 at EU28 level weighted averages (€/MWh_e). External costs are characterized by the life cycle assessment (LCA[3]), direct impacts at conversion, upstream fuel extraction, transport and processing, construction and end of life effects. The five main monetized effects are presented independently: climate change, particulate matter formation (air pollution), human toxicity, agricultural land occupation and depletion of energy sources. The minor ones are clustered in "other" which are: Ozone depletion, terrestrial acidification, fresh water and marine eutrophication[4], human toxicity, photochemical oxidant formation, terrestrial, fresh water and marine ecotoxicity, urban land occupation, natural land transformation and water and metal depletion (Sacha Alberici and Pieter van Breevoort et Al. 2014b).

As it is expected, green energies, together with nuclear gather lower external costs. Cogeneration or combined heat and power (CHP) shrinks the impact of regular coal-fired power plants but still remains ostensibly higher than renewables.

---

[3] LCA is a technique to compare and analyze the energy investment and the environmental impacts related with the development of products over their life-cycle (Cristina M Herce Villar 2015).

[4] Eutrophication: ecosystem´s response to the addition of natural or artificial nutrients, mainly phosphates, through detergents, fertilizers or sewage to an aquatic system ("Eutrophication" 2016).

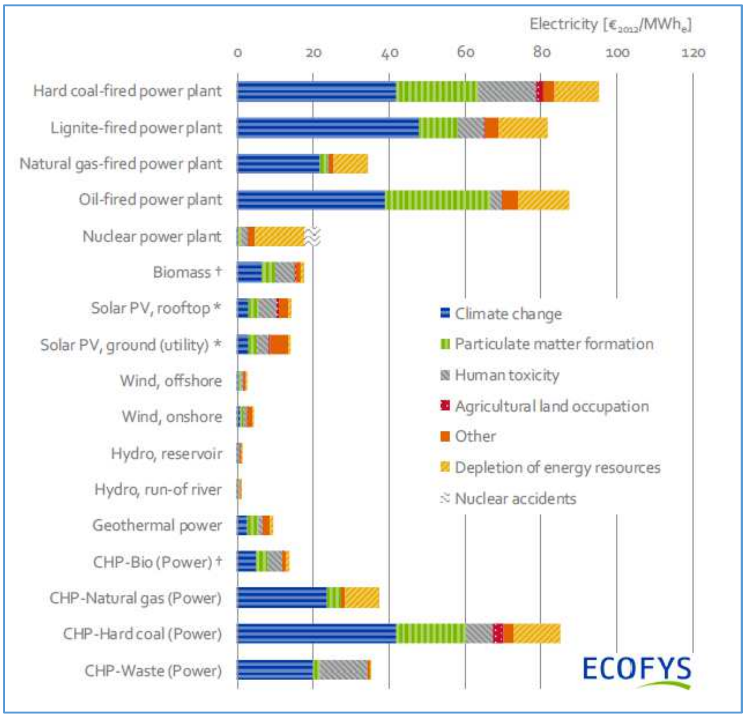


Figure 3. External cost per technology, EU28 weighted averages (in €/MWhe). Values for PV might be inflated due to the high rate of deployment of this technology. The biomass values recorded are sourced exclusively from agricultural and waste wood residues, not from energy crops (Sacha Alberici and Pieter van Breevoort et Al. 2014b).

Figure 4 presents the division of the total aggregated external cost in energy, 199 billion € in 2012. The three most significant impacts are climate change, accounting for nearly half of the total, depletion of energy resources, 22% and particulate matter formation embodies 15% of the total.

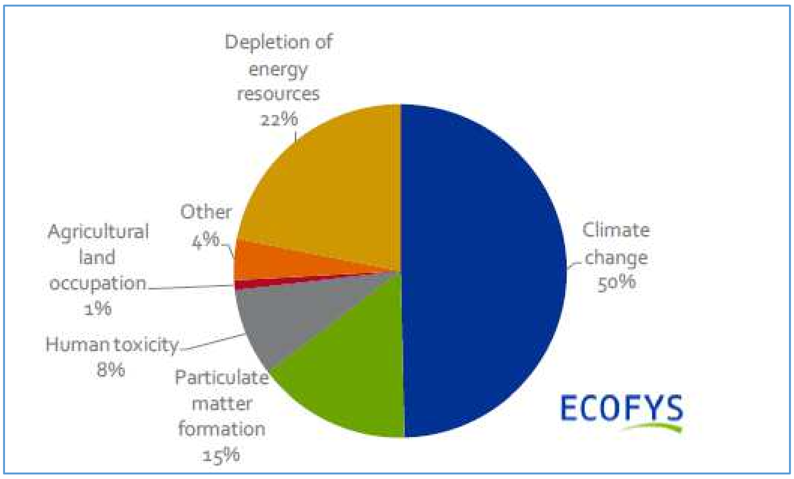


Figure 4: Breakdown of total aggregate external costs energy in 2012 (Sacha Alberici and Pieter van Breevoort et Al. 2014b).

Figure 5 shows the external cost by EU Member State. The low external impact of France is due to its high share of nuclear energy in its electricity mix whereas UK and Germany possess a relevant share of fossil energy. Carbon tax income (2 billion €) has been internalized in climate change so subtracted from the total.

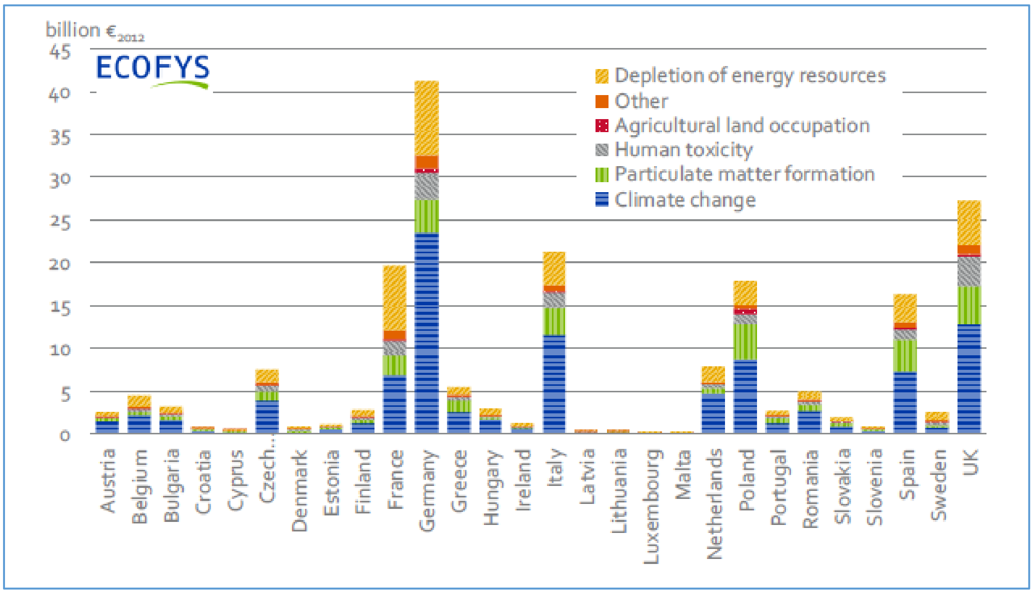


Figure 5. Total external cost per EU Country in 2012 (billion €) (Sacha Alberici and Pieter van Breevoort et Al. 2014b).

The following table represents the LCOE at realized full loads, external costs and the total costs, as an addition of the two previous ones. It stablishes the average of all technologies at each cost and the total cost deviation (in percentage) from the average total cost. Oil possess the highest LCOE at factual full loads (260€/MWh), doubling the value of the second most expensive technology, wind offshore with transmission (160€/MWh). Fossil fuels, have the highest external cost as they are more pollutant than renewable. Oil total costs are over eleven times greater than the most cost-efficient technology, hydropower with hardly 31€/MWh and almost three times more expensive than the average total cost, 130 €/MWh. Solar remains close to the average values, and its costs shall be reduced due to technological progress which entails lower prices.

Table 1. Summary of LCOE and External cost of the most relevant energy sources

Energy Source	LCOE: Realized full loads (€/MWh)	External Costs (€/MWhe)	Total costs (€/MWh)	%
HARD COAL	70	95	165	27%
NATURAL GAS	90	35	125	-4%
OIL	260	85	345	165%
NUCLEAR	100	25	125	-4%
BIOMASS	130	17	147	13%
SOLAR-PV SMALL SCALE	120	15	135	4%
SOLAR PV UTILITY	100	15	115	-12%
WIND ONSHORE	80	5	85	-35%
WIND OFFSHORE	130	3	133	2%
WIND OFFSHORE WITH TRANSMISSION	160	3	163	25%
HYDRO DAM	30	1	31	-76%
HYDRO RUN-OF RIVER	40	1	41	-68%
GEOTHERMAL	70	10	80	-38%
AVERAGE	106	24	130	

2.2.2 ENERGY GENERATION INCENTIVES

EU monetary interventions for energy production cover the whole energy generation spectrum, from RE to fossil fuels. The following figures collect data from 2012 where the total amount of public support in energy excluding transport amounted to 122 billion €, 39% less than the above total external aggregated costs (Sacha Alberici and Pieter van Breevoort et Al. 2014b).

Figure 6 sketches the support value of varied energy generation technologies in billions of € together with the budget devoted to energy demand and energy savings:

- Energy demand comprehends measures that would encourage consumption like tax reductions for particular users, price guarantee for fuel and electricity, e.g. social tariffs, and interruptible load schemes which provide payments to electricity consumers that accept to be switched off remotely where there is danger of system black outs.

- Energy savings include energy labelling, Ecodesign, building regulations and energy efficiency obligations (Sacha Alberici and Pieter van Breevoort et Al. 2014a).

- Free allocation of EU Allowance Unit of one ton of CO_2 (EUA) was conceived by lawmakers as a mildly way of introducing carbon emission costs and to facilitate time for the industry to adjust and restructure their energy functions (Ingrid Jegou 2011).

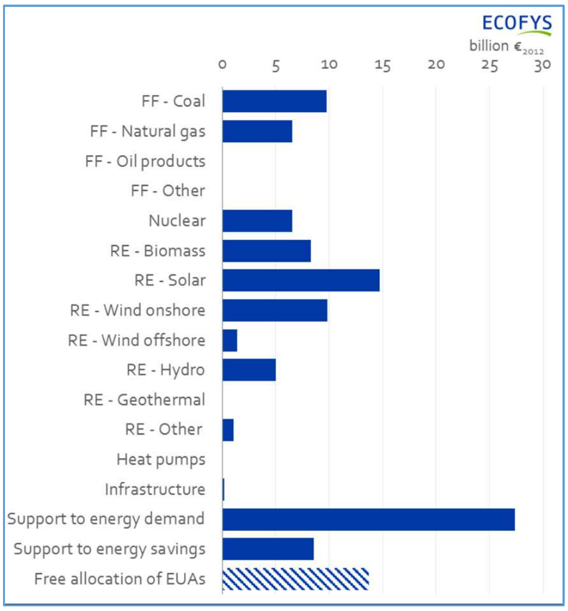


Figure 6. Total energy production support provided in the 28 Member States (in billion €), comprising EU level support in 2012 (Sacha Alberici and Pieter van Breevoort et Al. 2014b).

Figure 7 categorizes the assorted energy generation technology subsidies by Member Country in million €.

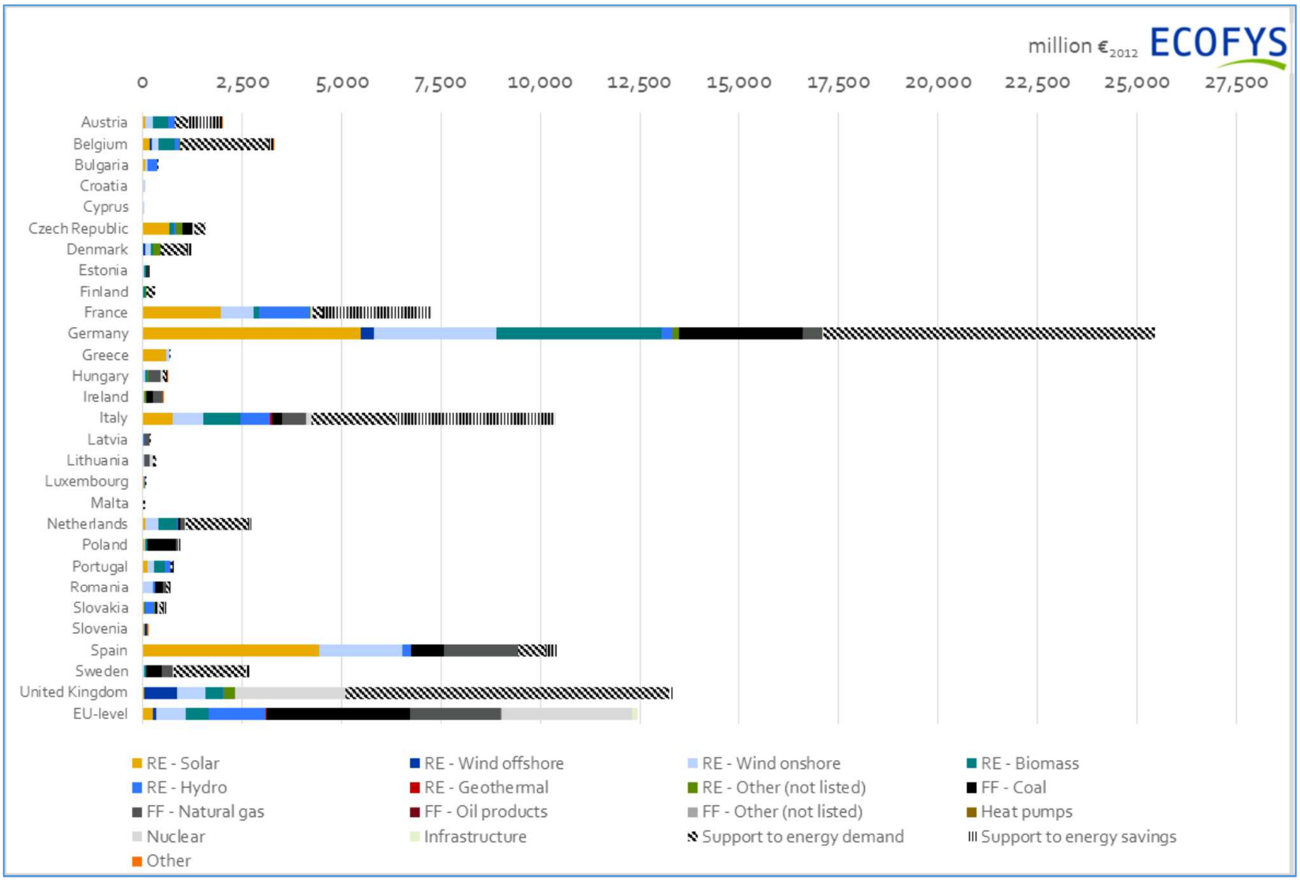


Figure 7. Energy generation technology subsidies per Country in 2012 (in million €) plus support to energy demand, savings and infrastructure. The EU-level intervention refers to support exclusive from EU, not by individual Member States (Sacha Alberici and Pieter van Breevoort et Al. 2014b).

Analyzing these graphs it could be concluded that indeed the major incentives are not granted to one specific technology but more to broaden measures as support to energy demand and to energy efficiency savings. At EU-level significant support is given to coal and nuclear, including decommissioning and waste disposal. Germany and Spain hold the highest solar support which is product of their investment attractive Feed-in Tariffs (FITs) implemented during last decade.

2.2 European energy sector overview

During industrialization in the XIX century, it could be said that the energy market was entirely liberalized. Financing gas and electricity stocks was endeavored exclusively by emerging industries for their own production. But over time, with a massification of the energy system, authorities had to grant the infrastructure so energy distribution, pricing and sources exploitation were intervened and capitalized by military or political jurisdiction.

After World War II, European cooperation was materialized with the creation in 1951 of the European Coal and Steel Community (ECSC). Member states would guaranteed customs-free access to coal and steel. A second pan-European association was constituted in 1957, the European atomic energy community. Until late 60s the overall trend among European countries was to promulgate energy policies orientated to assure security of supply for national economies.

Since 1990 and maybe even before, Europe has intended to quickly rise the proportion of native energy employing zero-carbon resources, stablishing new industries, banking on clean technologies and confronting the energy framework with a more distributed energy model (Carlo Stagnaro 2015).

This leading movement has been guided by concerns over climate change, as revealed in the Earth Summit in Rio of 1992 and the negotiation of the United Nations Framework Convention on Climate Change (UNFCCC), but also by the indelible memories of the 1970's oil price crisis, which affected many EU economies by cause of their large dependence on fossil fuel (FF) imports. The main milestones for Climate change fight in Europe have been the compliance of these events:

- The Kyoto Protocol , where Europe committed to cut emissions from 2008-2012 to at least 5.2% below 1990 levels (overachieved, 18% ("EU over-Achieved First Kyoto Emissions Target, on Track to Meet 2020 Objective - European Commission" 2016),("EUR-Lex - l28060 - EN - EUR-Lex" 2016))

- The European Union 2020 climate and energy package made three objectives compulsory and pooled for all Member States to be reached by 2020:

- Lowering GHGs emissions in a share of 20% compared to 1990.
- Reduction in primary energy consumption in a share of 20%.
- 20% of RE in final energetic gross consumption.

- 2030 EU climate and energy targets ("2030 Energy Strategy - Energy - European Commission" 2016):

- Lowering GHGs emissions in a share of 40% compared to 1990 (binding)
- Indicative of target of at least 27% energy efficiency savings.
- 27% of RE in final energetic gross consumption (binding)

2.2.3 EU ENERGY POLICIES

Climate Change related policies

Europe's world-pioneering renewables development and Greenhouse Gases (GHG) emission abatement have been promoted by a series of State individuals and EU-wide support mechanisms. These vary from FITs as employed with an enormous positive impact in Germany (by bringing down RE prices), to the less successful Emissions Trading Scheme (ETS).

Nevertheless, as a consequence of the economic crisis, the attention on climate change and accordingly RE, has been detained. Policy bodies have retreated RE financial support, and in several cases, for instance Spain, highly discouraging distributed generation, normally on RE´s hands as a hypothetical way of retrieving past returns (David Robinson 2013).

New appealing markets in Africa, Latin America and Asia have emerged replacing EU´s RE supremacy. Nowadays US, together with China dominate RE investments.

Thereupon are revised those specific climate-change mechanism developed and undertaken by EU members.

EU Emissions Trading System and Effort Sharing Decisions (ESD)

Fundamental pillars for EU's willingness to decarbonize its economy through climate legislation are the EU Emissions Trading System and Effort Sharing Decisions (ESD):

- EU ETS scheme became operational in 2005 and is the world´s biggest system architected to cap emissions from large installations in the power and industrial sectors, rights to emit GHGs, and market for trading allowances. Presently, there are 17 ETS operating through four continents, comprising 35 countries, 12 provinces or states, and seven cities. Together, these jurisdictions produce about 40 % of global gross domestic product (GDP) ("Emissions Trading Worldwide. Status Report 2015" 2015).

- Effort Sharing Decision (ESD) sets emissions reductions targets for the sectors not covered by the EU ETS, e.g. transport, agriculture, buildings and waste. The ESD was embraced in 2009 to implement the EU's 2020 climate target and has been planned for the 2013-2020 period. An updated legislative proposal to reduce emissions from ESD sectors in the 2021-2030 is due to be presented in 2016.

The non-ETS sectors account for 60% of the EU's emissions. The ESD fixes annual GHG emission reduction targets for each Member State depending on its wealth, measured in GDP per capita. The most prosperous Member States are urged to reduce their emissions by 20% below 2005 levels by 2020 and those whose poverty rates are higher, are allowed to increase emissions by 20% by 2020.These Member State targets accumulate to an overall EU ESD reduction target of 10% below 2005 levels by 2020.

The ESD targets for the 2013-2020 period are translated into an annual emission budget for each Member State known as Annual Emission Allocation (AEA). It correlates to the absolute amount of emissions that a Member State can emit in a given year. In case of non-compliance, Member States encounter an automatic penalty which takes into consideration the environmental cost of postponing emission reductions (Carbon Market Watch 2015).

- ETS, together with the project-based mechanisms compose the Kyoto or Flexible Mechanism intended to diminish the overall expenditure of attaining Kyoto emission targets (Fischer 2005). Project-based mechanisms include emissions trading among participants and project-based emissions reductions in countries or sectors not subject to emissions caps (Non-Annex I[5]):

- Clean Development Mechanism (CDM) has dual objectives, one is to help Annex I[6] countries to reach their commitment targets at a lower cost than exclusively relying on efforts conducted at home and to provide sustainable development opportunities for the non-Annex I parties. Certified Emission Reductions (CER) are licenses conceded to projects (financially incentivized) which offer emission

---

[5] Undeveloped countries, India, China, Brazil, Israel and South Africa ("List of Non-Annex I Parties to the Convention" 2016)

[6] Developed countries (EU, USA, Canada, Australia, New Zealand, Japan), Russia, turkey and Ukraine ("List of Annex I Parties to the Convention" 2016)

reductions or sequester carbon emission in Non-Annex I states as well as provide benefits, such as the transfer of environmentally sound technology and know-how. Then, under CDM mechanism CERs can be sold to annex I countries.

- Under Joint Implementation (JI) procedure, Annex I nations, cooperate with another Annex I country in a decarbonization project, called JI project obtaining in return Emission Reduction Units (ERUs).

Companies then with expensive or difficult carbon emissions decrease can purchase additional quotas on the market from those who have low marginal carbon reduction costs by means of EU ETS, CERs and ERUs.

As Climate credits prices are low (economic recession precipitated demand reduction for ETS and market overcapacity) and there are compensation schemes for firms (Allocation of Emission Allowances Free of Charge), there is almost not behavioral impact on industry, so Carbon credits seem to be purposeless ("The EU Emissions Trading System (EU ETS) - European Commission" 2016). As it is displayed in Figure 8, prices for carbon emissions fell from 20€ in 2011 to 5€ ton in 2013 (*The Economist* 2013).

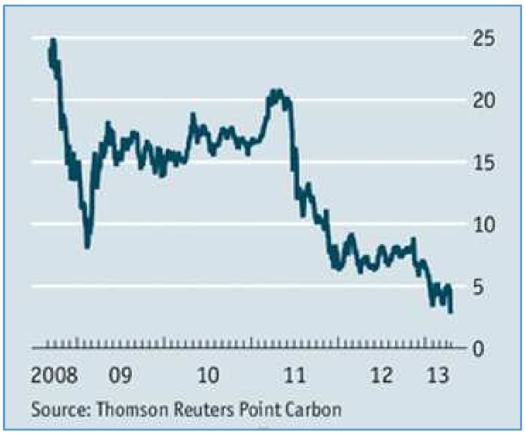


Figure 8. EU ETS carbon spot price, € per ton (Anthony Faiola 2013).

Indeed, these mechanisms in most cases have had little impact in reducing CO_2 emissions: Large companies in the EU use the Project-based mechanisms to offset their pollution within their borders or founding projects in Non-Annex I countries with their ancillary firms. As a result, these companies profit from buying Subsidiaries' CDM at a reduced price. Not only carbon markets permit companies to pollute over their limits, they allow benefits at the expense of local communities (Joanna Cabello and Tamra Gilberston 2013).

Politically, CO_2 emissions curtailment has an impact on domestic industry, resulting in a constituency punishment for policy makers. Also, there are concerns associated to bias competitiveness in such a way that industrial market shares are lost to foreign firms and carbon leakage, which means that the decrease in emissions in one country due to climate change regulations provokes an increase elsewhere (Ingrid Jegou 2011).

Main policy instruments to promote distributed RES-E

The RES-E breakthrough it has been a result of policy support, technology development and the invaluable assets RE confers (Carlo Stagnaro 2015):

- REs are free native resources, with an enormous economic potential if their performance is amplified.

- RE is easy, cheap and fast to construct and scale-up, it has low maintenance and operational risks thereby has a significant potential to promote local grids.

- RE bolsters the change of the business model, motivating the appearance of the prosumer figure in order to empower citizens to manage their energy consumption efficiency according with their production.

- REs are accessible to everyone: from pension funds, utilities, yield cos to small businesses, communities and consumers. This means that the energy infrastructure would be able to be financed by multiple parties.

Figure 9 depicts the progress with respect to the EU 2020 climate and energy package target (20% in global final demand) per country. Some jurisdictions have a long way to go, like UK, Netherlands, France and Ireland. On the other hand Bulgaria, Estonia and Sweden have already fulfilled their objectives and Lithuania, Romania and Italia are close. Therefore, continentally, RE´s share horizons need to be expanded.

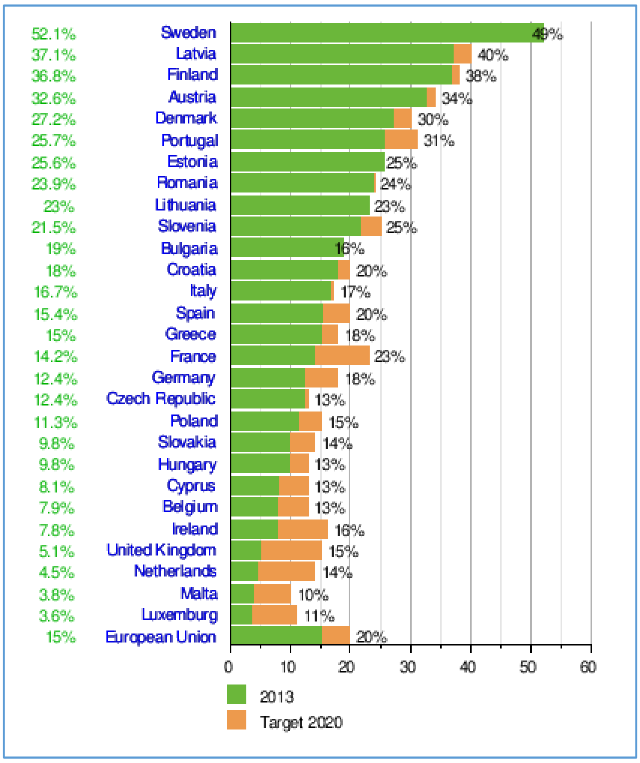


Figure 9. Share of energy from renewable sources in the EU Member States, 2013 (in % of gross final energy consumption) (Vincent Bourgeais 2015).

Special rates

There is an ample diversity of bonus for distributed renewable generation, as presented in **Error! Reference source not found.**:

- The FIT is a remuneration mechanism that consists in selling the electricity produced at a higher rate than the electricity market, i.e., it is a subsidized tariff. It is normally guaranteed for a long period of time, 15-20 years, to be economical attractive and is normally used on a first instance to motivate the investments in new energy technologies. The quantity of these incentives is technology and condition-specific based on size, location and load hours to allow flexibility for the promotion of different goals. The grid operator is obliged to enter into a contract on the purchase of electricity at a price set by law (Goswami and Kreith 2015).

Not all FIT models are equally implemented: while in the levy gradually decreases Germany after some years, in Great Britain the fixed rate is indexed to the inflation. Under this structure, the outlay remains independent from the market, leading to a higher level of profitability due to the lower investor risk.

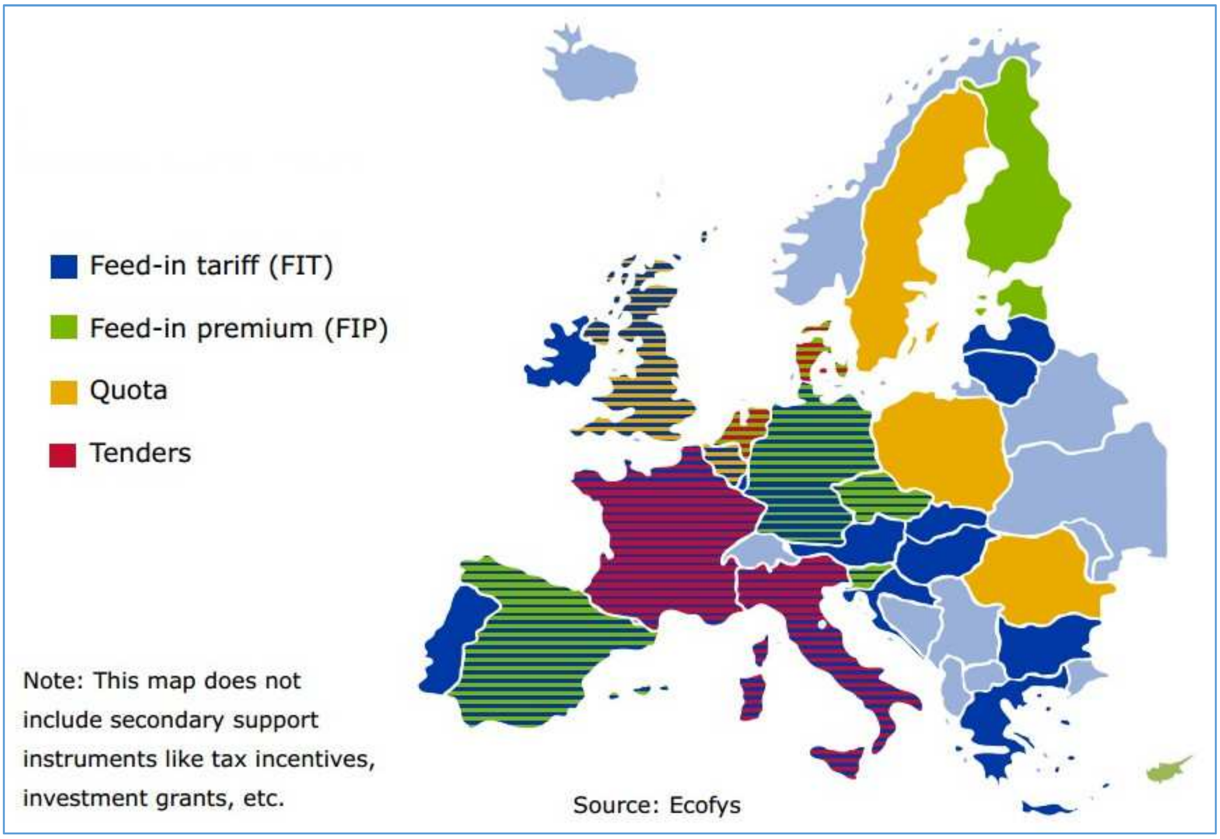


Figure 10. Main RES-E support instrument in the EU-28 in 2014: Quota obligation, FIT, FIP, tender instruments and some combined working in parallel (Corinna Klessmann 2014)

Au contraire, Feed-in Premiums (FIP) provide bonus payment on top of the electricity market price. These premiums can be either constant or can vary depending on a sliding scale: in Denmark the return guaranteed price fluctuates as a function of electricity pool price. To avoid a large discrepancy between gains and losses, the support mechanism can be designed with payment caps and floors, as happens in Spain (IRENA 2012),(Kyriakides Georgopoulos & Daniolos Issaias Law Firm 2012).

- Quota obligation establish the amount or proportion of renewable electricity that must be produced, consumed or supplied in a given year. To prove compliance with the required quota in a flexible way “Tradable Renewable Energy Certificates” (TREC) are banked, consumed and traded. The TREC betoken the renewable value of electricity produced from a renewable source (Van der Linden et al. 2005).

However, now that distributed renewable production has more than a decade, its incentives are decreasing and competing in market-based auctions, like conventional energy sources, is the new tendency for RE to reach grid parity and to assure a cost-effective future for the electricity market. In fact, this mechanism will be adopted after 2017 by the whole EU, endeavoring a wide harmonization by the use of competitive market tools for dissimilar programs. FITs are quickly being precluded as the default path to backup capacity development for renewable mature technologies:

In the UK, the introduction of a FIT moved immediately to an auction mechanism. In Germany, the new laws providing for continued but capped support will facilitate a transition to auctions after 2017. The new Portuguese remuneration regime for RES-E came into force in January 2015 and is based on a bidding model.

Lamentably, some countries, like Spain and Italy, have harmfully applied retrospective subsidies changes which have ended in bankruptcy on independent renewable power generation projects with the ensuing impact on future investments (Nathanson 2012). Now, Spanish legislatively reliability is on the eye of the storm, due to the revocation of several FIT benefits that the country implemented to attract foreign investment in solar PV energy.

Grid-related regulations

Electricity Directive (2009/72/EC) repeals Directive 2003/54/EC and is part of a legislative package for an internal gas and electricity market in the EU, called Third Energy Package. This directive concerns common rules for the internal market in electricity. It promotes:

- The achievement of large and small-scale RES-E and distributed generation in transmission and distribution units cost-effectively.

- Network access facilitation to new production capacity, specially eliminating barriers which could prevent access for new market entrants and RES-E.

As a result Electricity Directive 2009/72/EC, three options to integrate competitive electricity markets in the Community were promulgated (Jäger-Waldau et al. 2011):

- Ownership unbundling, which is defined by an absolute segregation among production, supply and transmission activities in the form of independent companies, with no common shareholders and managerial positions.

- Enforcement of an independent system operator (ISO) which coordinates, controls and monitors the operation of the electrical power system removing conflict of interest between transmission and generation.

- And as the last option an Independent transmission operators (ITO) which owns the assets and resides within a vertically integrated company, with special rules to guarantee its independence.

Besides, the Directive undertakes several grid-related regulations. Associate states have to guarantee that national Transmission System Operators (TSO[7]s) and distribution system operators (DSOs) ensure transmission

---

[7] "natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity"("Transmission System Operator - EnergyWiki - Userwikis Der Freien Universität

and distribution of RES-E. The directive specifies several technical actions to be applied in the grid (Gudas 2015):

- With Priority connection, Member states are required to grant preference communication to REs generators.

- Priority dispatch means that before dispatching electricity from other plants, electricity from REs has to be expedited.

- Through Priority access, RE installations can sell and transmit their generated energy whenever the source is available in accordance with the connection procedures.

- The assurance that the maximum amount of electricity from REs sold will obtain access to the grid, is pledged to guarantee access.

Most of the Member States have different connection charges and distribution cost regimes. Figure 11 pictures the availability of priority of connection and dispatch of EU countries and Turkey.

Country	Priority of connection	Priority of dispatch	Country	Priority of connection	Priority of dispatch
Belgium	🟢	🟢	Ireland	🔴	🟢
Germany	🟢	🟢	Poland	🔴	🟢
Hungary	🟢	🟢	Portugal	🔴	🟢
Italy	🟢	🟢	Romania	🔴	🟢
Lithuania	🟢	🟢	Bulgaria	🔴	🔴
Malta	🟢	🟢	Croatia	🔴	🔴
Slovakia	🟢	🟢	Estonia	🔴	🔴
Slovenia	🟢	🟢	Finland	🔴	🔴
Spain	🟢	🟢	France	🔴	🔴
Czech Republic	🟢	🔴	Latvia	🔴	🔴
Turkey	🟢	🔴	Luxembourg	🔴	🔴
Austria	🔴	🟢	Netherlands	🔴	🔴
Cyprus	🔴	🟢	Norway	🔴	🔴
Denmark	🔴	🟢	Sweden	🔴	🔴
Greece	🔴	🟢	UK	🔴	🔴

Priority 🟢 No priority 🔴

Source: EY analysis based on various public sources.

Figure 11. Priority of connection and dispatch for renewable energy by Member State (“EY - Renewable Energy Country Attractiveness Index” 2016).

Economic EU RE support instruments comparison

The prospect of a proliferation of support tools indicates a progressively intricate regulatory environment for power in Europe in the next decades (Arnaud Coibion 2014). These dissimilarities place the developers and the traders of renewable electricity, in different Member States, in completely different positions undermining the incentive to local production where the efficiency on production/consumption is optimal.

Figure 12 portrays the average support to overall RE production in the EU (€/MWh) by country in 2013. For instance, subsidies for photovoltaics (PV) in Czech Republic are almost 200 times larger than waste and biogas in Finland.

Berlin” 2016).

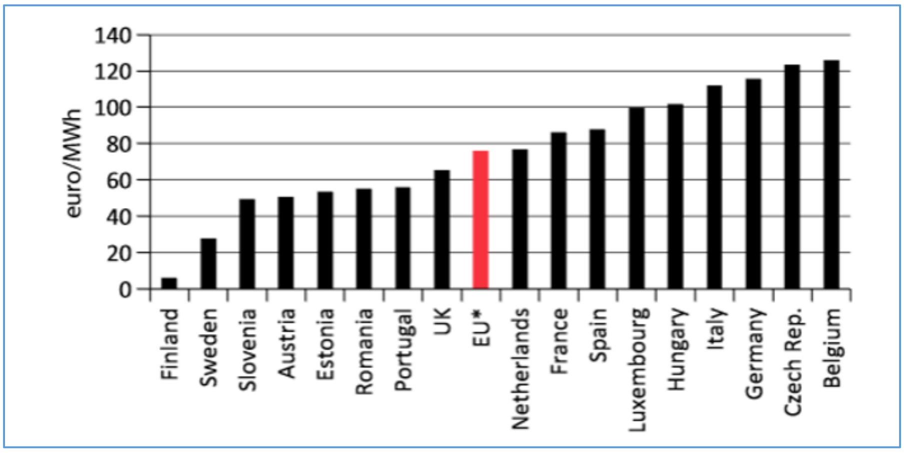


Figure 12. Average support to renewable energy production in EU (€/MWh) by country in 2013 (Carlo Stagnaro 2015).

Figure 13 depicts the support costs in €/MWh among various technologies. It is evidenced that, it is PV which gather the higher part of the bonus, 350€/MWh versus an average of 80€/MWh and a Portuguese price of 55€/MWh.

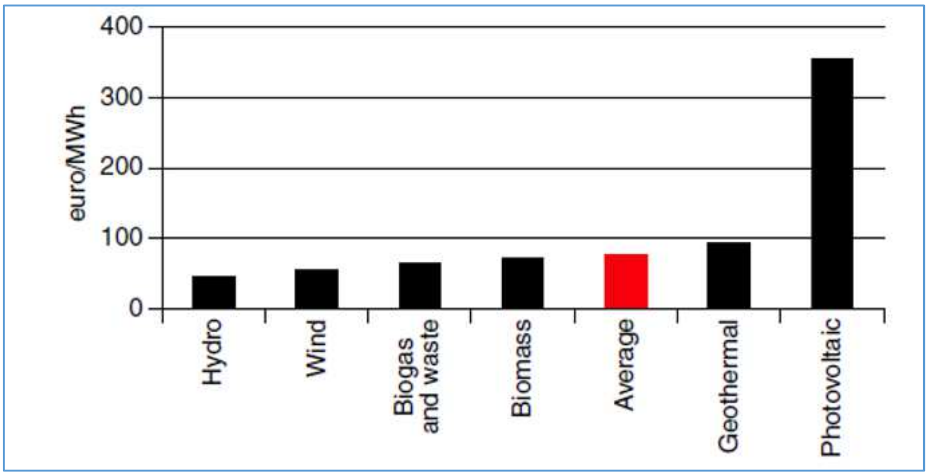


Figure 13. Average support to RE production in the countries listed in Figure 3 (€/MWh) by technology (Carlo Stagnaro 2015).

GHG emission reduction costs

Incentives for RE deployment, as previously revised, have become a key instrument of climate policy as a mean to reduce GHG emissions (Marcantonini and Ellerman 2013). It is also intended to monetarily evaluate how much cost-effective are the implemented mechanisms per Member State.

Figure 14 reflects the net cost over CO_2 emissions reductions attributed to RE in a sample of EU countries in €/ton CO_2 regarding 2012 data. The smallest expenditure in CO_2 reduction corresponds to Finland, with 27€/ton CO_2. On the contrary, France and Sweden hold the highest costs being up to 50 times more. These Member States rely on hydropower and nuclear power respectively, which are low-emitting sources, therefore the amount of emissions cutback remains low.

CO_2 abatement cost are calculated as the ratio of the net cost (sum of the costs and cost savings due to the injection of renewable energy into the electric power system) over the CO_2 emission reductions attributed to RE. These costs are correlated with the average incentives per technology in the previous paragraph.

In Germany, the CO_2 abatement cost of wind for 2006-2010 was on average 43€/ton CO_2 while for solar reached 537€/ton CO_2, being the main reason the remuneration to producers determined by the FIT (Marcantonini and Ellerman 2013). These values fluctuate due to variations in fossil fuels prices, carbon price and the amount of generated RE. For instance, in 2008 CO_2, the abatement cost of wind was 20€/ton CO_2 owing to a combination of high fossil fuel prices and a high annual capacity factor (Marcantonini and Ellerman 2013).

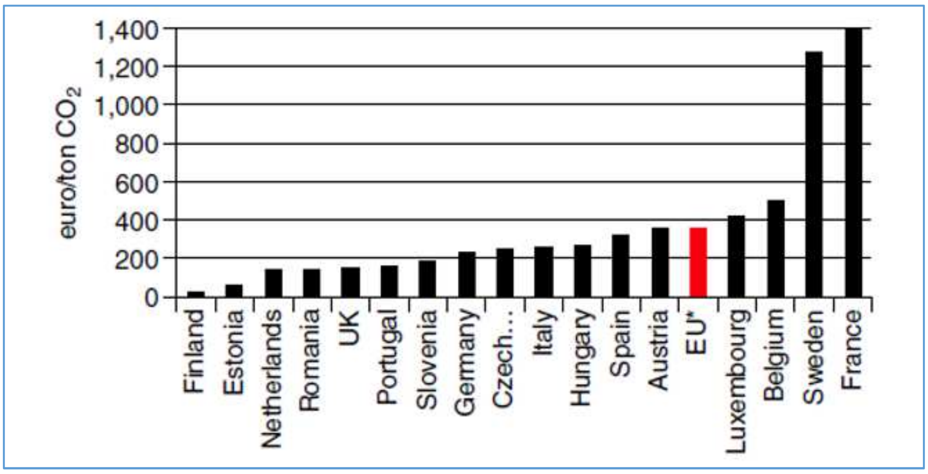
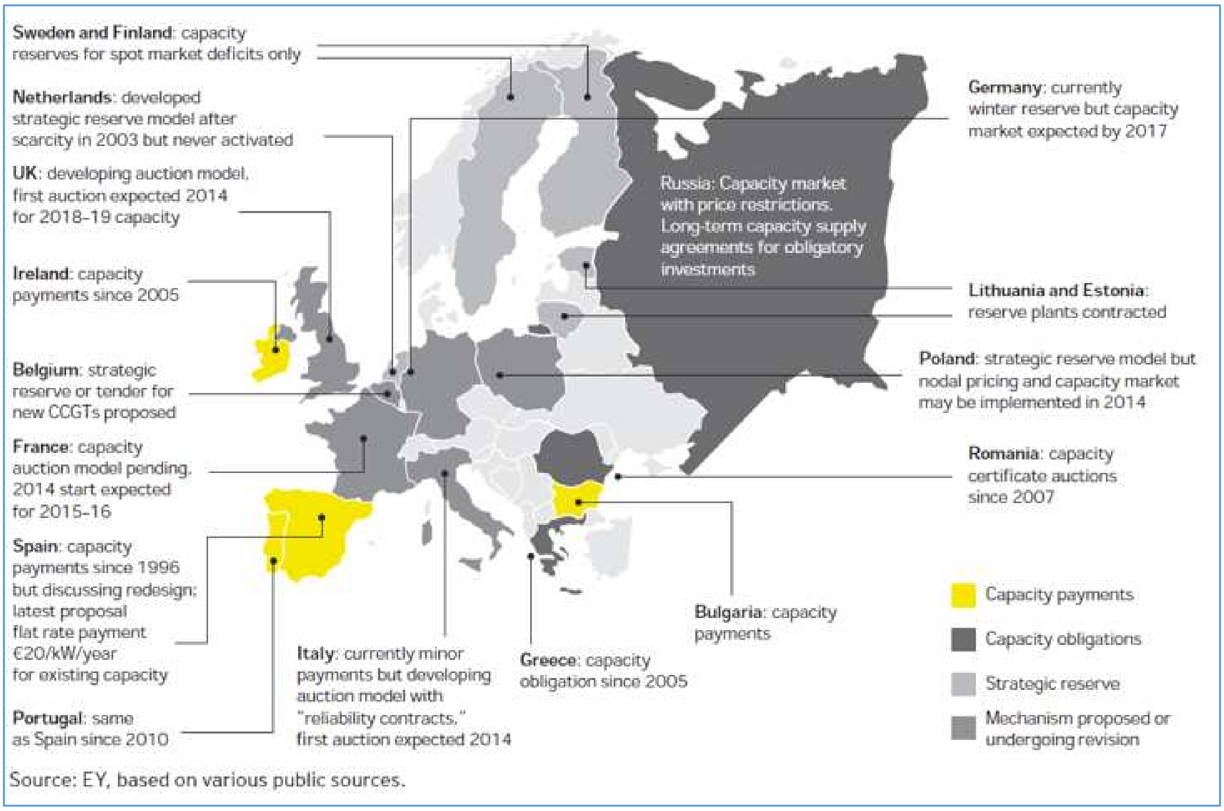


Figure 14. Average CO_2 abatement cost in some EU member states in €/ton CO_2 (Carlo Stagnaro 2015).

Security of supply related policies: capacity markets

The creation of capacity markets consist of a support technique to ensure security of electricity supply whilst the energy transition. These are based on fixed payments to electricity generators to deliver (or being ready to deliver) a certain power when needed (e.g. in peak winter demand) in order to assure backup for intermittent low carbon sources. Capacity markets also promote active demand management, old power stations replacement and encourage new build generation. There is a wide menu of mechanisms within capacity markets. The main choices are displayed in Figure 15, modifications and hybrid models are also possible.

- Capacity payments are executed in the Iberian Peninsula, Ireland and Bulgaria, being entirely supported by governmental rents. These wages are permanent or variable and are given to all or part of the qualified capacity declared or available. This model has been in place for years on European periphery where markets are less well-interconnected. Nowadays, the dominant tendency is to move from a more administration-set capacity prices into a market-based approach as Italy shifted to an auction model and Spain is considering as well some change.



Source: EY, based on various public sources.

Figure 15. Summary of existing and projected capacity systems in Europe: Capacity payments and obligations, strategic reserve and other mechanisms (“EY - Renewable Energy Country Attractiveness Index” 2016).

- The capacity obligation regime is characterized by the fact that each supplier contracts an advanced load of his customer´s portfolio and a predesignated security margin. This is the case of Greece. Romania on the contrary, is rather a capacity auction mechanism, where several years before the capacity is necessitated, the TSO, opens an auction and selects the sources to acquiesce to the margin above the forecasted peak demand (Arnaud Coibion 2014).

- In the strategic reserve mechanism, an autonomous agent (normally the TSO) tenders or contracts peak load production to backup capacity. This is typically implemented in states which rely profoundly on hydropower and are concerned about the years of drought so, they safeguard supply by this method.

- UK is pioneering the auction model for 2018-19 capacity. The first auction was held in December 2015. The procedure has been highly criticized (“UK ‘capacity Market’ Is Not a Market – It’s State Aid (£1 Billion/year)” 2015) because the subsidy was not restricted to peak capacity (12.3% of total) but to the entire forecasted 2018-19 UK capacity. Plus, any producer was allowed to bid causing low final prices failing to encourage new-build generation (5.3%). Consequently, main fossil generation firms were the resulting beneficiaries of this scheme, now that they will take in the majority of the state aid doing what they would have done anyway, which is producing base load. Demand response mechanisms would have abated the peak demand to 8.9%, so together with new generation would cover real peak demand (Ofgem 2015).

2.2.4 ENERGY MARKET EVOLUTION: DRIVERS

The energy system in the past worked steady and straightforward. Baseload was supply by coal, hydro or nuclear plants 24/7. For peak load, easily powered up and down plants like gas came into play. Then, liberalization during late 90´s adjusted this model to optimizing marginal cost of electricity and the debut of RE catalyzed it. Marginal cost for supported solar and wind is zero (not fixed cost, which are substantial). Therefore, grid consumes them first, even if in many Member States renewable´s policies have been "granted" with "grid priority".

So RE, become paradoxically an irregular base load which needs to be supported by complement sources. Gas turbine power stations that can dispatch energy within minutes are mostly valuable for keeping grid reliability and harmonizing loads. Whereas combined cycle gas turbines take over 30 minutes to reach full load or being switched-off, steam cycle generators more than 12 hours and nuclear plants days. The design of nuclear and coal plants is optimized to run full blast, regardless the grid needs, therefore to decrease production means malfunctioning, entailing an exiguous revenue, making prices volatile and having an even bigger environmental impact.

Especially in Germany, with a wealth of renewable share compared to other Member Nations, installed firms are struggling due to this loss of money. The following Figure 16 poses the evolution of the share price (€) of the Energy European enterprises (MSCI index) (Christos Papadopoulos 2015).

Source: Thomson Reuters

Figure 16. MSCI European enterprises share price, $ ("How to Lose Half a Trillion Euros | The Economist" 2016).

At their peak in 2008, the dominant 20 energy business were worth €1 trillion whilst in 2013 the amount was reduced to 1/3 ("How to Lose Half a Trillion Euros | The Economist" 2016). This profit-making crunch can also give space to inexpensive FFs renascent, like lignite. Lignite is well stablished in Germany, Poland, Czech Republic and Greece and their production account for over a third of the world's lignite output. Apparently RE would diminishes its profitability but manufacturers are resisting by exporting to third-party clients and by promoting distributed energy generation through plants below the 20 MW in order to avoid CO_2 penalties under ETS ("Lignite in Europe: Fighting Back Renewables" 2015), (European Commission 2010). Plus, even if facilities have to comply with carbon emissions regulation, as ETS prices are extremely low, the carbon price needed to shift from emissions-intensive coal-fired power generation to cleaner natural gas would be at least 6 times more expensive than nowadays ("Henbest: Fix the EU ETS, and Carbon Markets Can Be Serious Business" 2015).

Thus, lignite´s rebound and peak generation, which before was in the hands of expensive gas-fired plants, and now belongs to solar, destroys gas previous cost-effectiveness and shifts it out of the energy generation equation ("Combustion Engine vs Gas Turbine- Startup Time" 2016), (Lothar Balling 2011).

Besides, the cost of solar panels have been reduced from 76$/watt in 1976 to 0.30$/watt in 2015 ("PVprices. Energytrend" 2016) as it is depicted in Figure 17. This reduction has been motivate by R&D over the decades, Western countries demand and Chinese involvement in solar PV production.

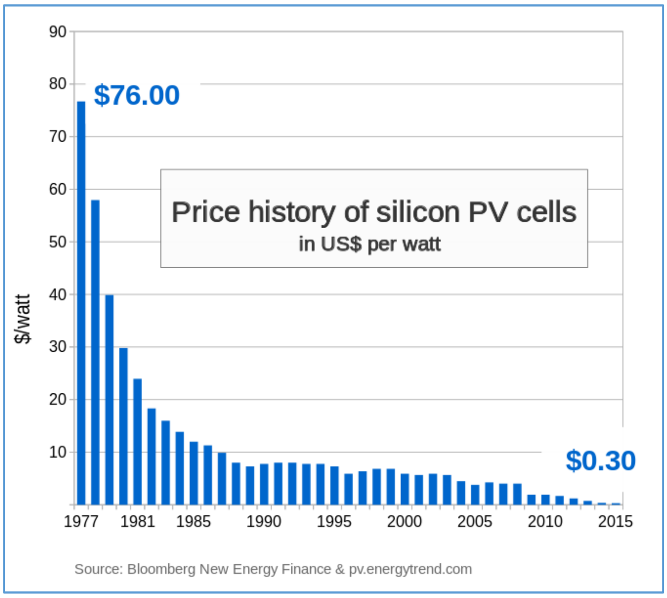


Figure 17. Price history of silicon PV cells ($/w) ("File:Price History of Silicon PV Cells since 1977.svg" 2016).

In Germany, as Figure 18 depicts, the expense of producing a megawatt hour of electricity has dropped to €150 in 2013 from almost €500 in 2006 (Wirth and Schneider 2013). This amount is higher than the wholesale price, but below the RE premium and the domestic prices. Still makes solar generation attractive, even without subsidies. Hence, solar capacity will continue upsurging.

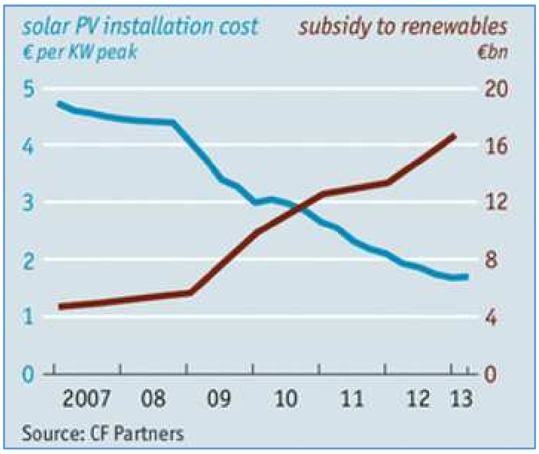


Figure 18. Solar PV installation cost (€/KWp) and subsidy to renewables in Germany (billion €) in Germany ("How to Lose Half a Trillion Euros | The Economist" 2016).

The current *status quo* and evolution of the EU energy markets it is not been marshaled unilaterally by RE but by a certain conjuncture:

In some Member States, as Spain, there has been an overinvestment during the 2000s in fossil generating capacity. In 2012 the installed capacity, 107.615MW, doubled the existing in 2000, being 2007 the year with the highest consumption energy peak, 45.450MW (NAVARRO 2013). At the same time, owing to the financial crisis, demand declined to levels seen only more than twenty years before as Figure 19 and Figure 20 show (Harvey 2015).

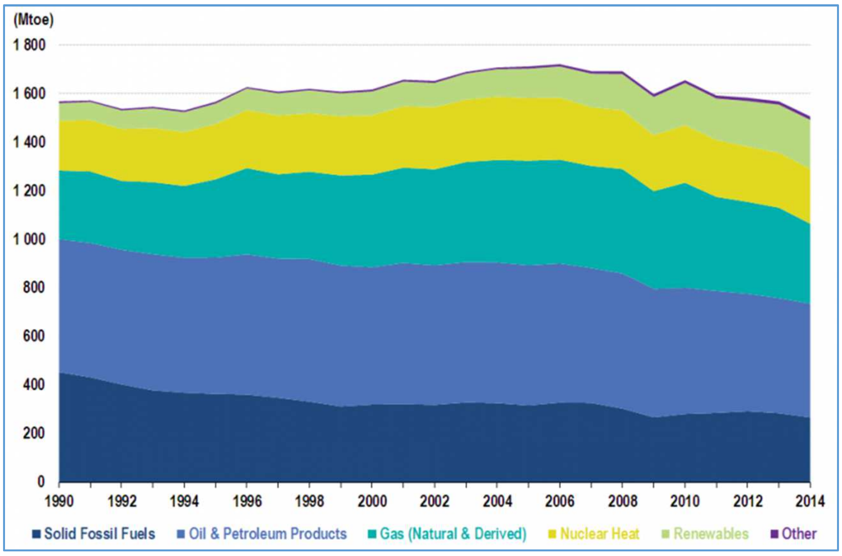
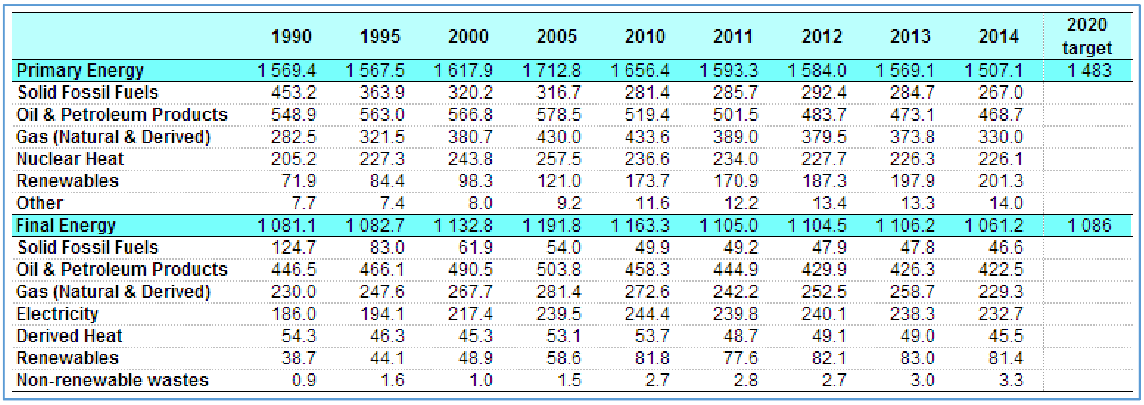


Figure 19. Primary energy consumption, EU-28 (Mtoe) from 1990 to 2014 (“Energy Saving Statistics - Statistics Explained” 2016).



	1990	1995	2000	2005	2010	2011	2012	2013	2014	2020 target
Primary Energy	1 569.4	1 567.5	1 617.9	1 712.8	1 656.4	1 593.3	1 584.0	1 569.1	1 507.1	1 483
Solid Fossil Fuels	453.2	363.9	320.2	316.7	281.4	285.7	292.4	284.7	267.0	
Oil & Petroleum Products	548.9	563.0	566.8	578.5	519.4	501.5	483.7	473.1	468.7	
Gas (Natural & Derived)	282.5	321.5	380.7	430.0	433.6	389.0	379.5	373.8	330.0	
Nuclear Heat	205.2	227.3	243.8	257.5	236.6	234.0	227.7	226.3	226.1	
Renewables	71.9	84.4	98.3	121.0	173.7	170.9	187.3	197.9	201.3	
Other	7.7	7.4	8.0	9.2	11.6	12.2	13.4	13.3	14.0	
Final Energy	1 081.1	1 082.7	1 132.8	1 191.8	1 163.3	1 105.0	1 104.5	1 106.2	1 061.2	1 086
Solid Fossil Fuels	124.7	83.0	61.9	54.0	49.9	49.2	47.9	47.8	46.6	
Oil & Petroleum Products	446.5	466.1	490.5	503.8	458.3	444.9	429.9	426.3	422.5	
Gas (Natural & Derived)	230.0	247.6	267.7	281.4	272.6	242.2	252.5	258.7	229.3	
Electricity	186.0	194.1	217.4	239.5	244.4	239.8	240.1	238.3	232.7	
Derived Heat	54.3	46.3	45.3	53.1	53.7	48.7	49.1	49.0	45.5	
Renewables	38.7	44.1	48.9	58.6	81.8	77.6	82.1	83.0	81.4	
Non-renewable wastes	0.9	1.6	1.0	1.5	2.7	2.8	2.7	3.0	3.3	

Figure 20. Primary and final energy consumption itemized by type of source, EU-28 (Mtoe) from 1990 to 2014 and 2020 target (“Energy Saving Statistics - Statistics Explained” 2016).

Mostly of the Spanish overcapacity planning corresponds to gas plants. This country could embody the gas-provision alternative to the problematic Russian gas, owing to the Russia-Ukraine gas disputes which lead to gas supply disruptions in January 2009 (Russia supplies almost a quarter of the natural gas consumed in the EU and approximately 80% of those exports run via through pipelines across Ukraine before entering the EU)(Stern, Pirani, and Yafimava 2009) . Spain possesses a very sophisticated natural gas infrastructure, which represents the largest liquefaction capacity in Europe and has a good connection distribution system with Algeria thanks to the gas pipeline *Medgaz* (“3.5. Transporte Del Gas Natural Por Gasoducto” 2016) and could supply 35 to 40 billion cubic meters of gas per year to the rest of Europe, quantity equivalent to the 50% of the Russian gas which travels across Ukraine (“Spanish Energy Minister: ‘Spain Could Be the Solution’ for Europe’s Gas Woes” 2016). Nevertheless, this disproportionate investment realized by the Spanish government might be convenient in the long-term to the EU´s energetic security planning. The general trend of legislators is to tackle Security of Energy Supply matters higher in the national policies agendas rather than issues on the efficiency of markets operation (Christos Papadopoulos 2015).

Shale gas is also performing an important role. Due to its success in North America, European coal exportation has abated and together with cheap and numerous EU emission carbon permits, coal prices have been pushed down compared to gas. Also, during the last decade production increased in some of the main suppliers, particularly in Indonesia which contributes to this vertical drop of prices (“Global Trends in Coal to 2020” 2016).

The Fukushima nuclear disaster, precipitated strict policies in Germany against nuclear. Eight plants were closed urgently and other nine were issued to phase-out by 2022 (“Nuclear Power in Germany - World Nuclear Association” 2016). This lack of prevision has led extra pressure and burden to the existing facilities and opening or reopening bargain coal fueled plants causing an increase in GHG emissions.

As a consequence of abovementioned factors, wholesale market profitability has plummeted so did power plants (Figure 21).

Figure 21. Germany´s wholesale electricity price (€/MWh) (“How to Lose Half a Trillion Euros | The Economist” 2016).

As a response, centralized energy producers have applied a range of actions and new business models have arisen:

- Hedging has become a common practice for production companies. It shields the collapse of energy prices by offsetting with future contracts, whence facilities are settling long-term electricity-price agreements with the administrations.

- Business diversification to RE generation or “downstream” activities, like energy efficiency consulting or trading. The trend is to focus in providing services rather than truly owning the asset.

- Some utilities entrust third-party investors to sell, manage and deploy their renewable assets. One of the major drawbacks for centralized utilities competitors regarding RE investment, especially solar, is that solar is highly scattered along the territory, so innovative models are surging replacing traditional ones. Third-party capitalizing is an established method in US and one of the most popular solutions for consumer-level solar financing. It essentially occurs through two configurations:

- A traditional lease client, signs a contract with the developer and pays for the installation in a flexible way before the end of the lease term(“Third-Party Solar Financing” 2016).
- In the Power purchase agreement (PPA) model, the customer does not own the system but purchases the power generated at a fixed rate, generally lower than the local price. At the expiration of the contract, the property owner can extend it or buy the equipment (“Third-Party Solar Financing” 2016).

PPAs and solar leases have been already revolutionary in the US and are gradually expanding in Europe (“Solar Leasing Boosted in Europe with RWE, Conergy Deal” 2014) (GmbH 2016).

2.2.5 EUROPEAN LEGISLATIVE REVIEW

Since their emergence in the 1970s, renewable energy policies and targets have taken an assortment of shapes. It is the intention of this section to fathom their trajectory. However, there is an ambiguous differentiation in the terminology to draw the line among aspirational statements of RE targets and those ones fully articulated accompanied by clear, quantifiable policies and measures backed by legally binding obligations (Ghislaine Kieffer 2015). Therefore, it is introduced this spectrum (Figure 22) to depict the progression of complexity and level of obligatory applicability:

- The first tier would correspond to statements supported by further elaboration of the targets, e.g. White papers. White Papers are reports enclosing proposals for EU action in a specific area. When a White Paper is positively received by the Council of the EU, it can lead to an action programmed for the Union in the field concerned. Also Green Papers belong to this initial step, which are documents promulgated by the European Commission to encourage discussion on given topics at European level. They may generate legislative progresses that are then outlined in White Papers (“Green Papers - European Commission” 2016) (Commission, Commission, and others 1997).

- The following step remains at the planning stage.

- In the third category, RE targets become more specific and measurable, and are geared towards implementation. As such, they grow more elaborated both in terms of alignment with broader economic and energy objectives and in terms of translation into specific actions plans and policy, regulatory, fiscal and financial instruments. Within this category are technology-specific roadmaps, programs, etc.

- In the 4th step of the spectrum the agreements are translated into specific policies and measures with clear compliance mechanisms to ensure their implementation. When the EU RE Directive was adopted in 2009, all EU Member States moved to this band of the spectrum. This is the reason why some of the following targets are overlapping or even opposing.

Figure 22. Spectrum of Renewable Energy Targets (Ghislaine Kieffer 2015).

1973's oil crisis acted as the breeding ground of the REs adoption. Since this moment, the creation of new energy policy strategies as the promotion of diversified and reliable external supplies and the development of the various domestic energy sources was urged (M. Dogushan Kara 2014).

In 1994 at the Madrid Conference, the "Madrid Declaration" was proposed. It set the first lines for RES-E deployment: among other actions it suggested specific measures to overcome obstacles to RE use, widespread utilization and development; by the year 2010 it planned the substitution of the 15% of the conventional primary energy demand by RE ("European Commission : CORDIS : News and Events : Action Plan on Renewable Energy Sources in Europe: Conference Proceedings" 2016).

In 1996, the Directive 96/92/EC served as a template for the subsequent liberalization of the electricity sector in all EU member states (Ciarreta and Gutiérrez-Hita 2009).

The European Commission White Paper of 1997 on REs (Commission, Commission, and others 1997) determined the goal of doubling the share of RE in the EU´s energy mix consumption from 6% to 12% by 2010 (Association and others 2011).

In 2001, European Union introduced the Directive 2001/77/CE, which is known as the REs Directive. It enacted national voluntary targets for RE production in order to comply 12% share of gross renewable domestic energy consumption by 2010 and in particular with the indicative share of 22.1% of electricity from RES-E out of the total electricity consumption of the Union. In 2004, with the accession of 10 new Member States the target was reduced to 21%. Satisfying EU commitments made under Kyoto on GHGs reduction emissions was also a pivotal objective for this directive. Therefore, Directive 2001/77/CE provided guarantee of origin for RES-E to simplify energy exchange, gaining transparency and facilitating customer choice. In addition, it drew numerous mechanisms that Member Countries could apply in order to attain their targets: support schemes, ETS, project-based mechanisms (seen in the section *Economic EU* RE support instruments comparison

The prospect of a proliferation of support tools indicates a progressively intricate regulatory environment for power in Europe in the next decades (Arnaud Coibion 2014). These dissimilarities place the developers and the traders of renewable electricity, in different Member States, in completely different positions undermining the incentive to local production where the efficiency on production/consumption is optimal.

Figure 12 portrays the average support to overall RE production in the EU (€/MWh) by country in 2013. For instance, subsidies for photovoltaics (PV) in Czech Republic are almost 200 times larger than waste and biogas in Finland.

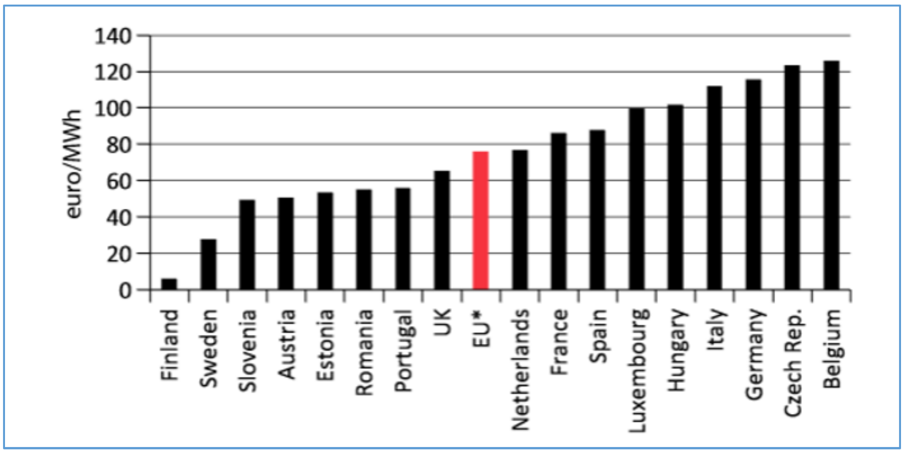


Figure 12. Average support to renewable energy production in EU (€/MWh) by country in 2013 (Carlo Stagnaro 2015).

Figure 13 depicts the support costs in €/MWh among various technologies. It is evidenced that, it is PV which gather the higher part of the bonus, 350€/MWh versus an average of 80€/MWh and a Portuguese price of 55€/MWh.

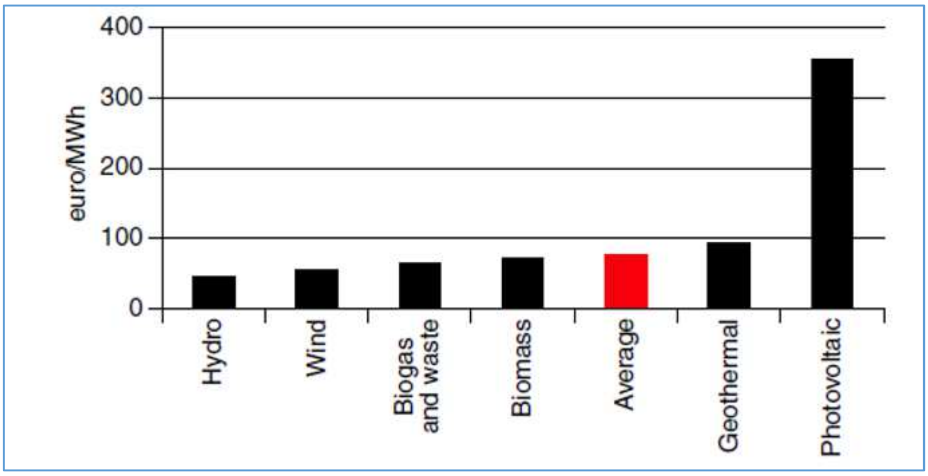


Figure 13. Average support to RE production in the countries listed in Figure 3 (€/MWh) by technology (Carlo Stagnaro 2015).

GHG emission reduction costs

Incentives for RE deployment, as previously revised, have become a key instrument of climate policy as a mean to reduce GHG emissions (Marcantonini and Ellerman 2013). It is also intended to monetarily evaluate how much cost-effective are the implemented mechanisms per Member State.

Figure 14 reflects the net cost over CO_2 emissions reductions attributed to RE in a sample of EU countries in €/ton

CO_2 regarding 2012 data. The smallest expenditure in CO_2 reduction corresponds to Finland, with 27€/ton CO_2. On the contrary, France and Sweden hold the highest costs being up to 50 times more. These Member States rely on hydropower and nuclear power respectively, which are low-emitting sources, therefore the amount of emissions cutback remains low.

CO_2 abatement cost are calculated as the ratio of the net cost (sum of the costs and cost savings due to the injection of renewable energy into the electric power system) over the CO_2 emission reductions attributed to RE. These costs are correlated with the average incentives per technology in the previous paragraph.

In Germany, the CO_2 abatement cost of wind for 2006-2010 was on average 43€/ton CO_2 while for solar reached 537€/ton CO_2, being the main reason the remuneration to producers determined by the FIT (Marcantonini and Ellerman 2013). These values fluctuate due to variations in fossil fuels prices, carbon price and the amount of generated RE. For instance, in 2008 CO_2, the abatement cost of wind was 20€/ton CO_2 owing to a combination of high fossil fuel prices and a high annual capacity factor (Marcantonini and Ellerman 2013).

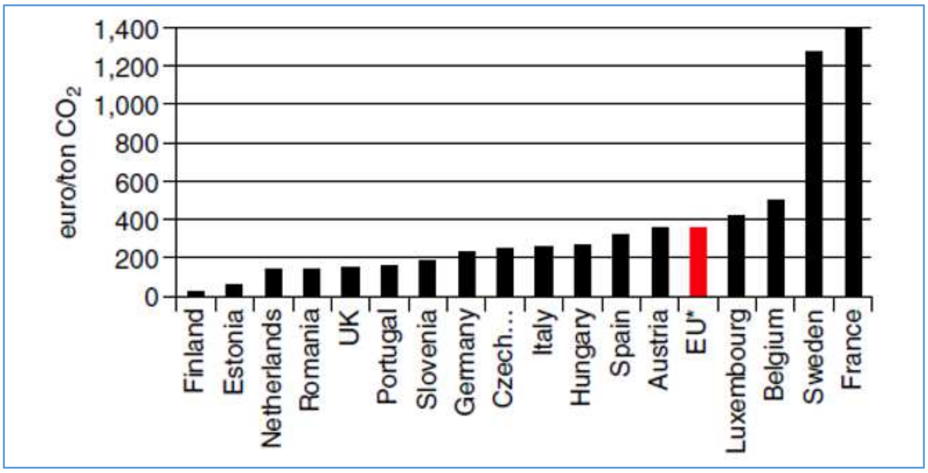


Figure 14. Average CO_2 abatement cost in some EU member states in €/ton CO_2 (Carlo Stagnaro 2015).

), along with sustainability criteria for biofuels.

In 2006, The European Parliament determined in the Green Paper 2006/2113(INI)) a target of 25% of RE in European energy consumption by 2020 (“Texts Adopted - Thursday, 14 December 2006 - A European Strategy for Sustainable, Competitive and Secure Energy - P6_TA(2006)0603” 2016).

In 2007, EU commission disposed the “Renewable Energy Roadmap”. This Road Map was an integral part of the review of European energy policy which took place in early 2007 ("Energy Package"). It responded to the request made by the European Council in the 2006 Green Paper for a further promotion of RES-E in the long term (“Renewable Energy Road Map” 2007). The highlight of this resolution was the compulsory target of having 20% of the EU's overall energy consumption coming from renewables by 2020, and a requisite of a minimum objective for each Member State to achieve at least 10% of their transport fuel consumption from biofuels. To comply with this request, it provided for each Member State obligatory targets and action plans in line with its potential. It constituted a flexible procedure which would leave Member States enough room for maneuvering.

Under the European Union 2020 climate and energy package, addressed in the introduction of this section, Directive 2009/28/CE amended and repealed Directive 2001/77/CE making three objectives compulsory and pooled for all Member States to be reached by 2020:

- Lowering GHGs emissions in a share of 20% compared to 1990 via ETS and ESD.

- Reduction in primary energy consumption in a share of 20% by means of 2012 Energy Efficiency Directive.

- 20% of RE in final energetic gross consumption via RE Directive.

With the purpose of acquiescing 2020 obligatory objectives, by June 30th 2010, each EU Member State designed detailed roadmaps known as National Renewable Energy Action Plans (NREAP). Besides every two years, EU countries are intended to account on their progress towards the EU's 2020 renewable energy goals. Since then, there has been various communications (2011, 2013 and 2015) from the commission assessing the progress towards 2020 common targets (European Commission 2013a) (European Commission 2015b) (European Commission 2011a).

Electricity Directive (2009/72/EC) revokes Directive 2003/54/EC involves common rules for the internal market in electricity and is part of the Third Energy Package as viewed in *Grid-related regulations* section. Among its measures, it allows Member States to introduce priority connection, priority or guaranteed access to the electricity grid, and priority dispatch for RES-E. Rules on priority dispatch of RE-sourced electricity emerged with the First Electricity Directive in 1996. Priority connection and access measures were introduced after the European Commission concluded the second (2003) and third (2009) packages of legislative proposals for the electricity and gas markets.

Table 2 collects the outline of the European electricity directives.

Table 2. Achievements of EU electricity directives (Carlo Stagnaro 2015).

	Most Common Form Pre-1996	1996 Directive	2003 Directive	2009 Directive
Generation	Monopoly	Authorization tendering	Authorization	Authorization
Transmission and distribution	Monopoly	Regulated - negociated TPA Single Buyer	Regulated TPA	Regulated TPA
Supply	Monopoly	Accounting separation	Legal separation from transmission and distribution	Ownership separation from transmission and distribution. Legal separation from transmission and distribution under ISO/ITO arrangements
Customers	No Choice	Choice for eligible customers	All non-household consumers have choice (2004). All consumers have choice (2007)	All Consumers have choice
Unbundling Of Transmission And Distribution	None	Accounts	Legal	Ownership Legal Under ISO/ITO
Cross-Border Trade	Monopoly	Negociated	Regulated	Regulated
Regulation	Government Department	Not Specified	Independent regulatory body	Independent regulatory body

In order to keep climate change below 2ºC, The EU stablished on the 8th of March 2011, a long-term goal for decreasing GHGs emissions by 80-95% compared to 1990 levels by 2050 (European Commission 2011b). Likewise, to keep exploring energy system transition in ways that would be compatible with this GHGs reduction target while also increasing competitiveness and security of supply, a new Energy Roadmap, “Energy Roadmap 2050” arose in December 2011. It predicted that after 2020 RE production would diminish without further intervention due to their high cost and barriers compared to fossil fuels, 30% of RE production would be reached by 2030 and the biggest share of energy supply in 2050 will come from RE. (European Commission 2011c, 2050), (Duscha et al., n.d.).

The Commission, in its communication of June 6, 2012 entitled ‘Renewable energy: a major player in the European energy market’ (European Commission 2012) pointed out the areas in which efforts should be boosted between then and 2020 for the European RE production to increase, particularly for RE technologies to reduce their cost, be more competitive and, ultimately, market-driven (with support schemes only for less mature technologies). Plus, it also indicated that investments in RE would be encouraged by the elimination of fossil fuel subsidies, a well-operated carbon market and accordingly designed energy taxes.

As additional guidance in November 2013, Commission announced the promotion of FIPs and quota obligations instead of the generally use FITs. (European Commission 2013c).

After the publication in March 2013 of the Green Paper ‘A 2030 framework for climate and energy policies’(European Commission 2013b), a report titled ‘A policy framework for climate and energy in the period from 2020 to 2030’ (European Commission 2014) was released on 22 January 2014. It focused on the opportunities and challenges for 2030 and delineated the proposals for a debate by heads of State and Government, recommending not to extend mandatory national objectives for RE after 2020. A compulsory target of 27% of energy consumption was then enforced at EU level.

Seven months later, In October 2014, the European council reinforced some targets for 2030: At least 40% GHG reduction (below 1990 levels), as aforementioned at least 27% for renewable energy and 27% for energy efficiency (European Council 2014). Unlike previous 2020 Package, the new EU targets under 2030 Framework will not be translated into national binding targets through EU legislation. Furthermore, was endorsed the goal of arriving at 15% of interconnectivity in electricity networks between Member States, manifesting the key role of electricity connectors to bolster the EU internal market for electricity to permit deeper penetration of RE and to ameliorate security of supply.

On 25 February 2015, the Commission passed "The energy Union Package, A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy"(European Commission 2015a). As energy in the EU is regulated at national level, the aim of the energy union is to transform the EU's energy system that currently comprises 28 national frameworks into one EU-wide framework. The package means to provide a coherent approach to climate change, energy security and competitiveness and to achieve the goals agreed under the 2030 Framework as a result collects these several main targets:

- The diversification of Europe's natural gas market and ensuring more transparency in gas contracts.

- Revamping the integrated electricity market, with substantial improvement in regional cooperation, stronger regulated framework and new legislation to protect electricity and gas supply.

- The development of energy efficiency focusing efforts on RE and Research and Innovation.

The Energy Union goals would be annually report on the 'State of the Energy Union'. On November 18, 2015 the first document was divulged (European Commission 2015e). It is meant to be a positive analysis of the progress shaped towards instituting the Energy Union, and to highlight the issues where further attention is required. Likewise, it gathers a series of Commission reports and initiatives in an integrated way.

2.3 The Portuguese Electricity market

2.3.1. Electricity System overview

In the seventies, after the military coup on the 25 April 1974, the Portuguese electricity sector was nationalized, constituting a monopoly, Electricity of Portugal (EDP). Anticipating the EU electricity internal market directive of 1996, (seen at *2.2.5 EUROPEAN LEGISLATIVE REVIEW*) the privatization of the electricity market in Portugal begun in 1995.

To comply with the Third Energy Package legislation regarding actions to promote access for new entrants by weaken the market power of the biggest electricity firms, Portugal adopted ownership unbundling. To do so, three gradual steps were needed to be fulfilled:

- Functional phase, characterized by an exclusive economic disintegration.

- Legal phase which separates the network services while remains connected with the production and trade operations.

- Ownership unbundling which assures that new companies are constituted out of the former vertical structure.

Electric transmission network legal unbundling was initiated in 1996. By year 2000 due to ownership unbundling, the state owned enterprise for high voltage, REN, was created. Nevertheless, a dual electricity trading system within the National electricity Portuguese system (SEN) was coexisting:

- The Public Service System (SEP), defined the obligatory exclusive selling energy agreement between generators and REN through PPAs. Most PPAs partners are locked into contracts that last between 15 and 25 years, but in the Portuguese case they are extended up to 75 years. PPA's were designed so that there was an 8.5% return on investment on the economic life time of the power plant. Howbeit, this wasn't an impediment for the power plant to keep running after his economic life time had ended (Amorim et al. 2013). This fact castled historical incumbents from potential generators who would be granted access in the market as a result of market liberalization. Generation was concentrated on the Portuguese company of electricity production (CPPE), which belonged to EDP production, Tejo Energia and Turbogás (Endesa, and Iberdrola contributed in a smaller scale). SEP also encompassed:

- The national transmission grid (RNT).
- The main distribution entities which all were part of EDP; Norther electricity (EN), Central electricity (CENEL), Tejo and Lisbon electricity (LTE) and Southern electricity (SLE)
- Eligible consumers whose annual demand was equal or over 9GWh, (Medium Voltage, High Voltage and Very High Voltage)
- Non-eligible consumers who opted to remain within the public system.

REN sold this electricity to distributors and the price embedded transmission system and global use of the system charges. Rates to SEP´s end customers and for the transmission and distribution parts (the monopoly segment) were regulated by ERSE, the Portuguese Electricity Regulatory Agency created in 1997 (Domínguez and Bernat 2007).

- Independent Electric System (SEI) was conceived as the liberalized institution, involving:

- The Non-Binding system (SENV), which would be the competitive segment. Producers, under the absence of PPAs traded directly with the REN, distributors or eligible consumers. The generators were mainly part of the EDP group such as Northern energy (HDN), Central energy (HIDROCENEL), and Tejo´s hydroelectric (Hidrotejo).
- Special regime (SR) producers, being CHP, mini-hydraulic (10MVA max) and other renewables. FITs were originally instituted in 1988 and the guarantee price is expected to last until 2020 (Amorim et al. 2013).

2001 led to the creation of an Iberian wholesale electricity market (MIBEL) together with Spain, which was initiated in 2003. Among its benefits was the plan to implement the interconnection capacity by an expansion to reduce constraints in the peninsular electricity wholesale trade and to upgrade and resolve congestion management policies, such as market splitting methodology: Grid bottlenecks are alleviated by comparison of the considered contractual flow with the factual transmission capacity for spot trading. When the flow surpasses capacity, the prices are adjusted on both sides of the bottleneck so that the flow equals the capacity, by reducing the price in the surplus sector and increasing it in the deficit area. This will diminish the sale and escalate the purchase in the surplus area and vice versa. As result, the required flow is reduced to match the available transfer capability. If the flow does not exceed the capacity, a common price is established for the whole area (Indian Energy Exchange 2016). MIBEL comprises:

- The spot market based in Spain, managed by the OMIE and launched in July 2007. It has been recently renamed as *Nominated Electricity Market Operator* (NEMO) applying UE 2015/1222 ("OMIE" 2016). It consist of a day-ahead (DAM), most popular trading system, and an intraday market (IDM), which delivery contracts are issued hourly.

- The Power Futures exchange market, placed in Portugal, managed by the Iberian Forward Market Operator (OMIP) and inaugurated in July 2006. It has been experiencing a continuous development in terms of number of participants and liquidity.

- The ancillary service market resides on real-time trading to overcome collateral asymmetries produced by other markets in the structure.

- The Over the counter (OTC) model is a bilateral trade between two parties, normally utilities and/or banks with a complete freedom of individual contracts. The trading products encompass tailored products agreed on between the two parties.

In 1999, the regulatory framework allowed free choice of the supplier, promoting competition and a *de jure* free entry for generation capacity, requiring a third Party access regime managed by ERSE. Thereupon, private investment on renewables prospered as a consequence of the favorable FITs (government acts of 1999 and 2001). But it was not until 2004 when *de facto* ordinary production acceded, being commissioned a combined cycle gas turbine (CCGT) at the end of 2003. In addition, only by 2002 all medium voltage customers were able to select supplier. These events, together with MIBEL facing delays for technical, operational and political reasons shriveled the stimulus of new electricity production.

One of the technical obstacles hindering integration was the incompatibility between wholesale Portuguese and Spanish markets owing to the existence of the SEP regime operating mainly with PPAs; special incentives and guaranteed purchased prices for SR and capacity payments for OR. This instability incurred in delays for the authorization procedures for new entrants.

Finally in 2006 the dual market, SEI and SEP was dismantled, PPAs were replaced by a compensation scheme (CMEC) which happen to be financially equivalent to its precedent (Amorim et al. 2013) and two regimes were redefined for electricity generation:

- An ordinary regime (OR), where the electricity produced is from conventional non-renewable thermal sources or from large hydro.

- A special regime (SR), analogous to the former mentioned SR but excluding CHP.

In 2007, REN entered the stock market by launching an Initial public offering (IPO[8]). As a consequence it was legislated that no single distributor was allowed to possess more than 10% of REN capital.

2.3.2. Portuguese Renewable energy and PV specific legislation

Briefly, Portuguese main RE and PV specific related legislation is revised and exposed in Table 3 ("IEA - Portugal" 2016) (Natascha Trennepohl 2013). Point 22 is considered pertinent to this study, so it is addressed in *4. CASE STUDY*.

Table 3. Portuguese main Renewable energy and PV specific related legislation summary ("IEA - Portugal" 2016).

#	Laws	Year	Policy Status
1	Decree-Law no. 189/1988	1988	Superseded
2	Electricity Generation Efficiency	1999	Superseded
3	Tax Reduction for Renewable Energy Equipment	1999	In Force
4	Revision of Energy Program	2000	In Force
5	Energy Efficiency and Endogenous Energies (E4) Program	2001	Ended
6	Decree-Law no. 312/2001	2001	Unknown
7	Decree-Law no. 339-C/2001	2001	Unknown
8	New Tariffs for Renewables	2001	In Force
9	Decree-Law no. 68/2002	2002	Unknown
10	Tax Incentives	2002	Unknown
11	Resolution of the Council of Ministries - 63/2003	2003	In Force
12	Resolution of the Council of Ministries - 171/2004	2004	Unknown
13	New feed in tariffs for Renewables - DL 33-A/2005	2005	Superseded
14	National Energy Strategy	2005	Superseded
15	Modified feed-in tariffs for renewables. Decree-Law no. 225/2007	2007	In Force
16	Decree-Law no. 363/2007	2007	Superseded
17	National Renewable Energy action Plan (NREAP)	2010	Superseded
18	National Energy Strategy 2020 (ENE 2020)	2010	Superseded
19	Microgeneration Law (Application Decree Law 118-A/2010)	2010	In Force
20	Mini Production Law amendment (Decree Law 34/2011)	2011	In Force
21	Feed-in tariffs for micro and mini generation for 2013 (Portarias 430/2012 and 431 /2012)	2013	Superseded
22	Feed-in tariffs for micro and mini generation for 2014	01/01/2014	Superseded
23	Law on Self-consumption Decree-Law No. 153/2014	20/1014	In Force
24	Portugal Green Growth Commitment 2030	2015	In force

1. In Portugal, the generation of electricity from RES-E is primarily endorsed through a guaranteed FIT. Decree-law 189/1988 was the first state-aid maneuver intended to promote RES-E adoption authorizing independent RE production under 10MW of installed capacity.

2. Electricity generation Efficiency law stablished monthly payments for capacity and energy supplied to the grid as a function of performance and availability for renewables, CHP and small hydro. The payments for REs were based on the market value associated to the environmental benefits generated.

3. Tax Reduction for RE Equipment was enacted in 1999 and remains in force. It provides a budget provision

---

[8] An IPO is the first sale of stock by a company to the public.

allowing purchasers of RE equipment to profit from reduced taxes.

4. A revision of the Energy Program was passed in 2000 adding to the former Program under the Community support Framework (POE) ("IEA - Portugal" 2016) incentives for energy efficiency and a diversification for RE projects.

5. Energy Efficiency and Endogenous Energies (E4) Program was implemented in September 2001 and surpassed in 2003 by the Cabinet Resolution No. 63/2003. This legislation aimed to stimulate investment in energy efficiency and RE generation. It simplified the licensing for installation and regulated attractive tariffs for the acquisition of RES-E by the national grid. It settled the rates portrayed in Table 4 for PV production.

Table 4. FIT remuneration levels for Portuguese generation (2001) ("IEA - Portugal" 2016).

Feed-in tariff remuneration levels for generation in 2001		
Renewable source	Capacity	FIT levels
Solar PV	> 5 kW	€ 0.284/kWh
	< 5 kW	€ 0.499/kWh

The estimated average before the implementation of this law was 0.064/kWh for RE producers in 2001.

6. Decree-Law no. 312/2001 instituted the procedures regulating the awarding and management of the interconnection points with the SEP for the electricity received delivery from new power plants (independent producers of CHP and REs) in the framework of the SEI.

7. This Decree-Law 339-C/2001 was implemented within the framework of the E4 Program package. It creates differentiated tariffs as a function of the technology and operating regime and modifies special regime rates.

8. The New Tariffs for Renewables law superseded the Electricity generation Efficiency law of 1999 being still applicable. It increases the buy-back tariffs [9] for REs and CHP in order to encourage deployment.

9. Decree-law 68/2002 intended to forge a faster administrative and technical methodology for the interconnection of micro-generators to the low voltage grid.

10. The tax incentives law of 2002, no longer in force, meant to favor taxation towards RE private investors having a VAT rate of 5% (versus the regular 12%) (Winkel et al. 2011).

11-12. Resolutions of the Council of Ministries 63/2003 and 171/2004 targeted the promotion of national competitiveness. They were focused on endeavoring energy intensity reduction, due to the high intensity and dependence of Portuguese economy in imported energy namely oil and market liberalization. Among the main actions addressed were pursuing a significant RE production increase, incentivizing energy efficiency and the use of renewables and cogeneration in the industrial sector.

13. Decree Law 33- A/2005 provided the manner of calculating FITs for REs and the validity time for them,

---

[9] Tariffs applied to any electricity exported to the grid by eligible renewable generators.

accounting technology, environmental aspects and the inflation rate through the index of prices to the consumer (Table 5).

Table 5. FIT calculation according to Portuguese Decree Law 33-A/2005 ("IEA - Portugal" 2016).

Renewable source	Power plant capacity	Criteria (whatever comes first)	Feed-in tariff level in EUR/kwh
Solar PV	≤ 5 kW	15 years or first 21GWh/MW	€ 0.444kWh
	> 5 kW		€ 0.317/MWh

14. Portuguese 2005 National Energy Strategy overruled the Resolution of the Council of Ministries 63/2003 and at the same time was annulled by the National Energy Strategy 2020 (ENE 2020). The goals meant to be attaint were the following:

- Assure security of energy supply, through the diversification of the primary resources, energy services and the promotion of energy efficiency.

- Vitalize and benefit competitiveness.

- Reduce environmental impact locally, regionally and globally with the object of guarantee the environmental sustainability of the energy processes.

Besides, the Strategy adopted these main actions in order to integrate the energy system:

- Market liberalization of gas and electricity.

- A definition of the structural framework for competition in gas and electricity by the establishment of two major competing operators for gas and electricity and a single transmission a sole system operator.

- Enforcement of the REs and energy efficiency deployment by public procurement energetically efficient and environmentally respectful, reorganizing the energy fiscal system, incentivizing schemes and fostering innovation.

- Communication, awareness and evaluation of the National Energy Strategy.

15. Pursuant Decree Law No. 225/2007 of 31th of May, FITs instituted by the previous Decree Law No. 33 A/2005 were amended as the Table 6 reflects.

Table 6. FIT remuneration levels for Portuguese generation (2007)("IEA - Portugal" 2016).

Feed-in tariff remuneration levels for generation in 2007			
Renewable source	Capacity	FIT levels	micro-generation FIT levels
Solar PV	< 5 kW	€ 0.45/kWh	€ 0.47/kWh
	≥ 5 kW, <5MW	€ 0.317/kWh	
	≥ 5 kW, <150kW		€ 0.355/kWh
	> 5MW	€ 0.310/kWh	

On 13 September 2007, the term micro-generation appeared for the first time in the Portuguese agenda. The rate introduced was 0.650€/kWh for an initial five-year period, via electricity bills. In order to ease the registration procedure and licensing an electronic platform was launched, e.g. System of Registration of Micro producers (SRM).

16. In November 2007 came into force Decree-law 363/2007 which defined the legislative framework of microgeneration (Rodrigues, Valdez, and Coelho 2013). Within this scheme, any entity that had a contract for purchasing electricity could be a producer of electricity from RES-E. The electricity generated, was primarily for personal consumption (at least 50% of the electricity mentioned in the purchasing contract), with any excess production available for distribution to third parties or the national grid, up to a limit of 150 kW. It could be distinguished two modalities:

- Special generation was integrated by microproduction units below 3.68kW and 11.04kW for condominiums. The tariff was granted for 15 years and it was annually fixed depending on the age of the PV installation. Yearly, a maximum of 2.4MWh per KW of installed capacity was the quantity allowed to be fed into the grid gainfully.

- Under the general program, which encompassed facilities under 5.65 kW, the exports were traded at the price of the Provider of Last Resort (POLR).

Microgeneration was a mechanism open to all types of technologies but it was PV which almost exclusively hoarded the regime, holding a 98% share.

17. EU Directive 2009/28/EC obliged Member Countries of the European Union to draft and submit to the European Commission National Renewable Action Plans (NREAPs) outlining pathways which would allow them to meet their 2020 RE, energy efficiency and GHG emission reduction targets. In 2010, Portugal enacted its NREAP which was eventually superseded by the National Energy Strategy 2020 (ENE 2020). Portugal compromised to the following REs targets for 2020:

- Overall target: 31% of share in gross final energy consumption.

- Heating and cooling: 31% of heat consumption.

- Electricity: 55% of electricity demand.

- Transport: 10% of energy demand.

The measures related to REs ratified were:

- Promotion of more energy efficient technologies in the REs sector.

- Creation of a FIT scheme and fiscal incentives supporting RE micro and mini production.

- Support for demonstration projects.

18. The National Energy Strategy (ENE 2020) was product of a strategical desire for this tumultuous international period of placing energy as the crucial driving force to modernize Portuguese economy, deploy a territorially-

balanced growth. ENE 2020 is articulated into 5 axis:

- Agenda for competitiveness, growth and energy and financial independence. ENE 2020 triggers economic areas adding value and job creation. It relies on the promotion of innovative projects in the fields of energy efficiency and RE, including decentralized production and electric mobility in a balanced territorial framework, boosting competition in the marketplace by consolidating the MIBEL, creating the Iberian Natural Gas Market (MIBGAS), and regulating the national oil system, thus contributing to enhance Portugal´s energy and financial independence.

- Banking on RE. Portugal aims to reduce its external dependence, so it is translated in a larger supply safety.

- Promotion of energy efficiency, so that the target of 20% reduction overall energy consumption can be reached. The actions implemented are behavioral, fiscal and innovative such as electric vehicles, smart grids, renewable-based decentralized production and energy management of public, residential and services buildings.

- Guaranteeing security of energy supply. By consolidating the Iberian market, widening the energy mic sources and strengthening transport and storage infrastructures.

- Sustaining the energy strategy - ENE 2020. It shall be enforced a tariff equilibrium fund that enables a continuous RE growth process by resorting to instruments of fiscal policy.

19. Decree-Law 118A/2010 modified some jurisdictive aspects of the former law (Decree-law 363/2007) to ease, simplify and make more transparent the access to production; expand the annual upper limit for installation to 25MW and streamlined the access to the Micro Production regime for public, social, education, defense and local institutions for installation up to 25MW and (Rodrigues, Valdez, and Coelho 2013). Besides, In order to be granted with the special tariff, home owners would have to comply with energy efficiency measures and the use of solar thermal collectors or biomass boilers. An incentive was also provided for State Laboratories to increase R&D in this field. The gestation of Micro production decline occurred after 2013(DL25/2013), where bonus tariffs and capacity were abated to the point of annihilation.

20. The minigeneration program established in Decree-law 34/2011 enabled small companies to install renewable-based production centers which used a single production technology (contrary to micro) up to 250 kW (therefore Medium Voltage). Comparatively to microgeneration, the installed capacity of plants considered to be mini production units was limited to 50% of the consumption level defined in the power purchase agreement and two types or regimes could be found:

- Under the general, the electricity was sold at the whole market price.

- In the Special scheme, with an annual ceiling of 50MW, the tariff was set by different procedures depending on the installed capacity:

- For Utilities over 20kW the rate was fixed using a tender mechanism to select the systems that offer better discount against the reference tariff

- Under 20kW the pricing was applied by “the first come, first served' method being the special reference tariff 250€/MWh.

The candidates for the special tariff, as for microgeneration were subjected to strict efficiency criterions and to an energy audit. As for the previous regime, an electronic platform named System of Registration of Minigeneration (SRMini) was constituted to manage the viability authorizations (“IEA - Renewable Energy” 2016).

21-22.The FIT for micro and mini PV generators dropped by 30% in 2013 as Table 7 portrays.

Table 7. FIT remuneration levels for Portuguese generation (2013)(“IEA - Portugal” 2016).

Feed-in tariffs for micro and mini PV generators in 2013				
Renewable source	Power plant capacity	Period of time	Feed-in tariff level in EUR/kwh	
			First 8 years	Following 7 years
Solar PV	< 3.68kW (mini)	15 years	0.196	0.165
	3.68-20kW (micro)		0.151	

Table 8 and Table 9 picture the FITs for micro and mini in 2014.

Table 8. FIT remuneration levels for Portuguese micro generation (2014)(“IEA - Portugal” 2016).

Feed-in tariff remuneration levels for microgeneration in 2014				
Renewable source	Total period of time	First 8 years	Second 7 years	Capacity
Solar PV	15 years	€ 66/MWh	€ 145/MWh	15.12 MW in 2014
All other RE technologies		€ 218/MWh	€ 115/MWh	

Table 9. FIT remuneration levels for Portuguese mini generation (2014)(“IEA - Portugal” 2016).

Feed-in tariff remuneration levels for minigeneration in 2014			
Renewable source	Total period of time	FIT levels	Capacity
Solar PV	15 years	€ 106/MWh	30.25 MW in 2014
All other RE technologies		€ 159/MWh	

23. The Decree - Law 153/2014 is addressed in the case study (*4.1.2. SELF-CONSUMPTION IN PORTUGAL).*

24. As a recognition of the importance of sustainable development and natural resources preservation, Portugal compiled a document, “Green Growth Commitments” with eleven goals stablishing an energy target for 2030. Goal ten refers to the intention of CO_2 emissions abatement from 87.8 Mt CO_2 in 2005 to 68-72 Mt CO_2 in 2020 and 52.7-61.5 Mt CO_2 in 2030, (contingent on the conclusions of the European negotiations). Particularly related to REs, Goal eleven commits to an Increment of REs share from 25.7% of final energy consumption in 2013 to 31% in 2020 and 40% in 2030.

3. SOLAR ENERGY

As described in *1. INTRODUCTION,* PV uniqueness bestows the best characteristics to warrant SC revolution. Therefore, in order to assess the certainty of being PV one of the major RE resources with the scalability, technological maturity and sustainability to help meeting ever-growing global demand of electricity by means of SC, along this section, a characterization of the state-of the art photovoltaics is summarized and the results of a technological appraisal of five PV mean technologies (sc-Si, mc-Si, a-Si, CdTe and CIGS) are presented.

3.1 Solar technologies characterization

Solar cells are a large area semiconductor diodes. Owing to the photovoltaic effect, energy of light (photons) is converted into electrical current. Light shines onto the n-layer penetrating into the p-n junction, where an electric field is built up leading, if the energy of the photon is sufficient, to the separation of the charge carriers (electrons and holes). The electron is pulled into the n-layer by the positive space charge and the hole to the p-layer. Contact to a solar cell is realized by metal electrodes and when the circuit is closed a direct current flows, causing 0.5V between the contacts. Figure 23 pictures a solar cell with a nominal voltage of 3V by connecting internally six solar cells in series.

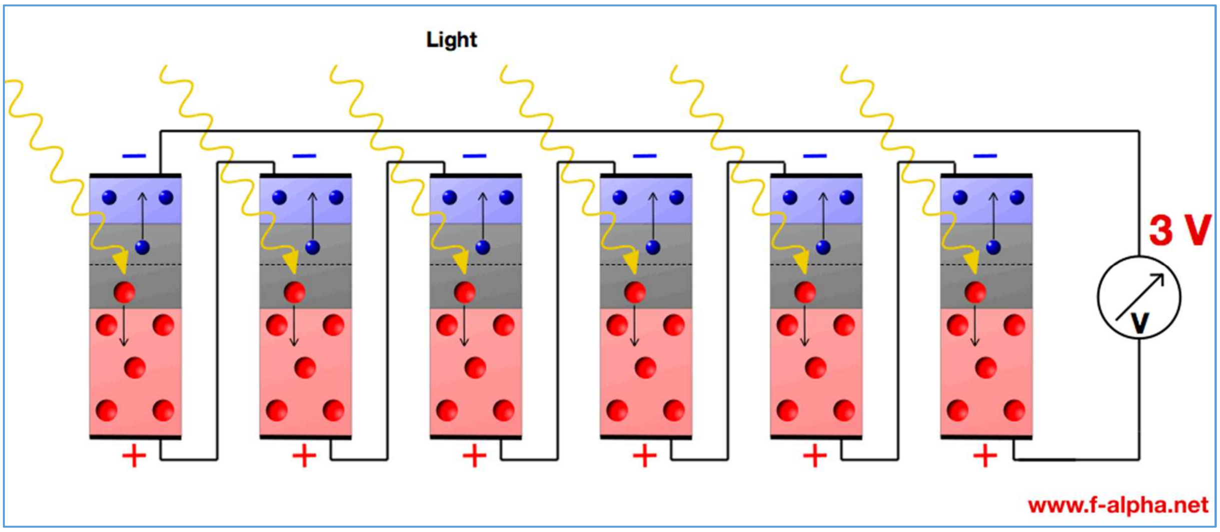


Figure 23. Photovoltaic effect. The blue band corresponds to the n-type, the grey to the n-p junction and the red to the p-type. The light separates the electron-hole pair creating a voltage of 0.5V between contacts (“F-Alpha.net: Experiment 4 - Photovoltaic Effect” 2016).

A number of properties are required for candidate PV materials and device structures. The most essential ones concern optical and electrical conditions (Dimova-Malinovska 2010):

- Strong light absorption over a large spectral range. This property implies that a tunable band gap is desirable. The peak of absorption should be at 1.4–1.5 eV, for optimal efficiency.

- Good carrier collection properties for both, minority and majority carriers, a low carrier recombination loss (in the bulk, at grain boundaries and at the front and back surfaces).

- Stability as functions of both time and illumination conditions (stable active materials, stable metal contacts, and resistance to corrosion).

- High abundance of the source materials (for large-scale production).

- Environmentally sustainable technology.

In 1954 the first solar cells were fabricated and implemented in 1958 on a U.S. Satellite. The technology has progressed enormously since then towards a lower materials use, a higher performance and an improved manufacturability (Jean et al. 2015). Figure 24 summarizes all terrestrial technologies available, distinguishing among their current state of mature/commercialization by color and in annexes each type, sorted according to their nature would be shortly described.

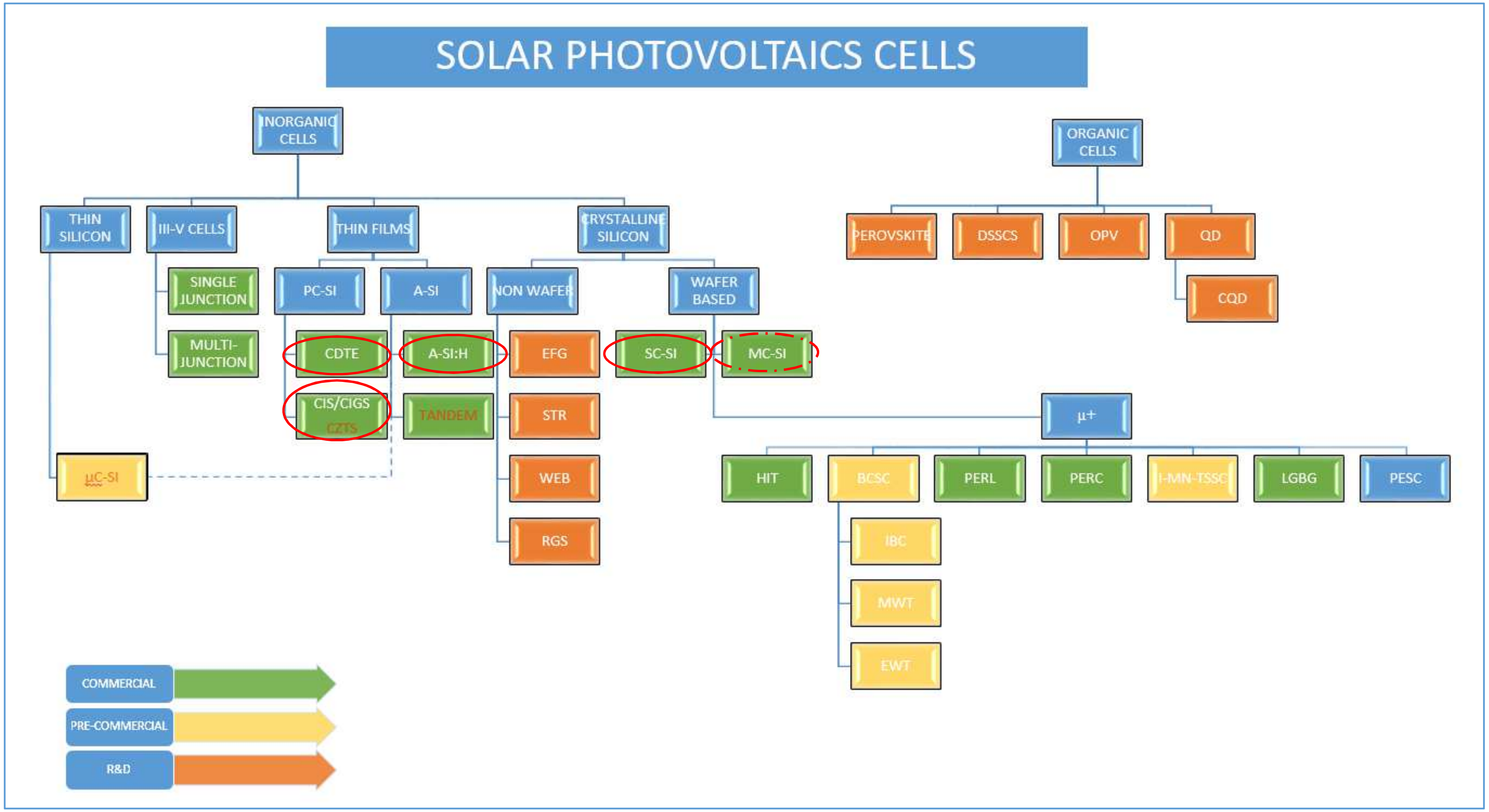


Figure 24. Classification of solar photovoltaics cells according to their nature (Organic and inorganic) A color code is used to associate each technology to its commercial statement. Green represents commercial, yellow pre-commercial and orange research and development. Besides, the technologies assessed are highlighted by a red circle and the solar cell employed in the case study (section 4) is signalized by a dash line.

3.1.1 INORGANIC CELLS

Crystalline silicon (c-si)

Silicon can be manufactured into reliable, non-toxic and efficient solar cells. It represents the most mature of all PV technologies and it represents 90% of the world installed capacity (Hsu et al. 2012), (Turney and Fthenakis 2011). C-Si cells demonstrate a weak light absorption by reason of its indirect band gap, so require thick wafers about 100µm or further light-trapping strategies, rigid, impurity-free and expensive wafers. As a result, new drawbacks and challenges comprehend this technology like limited module form factor, batch-based and expensive cell fabrication with low throughput. Based on the structured of the cells, we can differentiate wafer-based PV and non-wafer based PV.

Wafer-based PV

The cells are manufactured on semiconducting wafers, with no other substrate but frequently protected with glass for mechanical stability. We can classify three different types, high efficiency crystalline silicon (µ+), single-crystalline silicon (sc-Si), representing approx. 35% of the market share of crystalline silicon, and multicrystalline silicon (mc-Si) with a 55% in 2014 (Forstner and others 2015).

Single-Crystalline Silicon (sc-Si/mono-Si)

The panels are made out of cylindrical single crystals (sliced ingots) of the highest grade silicon. This is the reason why the maximum efficiency of these cells is so high: 25% and 27.6% under concentrator ("National Renewable Energy Laboratory (NREL)" 2016).

Multicrystalline silicon (mc-Si)

The blocks are elaborated by casting. Raw silicon is melted and poured into a square mold, which is cooled and cut into perfectly square wafers. As a result the cells are formed by randomly oriented grains of 1cm^2 which efficiency is lower than the preceding, record cell efficiency of 20.8% ("National Renewable Energy Laboratory (NREL)" 2016).

High efficiency crystalline silicon

In order to increase efficiency, cells are subjected to a diversity of process to ameliorate the following crucial aspects (Solanki 2015):

- Photon absorption. The improvement in the absorption which results in high short circuit current density can be achieved in terms of surface texturing, appropriate Anti-reflection coating (ARC) layer and optimized grid pattern for minimum shadowing losses

- Low recombination of generate carriers, which increases open circuit voltage. Further upgrading in cell efficiency can be obtained by enhanced surface passivation at the back and front surface.

- Low resistive losses. The use of vacuum evaporated metal contacts, instead of screen-printed contacts, contributes in reducing shadowing losses and metal contact resistance.

As a result of these developments the following cells have been created. Many of them are not commercial due to cost reasons:

-Passivated emitter solar cells (PESC) using microgrooving as the technique employed to reduce reflection losses instead surface texturing.

-Laser grooved buried grid solar cell (LGBG) uses laser grooving to eliminate the utilization of photolithography and also avoids the use of vacuum evaporated metal contacts.

-Back contact solar cells (BCSC). The gain in efficiency is possible because the thermal oxide layer is applied as a surface passivation layer for both, at the front surface and at the back surface. The whole back contact technology can be categorized into three different technologies, back junction solar cell/ Interdigitated Back-Contact (IBC), metal wrap through solar cell/ Metallization wrap-through (MWT) and emitter wrap through solar cell (EWT) / rear point contact solar cell (RPC).

-Ion-implanted N-Type Silicon Solar Cells (I-MN-TSSC). Ion implantation can produce advanced high-efficiency cell structures with fewer processing steps.

-Passivated emitter and rear contact solar cells distinguishing the passivated emitter and rear cell (PERC) and the passivated emitter and rear locally diffused cell (PERL).

-With regard to reduce interface recombination and increase open-circuit voltages by 5-10%, there is a variant of sc-Si which is the heterojunction with intrinsic thin layer (HIT), merging n-type sc-Si with thin amorphous silicon films.

Non-Wafer-based PV

Non wafer approach offers a cost advantage over the wafer technique, thanks to the elimination of the slicing process, through increased yield in material usage. The manufacturing of String Ribbon solar panels only uses half the amount silicon as monocrystalline manufacturing, by directly growing the final wafer from the silicon melt, using different techniques to confine and stabilize the edges. The most representative are Edge-defined-film-fed-growth (EFG), String Ribbon (STR), Dentritic Web (WEB) and Ribbon Growth on Substrate (RGS) (Solanki 2015).

III (Al, Ga, In) – V (N, P, As, Sb)

Several properties of III-V semiconductors are better than Si; therefore, they are good choice for electronic materials (unfortunately the cost is too high). In reference to Si, these properties are very useful (Solanki 2015):

-The III-V compounds are direct band gap semiconductors having high absorption coefficient; thus, only thin layers are required for complete solar spectrum absorption.

-The band gap of GaAs is very close to the ideal band gap, 1.42 eV, required for high efficiency single junction cell.

-It is possible to alter the crystal composition wherein some of the atoms from group III are replaced by other atoms from group III or group V. This allows change in the band gap and makes them suitable for application in multijunction solar cells. One example of ternary compound is $In_xGa_{1-x}As$, where the fraction x of the Ga atoms is replaced by the In atoms. Other useful ternary compounds are $Al_xGa_{1-x}As$ and $In_xGa_{1-x}P$.

The solar cells made from III-V compound semiconductors, particularly GaAs and InP, provide more radiation hardness (refers to the degradation of cell efficiency due to extra-terrestrial radiation exposure) than Si solar cells.

Single Junction Gallium Arsenide (GaAs)

This cell has attained the highest power conversion efficiency of any material system: 28.8% in lab cells and 24.1% ("National Renewable Energy Laboratory (NREL)" 2016).

Multijunction (MJ)

This type of cells combine two or more single-junction cells to increment its global capacity of light efficiency absorbance across the solar spectrum, since it reduces thermal losses and has diverse band gaps. The elements of the multijunction form high-quality crystalline film, as the number of junctions increases, from 2J cells to 4J cells, so does the performance, achieving 38.8% (5J) and, under concentrated illumination 46% (4J) ("National Renewable Energy Laboratory (NREL)" 2016).

Thin Films

Thin films represented in 2014 the 10% of global PV module production capacity (Forstner and others 2015). Nevertheless it has a potential projection in the long run. PV modules are manufactured on either rigid glass substrates or flexible substrates (thin metallic or plastic foils).

Amorphous Silicon (a-Si)

The amorphous Si (or a-Si) material become an interesting material when it was discovered since its conductivity could be changed. It can be made to p-type and n-type, thus, allowing the formation of a junction. Unfortunately amorphous Si material has a feature of very short range arrangement of Si atoms. Due to this, the material is very defective, but subsequent modifications have improved this fact (Solanki 2015):

Hydrogenated amorphous silicon (a-Si:H)/a-Si)

The material quality of hydrogenated amorphous Si (a-Si:H) is much better than that of pure amorphous Si. Even if lacks long-range periodic ordering of its constituent atoms, it does have local order on an atomic scale directly responsible for the observation of semiconductor properties such an optical absorption edge and an activated electrical conductivity. In 2013, this technology represented 2% of the global market and 22% of the thin-film market (Forstner and others 2015).

A-Si:H faces two major drawbacks which hinder market deployment. It accomplishes low efficiencies (13.4% triple-junction and 12.2% dual-junction) and it suffers from light induced degradation, known by the Staebler-Wronski effect.

Multi-Junction a-Si:H solar cells: Tandem/Double-Junction and Triple-Junction

A solution to obtain cells with a better stability and at least similar absorption as in the case of the conventional single junction solar cells is to stack two or more single junction solar cells with thin intrinsic layers on top of each other. The total thickness of the multi-junction solar cell is similar to a conventional single junction solar cell, but each component cell is thinner and therefore less sensitive to light-induced defects. An additional advantage of a multi-junction cell structure is that each component cell can be tailored to a specific part of the solar spectrum, thereby extending a usable part of the spectrum and increasing the solar cell conversion efficiency.

Polycristalline Silicon (pc-Si)

Polycrystalline Si is a film with grain size in the range of 0.1 µm to about 1 mm. The crystalline volume of the film is typically 100%; it does not have any Si atoms in amorphous phase. It should not be mistaken with mc-Si, as often happens, as the case of the denomination of the solar panel utilized in our study, which is mc-Si.

Cadmium Telluride (CdTe)

With the 56% of the thin market, CdTe constitutes the leading technology and shares the 5% of the total PV market in 2013 (MIT 2016). The efficiencies achieved are the highest among the thin film technology, being 22.1% for cells. The main obstacles of this technology are the scarcity of materials (Tellurium) and toxicity of elemental cadmium.

Copper Indium Gallium Diselenide ($CuIn_xGa_{1-x}Se_2$ or CIGS)

It presents high efficiencies, 21.7% for cells and 17.5% for modules although this technology deals with Indium paucity to develop large scale-up (Jean et al. 2015).

Copper Zinc Tin Sulfide (Cu_2ZnSnS_4 or CZTS)

The record cell efficiency is 12.6% achieved in 2013 due to cation disorder. This effect creates point defects that hinder charge extraction and reduce open-circuit voltage.

Thin Silicon

Thin silicon solar cells is an umbrella term describing a wide variety of silicon photovoltaic device structures utilizing various forms of silicon – monocrystalline, multicrystalline, polycrystalline, microcrystalline and porous – and using several deposition and cell processing techniques (Maria João dos Santos Rodrigues 2009) . Thin silicon solar cells distinctive feature is the thickness of the active layer, which is less than 100 µm, as opposed to wafer-based technology thickness of around 300 µm.

Microcrystalline Silicon (µc-Si)

Microcrystalline thin films are commonly treated in thin-film related literature since it can be considered an extension or outgrowth of amorphous silicon technology. Its best application is as a part of tandem solar cells.

3.1.2 ORGANIC CELLS

Organic Photovoltaics (OPV)

The organic solar cells were first discovered in 1975. The solar cells based on organic semiconductor can provide a low-cost alternative for solar PV. The OPV however, presents low efficiencies due to inefficient exciton[10] transport and stability being 11.5% the maximum efficiency attaint (Green et al. 2015) . With the purpose of eliminating these drawbacks it has been applied and realized with OPV the tandem/multijunction concept.

Dye-Sensitized Solar Cells (DSSCS)

They are photoelectrochemical cells composed out of transparent inorganic scaffold anode (nanoporous TiO_2) sensitized with light-absorbing dye molecules (ruthenium complexes). The strong points of DSSCs are low cost materials, easy assembly and flexible and colorful modules. Nonetheless it has to improve its stability under illumination and high temperatures, reduce absorption in the near-infrared and interfacial recombination which causes low open-circuit voltages (Hagfeldt et al. 2010).

Perovskite Solar Cells

"Perovskites" is the nomenclature for any materials that adopt the same crystal structure as calcium titanate, namely, ABX_3. It has reached 22.1% efficiency, which has made this technology become one of the most promising ones. Like the rest of emerging cells the stability is a crucial point that has to be improved. Also

---

[10] "Combination of an electron and a positive hole (empty electron state in the balance band), which is free to move through a nonmetallic crystal as a unit"("Exciton | Physics | Britannica.com" 2016)

sensitivity to moisture, better control of film morphology and material properties and the use of toxic lead (Snaith 2013).

Quantum dot solar cells (CQD)

The emergence of semiconductor nanocrystals as the building blocks of nanotechnology has opened up new ways to utilize them in solar cells. The three major ways to employ semiconductor dots in solar cell include metal-semiconductor or Schottky junction photovoltaic cell, polymer-semiconductor hybrid solar cell, and quantum dot sensitized solar cell. When the light absorption is executed through solution-processed nanocrystals, the cell formed is known as colloidal quantum dot photovoltaics (CQD) (Solanki 2015).

3.2 Solar technologies efficiencies

Shockley-Queisser limit restricts PV crystalline efficiency to 33.7% for single junction cells operating at standard conditions. As it has revised across all different cell technologies, there are key technological approaches to breakthrough cell efficiency. The metric used to evaluate efficiency is *Power conversion efficiency* (PCE) [% or Wm^{-2}], which compares different cells performances.

The following **Error! Reference source not found.** depicts the evolution of the cell efficiencies along its existence up to the last records harvested. The highest efficiency attaint corresponds to 46% using a four-junction under concentrator (Fraunhofer ISE/Soitec). It is remarkable the meteoric trajectory of perovskite solar cells since its first incorporation into solar cells in 2009, achieving a 22.1% efficiency this year (2016) (“National Renewable Energy Laboratory (NREL)” 2016).

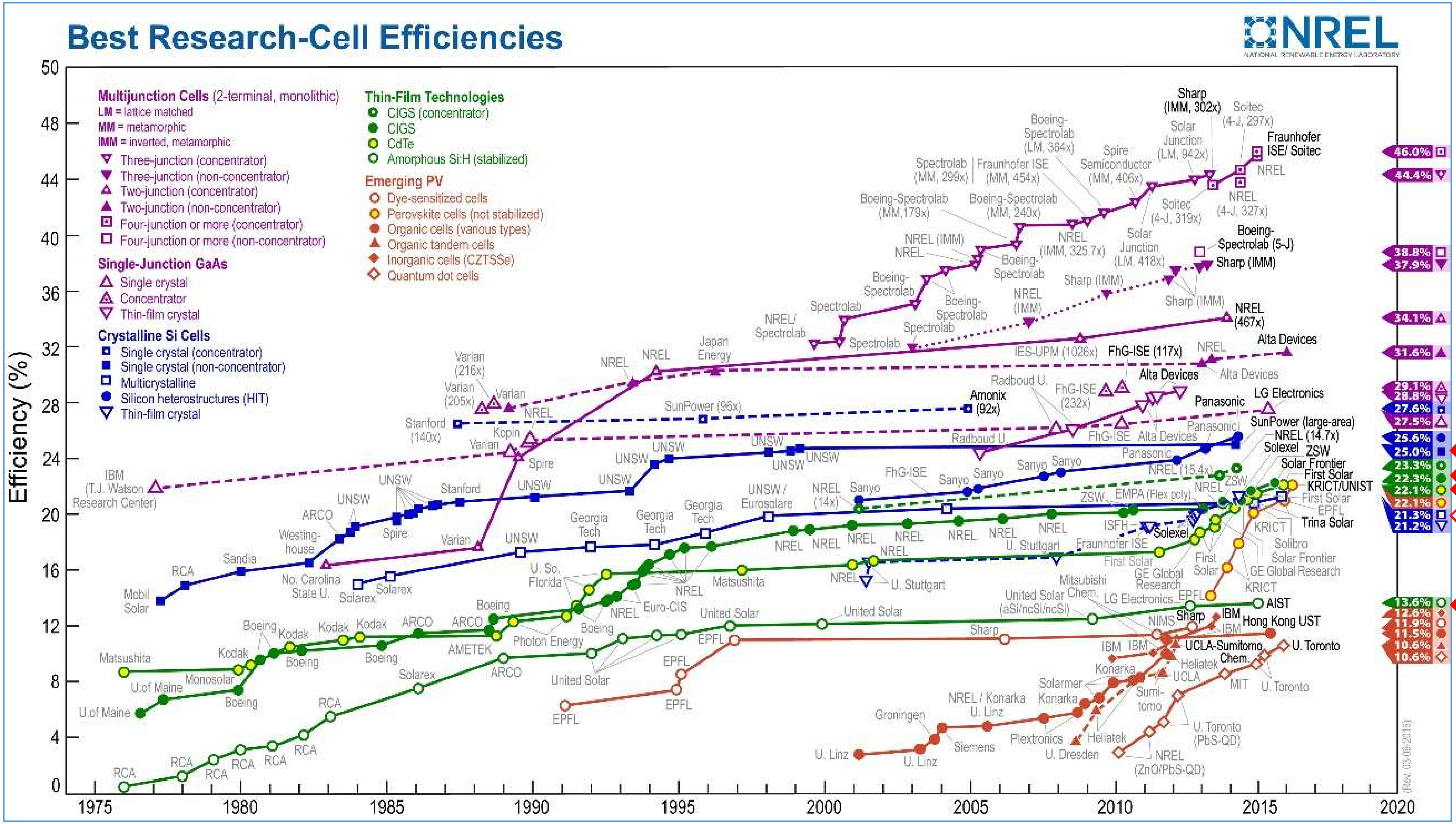


Figure 25. Best Research-Cell Efficiencies ("National Renewable Energy Laboratory (NREL)" 2016). Besides, the technologies assessed are highlighted by a red shaped and filled arrow and the solar cell employed in the case study (section 4) is signalized by a red outline arrow.

3.2 Solar technologies multidisciplinary assessment

The following factors, together with the efficiency performance (covered in the above section *3.2 Solar technologies efficiencies*) are compared and interpreted based on Peng et al. and Jean et al. figures according to a common comparative "code" from 0 to 2, being 2 a better mark than 0. The results, which are summarized in Table 10 and displayed in Figure 26 and Figure 27, are extracted from the PEGE (Project in Engineering and Management) of the author of this master thesis.

- Life cycle assessment (Peng, Lu, and Yang 2013).

- Energy Payback time (EPBT). Years required of a PV system to generate the energy to compensate the consumption over its life cycle (which includes the energy requirement for manufacturing, installation, energy use during operation, and energy needed for decommissioning) (Peng, Lu, and Yang 2013).

- GHG rate. Total GHG emissions of a PV system (including BOS) divided by the generated electricity amount during its life cycle (Peng, Lu, and Yang 2013).

- Critical Material scaling. Total amount of material (Ge, As, Si, Ag, In, Ga, Cu, Cd, Se, Te, Zn, Pb, Sn) required to deploy sufficient solar PV capacity to satisfy 5, 50 or 100% (1.25, 12.5, 25 TW_p) of the 2050 electricity demand predicted by the IEA scenario referred in section *1. INTRODUCTION*, that can be attaint in less than a year (Jean et al. 2015).

- Raw material costs, ($/t) with market prices of 2014 (Jean et al. 2015).

- Material intensity, grams of material per W_p produced (Jean et al. 2015).

- Efficiency performance, covered in the following.

Table 10. PV selected cells coding results of all factors taken into account.

FACTORS	**PV CELLS**				
	sc-Si	**mc-Si**	**a-Si**	**CdTe**	**CIGS**
Efficiency	2	1	0	1	1
Material cost	1	1	1	1,5	1,75
Material Intensity	0	0	1	1	1
Critical Material Scaling	1,34	1,34	2	0,83	0,67
LCA	0	0	2	2	2
EPBT	1	1	0	2	1
GHG emission rate	0	1	1	2	1
TOTAL	5,34	5,34	7	10,33	8,42

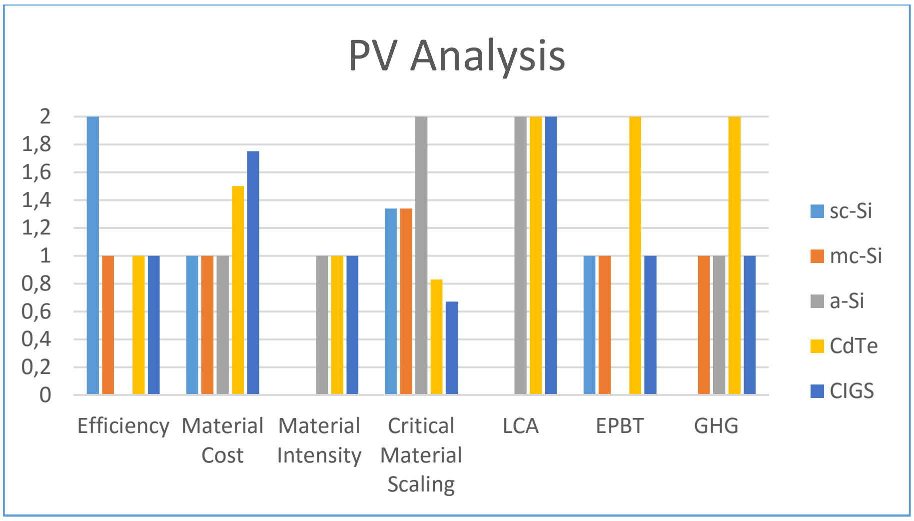


Figure 26. Bar chart depicting in X-axis the 7 factors employed for the analysis and in the Y-axis the numerical results of the five PV technologies selected.

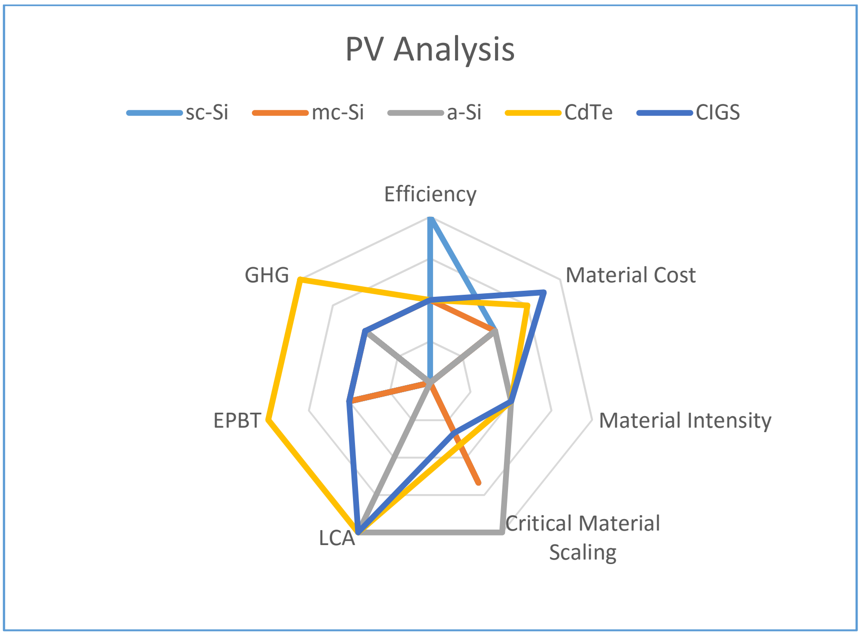


Figure 27. Radial chart depicting the behavior of the PV technologies according to the parameters adopted.

Interpreting the results of this comparative analysis it could be state that:

- Most of the technologies hold reasonably acceptable efficiencies, highlighting the 25% of sc-Si and the particularly low efficiency of a-Si with a limited 13.6%.

- The material intensity of c-Si technologies is higher than thin film materials together with the high price of the Silicon. In contrast, their availability for scaling up to meet future electricity demand is not a hitch. On the other hand, non-Si based thin cells, do have a major obstacle to their deployment: the lack of their essential materials to make the technologies scalable.

The environmental factors, LCA, EPBT and GHG emission rate reveal that two aspects of PV solar cells are indeed significant to determinate their impact: efficiency and intensity of manufacture process (portrayed through material intensity). CdTe is the only technology with the ability of keeping its building process simple without disregarding a good cell performance. The score for c-Si remains low because of its fabrication and material used, and the minor efficiency of a-Si provokes an escalation on its EPBT.

4. CASE STUDY

4.1 Introduction

One of the key defiance SC presents is the level of complementarity or synchronization of the production and demand profiles. This fact is a challenge for SC valorization, since the way the excess energy is counted and remunerated will limit its economic viability.

Generalizing, it could be agreed that for residential sector the major part of the production occur during the hours that home owners are away, devoted to their daily tasks, either at school, work, etc. Therefore, solar SC potential fluctuates between 17 - 44 % of the total solar energy generation.

The demand pattern is dependent on large spectrum of factors that goes from the type of family (adults, kids, elderly, etc.), hourly occupancy (employed, unemployed, studying or not), monthly income (availability to spend money on energy and equipment), size of the house, orientation and location, etc. On the other hand, technical implementation of SC systems, namely solar, will be dependent on available roof or land area, suitability of the orientation of the roof, inclination, solar exposure, etc. In this way, the SC will be maximized if there is an optimal implementation regarding the demand pattern, of course, if other mechanisms as energy storage and active demand management (Luthander et al. 2015) are not taken into account. In this way, the business and service sector buildings will report higher percentages of self-consumed energy, since they are characterized by daily full load profiles (European Commission 2015d).

With the purpose of assessing the segments with the highest adoption potential, defined by the number of adopters and installed capacity, a series of profiles and analyses have been realized in order to furtherly integrating the outcome in the projections of the adoption curves for solar technology in Portugal until 2030. These characterizations comprise demand and production benchmark profiles, which have been multiply crossed and combined in prosumer, imports and exports profiles to subsequently extract rate of investment and payback time of each result. As a necessary preface for this study case, SC legislation further detailed.

4.1.1. SELF-CONSUMPTION IN EUROPE

Nowadays, new business models for renewables are rising since the first step of their deployment and diffusion has been largely accomplished owing to the wide scope of support mechanisms reported in section *2.2.3 EU ENERGY POLICIES.* The current trend for PV is to encourage decentralized SC, sizing PV installations to be adequate for the demand site. In this way, energy exports are discourage, regarding the negative impact on the grid associated with massive RE spill during specific hours. SC is now at its first stage of formative and legislative development, and among EU State Members there is a plethora of regimes.

In Germany, between 2009 and 2012, FIT were progressively replaced by a SC scheme. At the beginning, for roof systems below 500kW, a bonus was granted for self-consumed, while exported energy had lower remuneration in order to prevent overcapacity installations. In the UK, the same system has been implemented, albeit with projects below 50kWp. In due course and owing to solar panels cutback prices, the German premium was just maintained for the generation surplus and from 2016 the capacity was restricted to 100kW. Analogously, Italy underwent the same process until 2013, when the energy generated began competing at wholesale market prices. Wholesale trading for excess production has been adopted as well in Portugal.

It is acknowledged that when SC penetrates up to certain beforehand stipulated limit, current incumbent legislation shall be modify to deal with the distribution, operational and backup grid costs that would be generated by a major RE share which nowadays devolves exclusively upon the regular consumers and prosumers (only while exporting) through the access tariffs.

As of August 2014, German systems above 10kW installed capacity or yearly self-consuming over 10MWh had to remunerate between the 30% and 40% of the Renewable energy act (EEG) apportionment. On the other hand, the Portuguese legislation has enacted a compensation provision if the 30% of the costs of energy policy, sustainability and general economic interest (CIEGS) for the national electric system once SC attaints 1% of national penetration.

The following Table 11 revises the current Eropean National schemes for SC.

Table 11. Overview of National Schemes for SC of RE in Europe in October 2015 (European Commission 2015c) (Jorge Aguirregomezcorta and José Mari 2015)[11]

Member State	Remuneration for self-consumed or surplus electricity sold to the grid	Grid and system cost contribution
Austria	PPA	>25 MWh/y pay 1.5 € cent/kWh on SC electricity
Croatia	PV system <300 kWp, 80% at the FiT rate	Exempted
Denmark	FiT (0.08 €/kWh)	< 50kW: no taxes or PSO charge > 50kW: no RES surcharge
Cyprus	PV system< 500kWp, 5 MW yearly cap (under revision), no compensation	Fixed Network charges: H. Voltage 1,31 € cent/kWh M. Voltage 1,63 € cent/kWh L. Voltage 2,01 € cent/kWh RES levy 0.5 € cent/kWh Public service obligation 0,134€cent/kWh
Germany	< 90% production: applicable FIT or FIP rate > 90% production, either: a) average spot market price for solar energy (4-5 €ct/kWh) b) income from electricity sale (market or PPA) plus management premium of 1.2 €ct/kWh (decreasing to 0.7 €ct /kWh by 2015) PV system > 100 kWp (from 2016): market price	Before 01/08/2014 : exempted. After 01/08/2014 : exempted if < 10 kWp and < 10 MWh/year If >10 kWp or > 10 MWh/y : subject to reduced RES-surcharge: 30% by end 2015 35% by end 2016: 40% by end 2017
Finland	Private purchase agreement (PPA)	<100 kVA or 800.000 kWh, exempted from electricity tax, electricity transfer fee, and VAT - fixed part of the grid charge applies
France	Under discussion	
Italy	<20 MWe: private purchase agreement (PPA)	< 20kW, exempted from grid and system costs 20-200kW partially exempted >200kW exempted only from system costs
Latvia	Regulation still to be adopted	
Malta	Private purchase agreement (PPA)	Exempted
Portugal	Average Iberian electricity market price minus 10%	If SC systems capacity <1% of total power capacity (TPC): SC exempted >1% and <3%, SC pays 30% grid fees, >3%, SC pays 50% grid fees
Spain	Up to 100 kWp, regulation still to be adopted	
Slovakia	Household with voltage level <0.4/0.23kV, connection capacity<16 A No compensation for excess power	Regulations still to be adopted
United Kingdom	PV and wind systems < 50 kWp: generation tariff + export premium of 4.77p £/kWh for up to 50% of excess power fed into the grid > 50 kWp and < 5 MWp : Feed-in-tariff	Exempted

---

[11] PSO: Government subsidy charged to electricity consumers to sponsor RE generation.

4.1.2. SELF-CONSUMPTION IN PORTUGAL

Prosumer figure sprung forth the Decree-law 68/2002, underpinning a local and decentralized archetype of energy generation. From this point, an assortment of regulated regimes succeed one another from microgeneration and minigeneration to SC, mainly promoted through incentive programs based on FITs (*2.3.2. Portuguese Renewable energy and PV specific legislation).*

During 2014, national subsidies for micro and mini generation were rectified and unified into a sole category called small production units (UPP) regulated by the Decree Law 153/2014. UPP facilitates the installation of renewable utilities with a capacity up to 250 kW, and an annual cap limit of 20 MW for grid-connected installations supplanting the remuneration regime heretofore applicable to micro and mini units.

Decree Law 153/2014 also defines the Self-consumption Units (UPAC), where the opportunity of self-consuming and trading the spare energy to the public electricity grid is finally legally conceived.

The essential variation has been the change of paradigm to a more rational maximization of local produced energy, with a more direct and subsidy-free market structure. Besides, the decree safeguards the electric system by a compensation provision once the penetration of SC reaches the 1% of the installed capacity.

The SC program sets up a limit of installed capacity according to the contracted power. Therefore an accurate plant scaling is required to size the system to the yearly demand. The surplus is allocated to the POLR and the price is tabulated to the 90% of the value of the simple arithmetic mean of the OMIE on monthly basis. The reason why 10% is retained, is to compensate for the energy trading costs and the guarantee purchase. The new remuneration mechanism is founded on a bidding model where each generator proposes discounts to a benchmark tariff, which is arranged annually by the authorities depending on the technology utilized. Nevertheless, the former FITs would remain valid for the existing systems during the statutory period (IEA WIND 2014 Annual Report, 2015). SC was *de facto* promulgate in March 2015.

4.2 Self-consumption analysis

4.2.1. DEMAND

To define the demand profiles, four categories have been created corresponding to the main sectors:

- Residential sector, which held the 27% share of the electric national consumption in 2014.

- Tertiary sector of economy encompassing retail and accommodation service (hotels).

- Industrial sector.

For the residential sector, three specific and individualized profiles, extracted from an every-15minutes data during two years of consumption, are representative of a relevant diversity of economic and power purchase types of clients. Given tertiary and industrial sector profiles are the result of a clustering based on the approximate maximum hourly daily average demand (KWh) and the similarities on the hourly average daily pattern obtained from the annual profile data. These models are graphically displayed for each sector. i.e., Residential, Retail, Hotel and Industrial in Figure 28, Figure 29, Figure 30 and Figure 31 respectively. In addition Table 12, Table 13 Table 14 and Table 15 collect the most representative values of each profile within its sector in kWh. i.e., hourly average consumption, annual peak load, total energy demand and the clustering criterion, approximate maximum hourly daily average consumption.

Residential

The selected profiles are below described:

- Demand 1. Couple or 2-member family, there is no consumption during the day corresponding to an outside daily routine (working…) and a peak rises in the evening. Low annually demand.

- Demand 2. Large family composed by a couple and 3 children/teenagers, there is a demand during the day with no relevant energy drop. Yearly consumption is high.

- Demand 3. Four member family unit, comprehending a couple and 2 children. The profile is analogous to Demand 1 with the significance of the use during low tariff periods of electrical appliances and a higher consumption.

Table 12. Residential representative values.

RESIDENTIAL VALUES	Demand1	Demand2	Demand3
Hourly average consumption (kWh)	0.23	1.63	0.63
Annual peak load (kWh)	2.08	4.91	4.73
Total energy demand (kWh)	1968.39	14245.73	5504.62

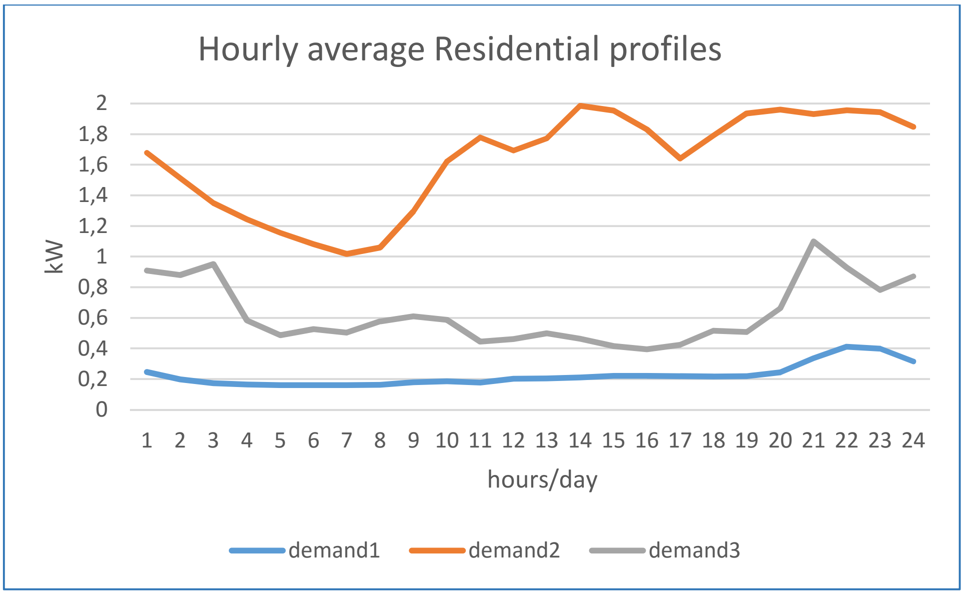


Figure 28. Hourly average Residential profiles. Based on yearly profiles data has been aggregated to create a daily representative profile.

Retail

A priori, it can be anticipated that the SC synchronicity would be better than for the residential case, since the loads are better fit to the solar generation, where there is a constant demand during the working days with night and weekends absence.

Table 13. Retail representative values.

RETAIL VALUES	Retail1	Retail2	Retail3	Retail4
Hourly average consumption (kWh)	25.68	63.90	120.34	202.54
Annual peak load (kWh)	50.25	98.75	199.25	404.75
Total energy demand (kWh)	224953.00	559771.80	1054140.00	1774263.00
Approx. Maximum hourly daily average consumption (kWh)	40.00	80.00	160.00	300.00

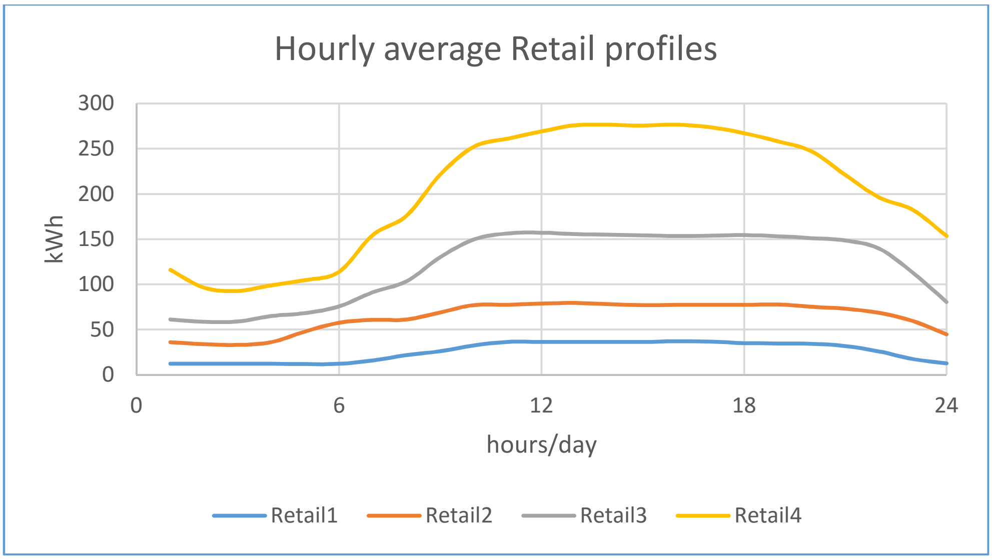


Figure 29. Hourly average Retail profiles. Based on yearly profiles data has been aggregated to create a daily representative profile.

Hotels

The demand follows a diary cycle, perceiving an increase of consumption during weekends and holidays, as supposed for a spare-time service.

- Hotel1: The model is quite irregular and it presents two facets, one full demand during the whole day and night with occasional lower demand and alternatively, there is another with two evening peaks with low demand between them and empty at night and low demand between the peak.

- Hotel2 and Hotel3: Peak at night and in the morning and medium demand between them.

Table 14. Hotel representative values.

HOTEL VALUES	Hotel1	Hotel2	Hotel3
Hourly average consumption (kWh)	3.42	12.63	33.90
Annual peak load (kWh)	21.50	22.44	69.06
Total energy demand (kWh)	29947.44	110655.10	296980.50
Approx. Maximum hourly daily average consumption (kWh)	6.00	16.00	50.00

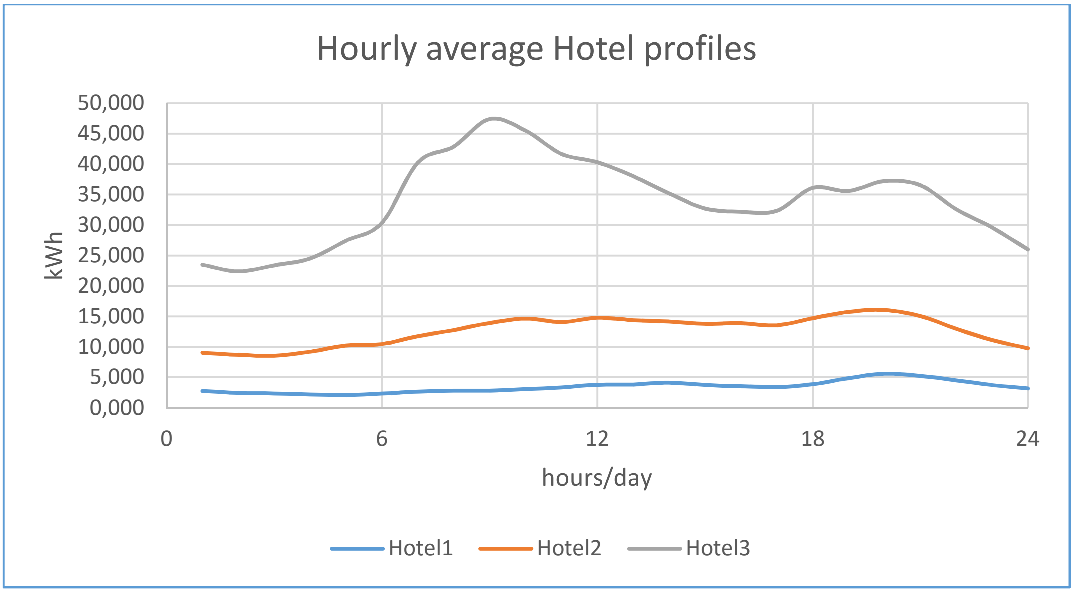


Figure 30. Hourly average Hotel profiles. Based on yearly profiles data has been aggregated to create a daily representative profile.

Industry

Industry could be the sector where aggregation is more difficult to epitomize. Generally, Industry retains a weekly profile, during working days, where the utilization is regular and very low during weekends.

- Industry 1, 2, and 3: Manufactory working at regular demand during the day, with almost no demand during night and weekends.

- Industry 4: Profile attributable to a 24/7 industry with uninterrupted demand but Sundays.

Table 15. Industrial representative values.

INDUSTRIAL VALUES	Industry1	Industry2	Industry3	Industry4
Hourly average consumption (kWh)	62.02	279.36	702.72	3371.32
Annual peak load (kWh)	320.00	484.56	1360.63	6230.00
Total energy demand (kWh)	543322.66	2447211.19	6155839.38	29532717.60
Hourly average daily consumption (kWh)	1500.00	6700.00	1700.00	80000.00

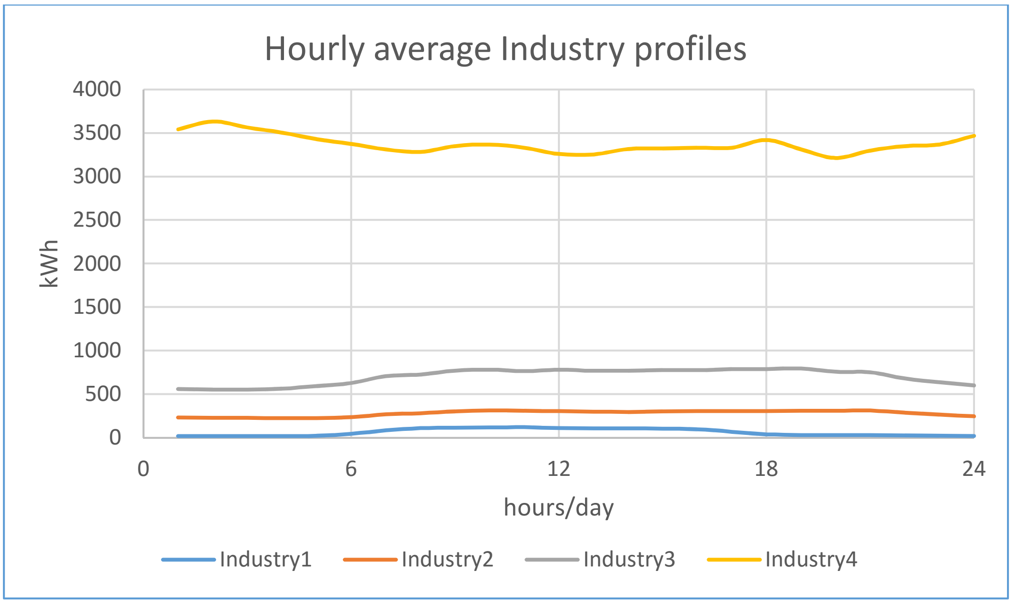


Figure 31. Hourly average Industrial profiles. Based on yearly profiles data has been aggregated to create a daily representative profile.

4.2.2. PRODUCTION PROFILES

The production profiles have been built with the PV software *PVSYST V5.54.* The type of solar panel employed has been a 250W polycrystalline (referred as multi-crystalline panel in *section 3. SOLAR ENERGY)*; built by the manufacturer *SolarWorld AG* being the model *Sunmodule Plus SW 250 poly.* The efficiency per module area is 15.18%.

The choice of sc-Si panels owes to the unrestrictive are basis, Portuguese mild climate (which allows to operate with practically all commercial technologies available) and a moderate budget assumption (sc-Si is more affordable than mono-Si).

The simulation encompasses a wide range of capacities, from low residential demand to massive industries. Hence it has been utilized two types of inverters. A microinverter of 250W (Inverter´s brand: *Enphase* and model *M250-60-208-S22/S24*) and a bigger inverter of 20kW (*Brand: Steca and model StecaGrid 20000).*

Twenty seven PV production profiles per inverter (fifty four in total) have been therefore created, in regard to:

- Three different locations: Lisbon, Porto and Faro with the following global horizontal irradiation (GHI) depicted in Table 16 (PVGIS Photovoltaic Software 2016)

Table 16. Global horizontal irradiation of Lisbon, Porto and Faro (Wh/m^2/day)

PORTUGUESE REPRESENTATIVE CITIES	GHI (Wh/m2/day)
Lisbon	4840
Porto	4680
Faro	5300

- Three PV panels’ inclinations, 10°, 20°, 30°

- Three PV panels' orientations: South (S), Southwest (SW), Southeast (SE).

The hourly based power (kW) results were exclusively calculated at the inverter output.

4.2.3. SENSITIVITY ANALYSIS OF THE PROSUMER PROFILE: Techno-economic Prosumer analysis

In order to evaluate the potential successful can be the implementation of SC in Portugal a techno-economic prosumer analysis has been performed. Demand and generation profiles are compared with each other to determine exportation and SC profiles. For residential and Hotel1, 0.25kW inverter profiles are employed whilst for Retail, Industry, Hotel2 and Hotel3, 20kW inverter. The techno-economic assessment takes into account the valorization of the exported and self-consumed energy whose costs are described in this section. The scenario presumed has a SC penetration lower than 1%, to avoid grid compensation as disposed in the legislation (*4.1.2. SELF-CONSUMPTION IN PORTUGAL).* In pursuance of the execution of this study, an excel tool has been implemented offering the possibility of automatizing the prosumer creation by coupling production and consumption profiles and selecting the appropriate electric tariff.

Noteworthy, the scope of the generation profiles is not limited to the normal optimal tilt and azimuths (30° and South respectively), since in many cases the operation of the PV installations are dependent on available area, orientation and angle of roofs. These restrictions may lead to different profiles of solar production for SC systems.

Therefore, even if *a priori* the object of this report is to exemplify which would be the ideal production profile and capacity installed for each demand real characterization, by virtue of the designed excel tool, the economic impact and relevant energy indicators of the different orientations, inclinations, installed capacity and electricity tariffs can be obtained.

Methodology: Economic and energetic indicators to represent PV Performance

Economic indicators

PV SC is installed by several types of market players, arraying from residential clients to large-scale project developers and facilities. Each sector usually employs a different economic performance metric to represent PV value because normally they are looking for different returns from a PV investment and, diverse metrics regularly exhibit dissimilar price threshold for the profitability of the PV investment. In addition, several project parameters might have a relevant impact on some metrics and almost none on others.

For instance, a residential PV system may engender an internal rate of return (IRR) greater than 40% and an analogous commercial project a payback time (PBT) longer than 12 years. So the same project could have a high or low return on investment depending on PV prices and revenues for each market segment.

In essence, the election of the economic performance indicators by each prosumer sector can quite shape the customer's perception of PV investment value and eventually their adoption decision. For this investigation the following economic performance metrics are utilized:

Internal Rate of Return

Net Present Value (NPV)

The NPV has to be defined previous to introduce the IRR. The NPV represents the net profit generated by an investment, calculated from the discounted sum of future costs and revenues.

$$NPV = \sum_{t=0}^{N} \frac{Revenue_t - Cost_t}{(1+d)^t} = 0 \tag{1}$$

The IRR is the discount rate at which the present net present value (NPV) equals zero and is commonly interpreted as the annualized return on investment. IRR is useful for comparing the returns on two or more investment opportunities(Easan Drury and Robert Margolis 2011).

$$IRR: NPV = \sum_{t=0}^{N} \frac{Revenue_t - Cost_t}{(1+IRR)^t} = 0 \tag{2}$$

N: number of years for the economic analysis (25 years)

t: year variable in each summation

d: discount/nominal rate: calculated with the electricity inflation and the solar panels aging values (see in following section *Non-Price Parameters*).

$Revenue_t$: revenue generated by the SC system in year t.

$Cost_t$: cost of the system in year t

Time-to-net-positive-cash-flow (TNP) Payback time

Payback time is the length required for the PV SC investment to pay for itself through solar energy savings. The energy bill savings from solar represent an avoided cost, and therefore gives money back to the prosumer, as revenue.

$$PBT = \sum_{t=TNP\ Payback}^{N} \frac{Revenue_t - Cost_t}{(1+d)^t} > 0 \tag{3}$$

Energetic indicators

Energetic indicators such as Self-consumed energy (% total demand) and energy surplus (%production) are strategical in the making and developing of the *smart grid*. They provide the characterization required to optimize DSM, storage and assure optimum reliability to the grid.

PV Economic Performance

Sizing Criteria

One of the most relevant decisions is to attribute correctly the optimum installed capacity for each demand profile. Apart from the simulated 0.25kW and 20kW inverters, it is employed a 10kW model (divisor from the 20kW inverter). It has been created an optimization criteria/metrics (Table 17) which is applied to the Lisboa30S of each profile in order to create a homogeneous base of calculous.

Table 17. Optimization criteria for the correct number of inverters according to each demand profile

Metrics	Residential	Retail	Hotels	Industry
PBT (years)	<13	<7	<7	<7
Energy surplus (%)	<10	<20	<10	<20
IRR (%)	Better IRR for 25 years			

Therefore, the installed capacity of each prosumer profile is the integer multiple of 0.25kW, 10kW and 20kW which has the best IRR and PBT maintaining the Energy surplus under the above mentioned values.

The figures have been provided by the company *Green Egg, Sustainability Solutions,* being employed as reference values for their calculations.

The PBT of residential is assumed to be longer than for the other demand profiles given the impossibility to opt with reduce consumption for an economy of scale.

The maximum energy surplus accepted varies depending on the project dimensions. For substantial demands, as it is typically the case of retail and industry more energy excess is accepted because any production-consumption mismatching can account for a massive feed back into the grid and therefore a higher percentage. Anyhow, 20% of energy exported would be the limit, and indeed, since its valorization is not lucrative, the less the better.

Parameters of influence

Particular project parameters, which are adopted according to demand profiles, impact PV economic performance. In this analysis, is evaluated how PV prices, non-price project parameters, and business models may have consequences on PV economics and how these influences vary depending on the use of different economic performance metrics.

PV Prices

PV project investment expenditure per unit of capacity (€/$Wp_{installed}$) is principally driven by installation size and type. Large SC projects are significantly cheaper per unit of installed capacity than smaller ones, based on unavoidable fixed costs, generating an economy of scale. As a result a monetary factor is applied to calculate the investment per W_{peak} installed as presented in Table 18.

Table 18. Summary of the monetary factor per $Wp_{installed}$ depending on the range of installed capacity (kW)

Monetary factor €/Wp installed	Range of Installed Capacity, IC, (Kw)
2.0	IC < 1.5
1.7	1.5 ≤ IC < 5
1.5	5 ≤ IC < 20
1.2	20 ≤ IC < 100
1.1	100 ≤ IC < 150
1.0	150 ≤ IC

The PV prices could be also affected by state and local incentives which in some experiences target specific market segments. In the Portuguese Prosumer study is not the case.

Non-Price Parameters

Besides the investment in the system installation, various project parameters influence SC PV economics as:

Yearly electricity bill inflation

The projected annual increase in electricity rates is notoriously difficult to predict. Nonetheless, there is some certainty about the rise of electricity prices in the coming years:

- Increase of wholesale or/and instable prices of gas and oil used for electricity generation, as they are sourced from many conflicted locations (Middle East).

- Increase of the share of RE by the replacement of the existing generation capacity and maintaining incentives.

- Tariff deficit growing interests.

- Need to fund energy efficiency improvements to reduce CO_2 emissions.

As a result, it is estimated a 2.8% of electricity price annual increase.

Aging of the solar panels

The aging of the solar panels affects performance. The rated power output of polycrystalline solar panels employed is considerate that degrades at about 0.8%/year.

Aging rate and electricity inflation are calculated on the original principal only. Accumulated rate from each year is not used in calculations for the following periods.

Special taxes

The European Energy Taxation Directive 2003/96 (Dr. Dörte Fouquet, Jana Viktoria Nysten 2015) came into force in 2003, setting a minimum level of taxation for energy products. The European Commission, together with the European Central Bank and The International Monetary Fund, applying the Portuguese Bailout program, imposed to enact this directive by the Special electricity consumption tax (IEC) through the law 64-B/2011. All suppliers were obligated to charge 0,001€/kWh to all clients but the social tariff holders (ERSE 2012).

Electricity rate

To assess accurately the annual energy savings for the prosumer is necessary to fully itemize and resolve which would be the most likely energy tariff or tariffs to be assigned to each demand profile constituting one of the most relevant parts for the execution of this survey. Hourly PV generation monetization accounts for the seasonal and daily variations in electricity value based on electricity prices in wholesale markets or different retail electricity rate structures as the one implemented here, which is the time-of-use rate based on time of day and season. Other options might be available like demand-based/ time-based rates formed on peak customer power use, or tiered rates based on total energy use. Intervening factors on the electricity rate and how this is adjusted to each scenario, are described next.

1. Energy supplier

As the market is liberalized, each SC unit must embrace a certain operator. In the case of the study the tariff EDP updated the 5th of November 2015, "*casa com débido direito*" ("Preços de Referência No Mercado Liberalizado de Energia Eléctrica E Gás Natural Em Portugal Continental." 2015) for LV is selected. Medium voltage prices, are always negotiated with the energy provider, therefore tailored depending on consumption. In this particular case, rates are gleaned from a *Green Egg, Sustainability Solutions* real industrial case. For retail calculous 5% over the active energy price is exercised, since it is presumed that the higher is the use, a better deal is obtained.

For special low voltage, as real data is not accessible, the transitory active energy price available online ("Tarifas de Baixa Tensão Especial" 2016) is adapted by reducing 10% its price. In August 2012, the Portuguese authorities announced the complete elimination of regulated tariffs. Due to this fact, a transitory tariff, which introduces an aggravation factor with a view to promoting switching, is placed being revised by ERSE on a trimester basis (European Comission 2014). Only for the transitory regime there is a complementary classification based on the number of hours consumed during full metering. For SLV there is a medium utilization regime (300h of full pricing/month) and a long utilization regime (500h full pricing/month) (ERSE 2016b). Medium usage is applied for the calculation.

2. Within each Voltage contracted, it can be found time-based pricing, varying the rate depending on the time of the day when the energy is provided:

- Simple or Single (S) rate. It charges at one single price and can't offer off-peak electricity. It is the only one available for extremely reduce demand residential customers (from 1.15 to 2.3 kVA contracted power). In any case, consumptions up to 20,7kVA could also choose it.

- Bi-Hourly rate (B). Exclusively available for contracted power between 3.45kVA and 20.7kVA. It is composed by peak and off-peak periods (Table 19).

- Tri-hourly rate. Employed by LV clients from 27.6 to 41.4 kVA. It consists of Off-peak, full and peak terms (Table

20).

- To conclude, tetra-hourly rate (Super-Off-peak, Off-peak, full and peak) is applicable for Special and MV (Table 21).

Table 19. Bi-Hourly rate in weekly cycle distribution (“Portal ERSE - Períodos Horários” 2016).

	BI-HOURLY RATE							
	Working Days		Saturday				Sunday	
			Winter		Summer			
off-peak	0:00	7:00	13:00	18:30	14:00	20:00	0:00	0:00
			22:00	9:30	22:00	9:00		
peak	7:00	0:00	9:30	13:00	9:00	14:00		
			18:30	22:00	20:00	22:00		

Table 20. Tri-Hourly rate in weekly cycle distribution (“Portal ERSE - Períodos Horários” 2016)

	TRI-HOURLY RATE									
	Working Days				Saturday				Sunday	
	Winter		Summer		Winter		Summer			
off-peak	0:00	7:00	0:00	7:00					0:00	0:00
peak	7:00	12:00	9:15	12:15						
	18:30	21:00								
full	7:00	9:30	7:00	9:15	9:30	13:00	9:00	14:00		
	12:00	18:30	12:15	0:00	18:30	22:00	20:00	22:00		
	21:00	0:00								

Table 21. Tetra-Hourly rate in weekly cycle distribution (“Portal ERSE - Períodos Horários” 2016).

	TETRA-HOURLY RATE									
	Working Days				Saturday				Sunday	
	Winter		Summer		Winter		Summer			
off-peak	0:30	2:00	0:30	2:00	0:00	3:00	0:00	3:30	0:00	4:00
					7:00	10:30	7:30	10:00	8:00	0:00
	6:00	7:30	6:00	7:30	12:30	17:30	13:30	19:30		
					22:30	0:00	23:00	0:00		
peak	17:00	22:00	14:00	17:00						
full	0:00	0:30	0:00	0:30	10:30	12:30	0:00	13:30		
	7:30	17:00	7:30	14:00	17:30	22:30	19:30	23:00		
	22:00	0:00	17:00	0:00						
super off-peak	2:00	6:00	2:00	6:00	3:00	7:00	3:30	7:30	4:00	8:00

Time of Day tariff is performed to cut down consumption of electricity during peak hours. To do this, electricity prices are raised during peak hours so that consumers have lower demand. As it is depicted, higher loads entail a higher hourly discretization. The more discretized is a tariff throughout the day, the more feasible is for prosumers to actively manage their demand, being translated in an improvement of the cost-effectiveness of the installation by switching demand to a time when prices are lower or by using efficient appliances. Besides, utilities in some countries (USA, (U.S. Department of Energy. 2015)) run initiatives called Demand Side Management (DSM) to administer and modify customers' electricity consumption through offering discounts on energy efficient appliances, helping clients in electricity consumption monitoring and also educating them on saving electricity.

Plus, there are two cycles to be involved in the definition of the hourly periods. In the *Diary cycle* there is not distinction among the days of the week and the seasons. The *Week cycle,* which is the model preferred for the production-demand affinity, is defined by the distinction of three categories, i.e., working days, Saturdays and Sundays and two legal timing periods, i.e., summer and winter. Summer is defined by the time term from the last Sunday of March, being for the year culled for the research (2015) the 25th, to the last Sunday of October, the 25th. Winter, in consequence, comprehends the rest. The season of the year affects the timing of the tariff application and only for MV also the price, being slightly lower during Summer time. A synopsis of the retail prices is depicted in Table 22.

Table 22. Summary of the total retail prices for energy ("Preços de Referência No Mercado Liberalizado de Energia Eléctrica E Gás Natural Em Portugal Continental." 2015)

Rates	**LV_S**	**LV_B**	**LV_T**	**SLV**	**MV**	
					Winter	Summer
Peak		0.1853 €/kWh	0.2817 €/kWh	0.2002 €/kWh	0.1075 €/kWh	0.1072 €/kWh
Full	0.1555 €/kWh		0.1415 €/kWh	0.1192 €/kWh	0.0958 €/kWh	0.0955 €/kWh
Off-peak		0.0978 €/kWh	0.0975 €/kWh	0.0823 €/kWh	0.0725 €/kWh	0.0724 €/kWh
Super off-peak				0.0723 €/kWh	0.0660 €/kWh	0.0662 €/kWh

3. Apart from the regular tariff, it can be find an extraordinary peak contracted charge (Table 23) only for relevant loads, which exclude LV.

In order to apply this levy, the monthly hours and pertinent peak power have to be calculated.

Table 23. Extraordinary peak fee for SLV and MLV ("Portal ERSE - Tarifas de Acesso às Redes Em 2015" 2016).

	SLV	**MV**	
		Winter	Summer
Peak contracted	0.5684€/kWday	0.2337€/kWday	

3. Contracted voltage and energy load determines the active energy price and the access tariff.

Low voltage (LV) contains two power bands, first one, below 20.7 kVA, and a second one to a limit of 41.4kVA. From this value to approximately 100kVA, special low voltage (SLV) would be regularly adopted, but there is not a restriction. From 100kVA on, normally Medium voltage (MV) would be selected. In the case of this study no High voltage regime has been endorsed.

Under *Green Egg, Sustainability Solutions* recommendation, contracted voltage under 3.45KVA has been precluded due to the fact that the majority of the corresponding costumers benefit from the social tariff[12], which is not considered in this study now that their lack of investment capacity to embrace SC. In addition, it has been taken into consideration the tendency of residential customers to oversize their contracted energy load, in this manner, demand2 and demand3 are evaluated under 5.75kVA and 6.9kVA contracted energy load.

The max hourly demand (kWh) from each consumption category is rendered in

Table *25*, being the value used to determine each demand´s profile contracted voltage and energy load as limned in Table 24.

Table 24. Summary of the demand profiles contracted voltage, energy load (KVA) and type of hourly tariff ("Preços de Referência No Mercado Liberalizado de Energia Eléctrica E Gás Natural Em Portugal Continental." 2015)

Demand	Contracted Voltage	Contracted Energy Load (KVA)	Type of Hourly Tariff
demand1	LV<=20.7KVA	3.45	S
demand2/3		5.75	S-B
		6.9	
Hotel1/2	LV>20.7KVA	27.6	T
Hotel3/Retail I	SLV	SLV	TT
Retail II/III/IV - Industry I/II/III/IV	MV	MV	TT

Table 25. Summary of max consumption (kW) used to determine the contracted voltage and energy load.

Type of Demand		Max consumption	
Residential	Demand1	2.0827	kWh
	Demand2	4.906	kWh
	Demand3	4.729	kWh
Hotel	Hotel1	21.500	kWh
	Hotel2	22.438	kWh
	Hotel3	69.063	kWh
Industry	Industry1	320.000	kWh
	Industry2	484.563	kWh
	Industry3	1360.625	kWh
	Industry4	6230.000	kWh
Retail	Retail1	50.250	kWh
	Retail2	98.750	kWh
	Retail3	199.250	kWh
	Retail4	404.750	kWh

---

[12] Electricity social tariff is a public reduced tariff intended to ensure electricity access to people in risk of economic exclusion ("Descontos Sociais de Eletricidade" 2016)

COMPOSITION OF THE ELECTRICITY VALUE

The final fee to be paid for the client consists of the two main components addition; the energy itself whose price is determined by the wholesale market, and the access tariff who in turn has another two items; the grid access rates, which are regulated by ERSE, and the CIEGS. Each client, according to its contracted power is subjected to different proportionality of each of these terms as pictured in Figure 32 (ERSE 2016a).

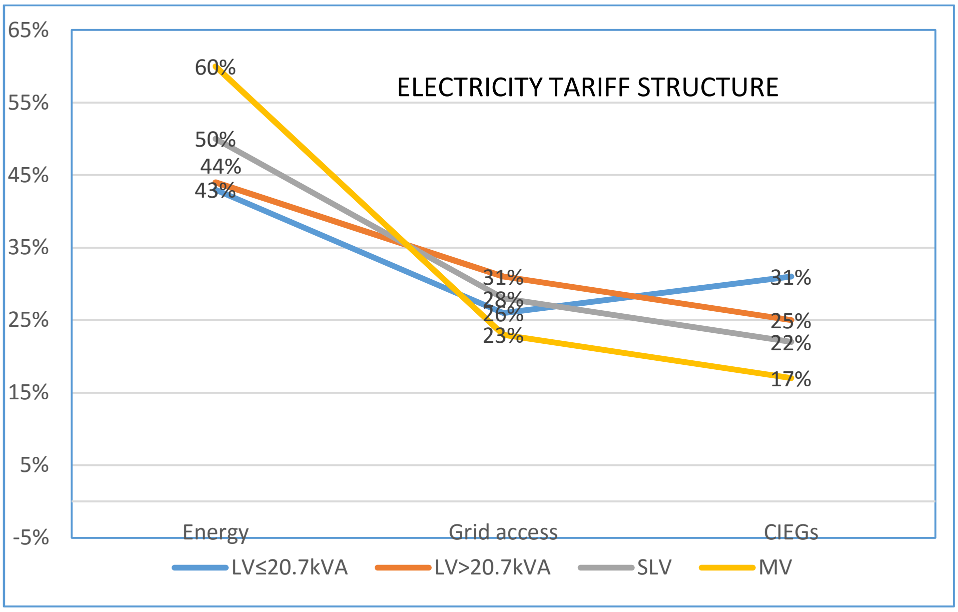


Figure 32. Electricity tariff structure composition depends on the contracted voltage for 2013 (ERSE 2016a).

Higher voltages pay more for energy than for access and taxes compared to lower voltages on the grounds that there are some fraction from the grid access and the CIEGs from which are exempted, as it is explained subsequently. Grid access and CIEGS are subdivided in the fields portrayed in Figure 33 and Figure 34.

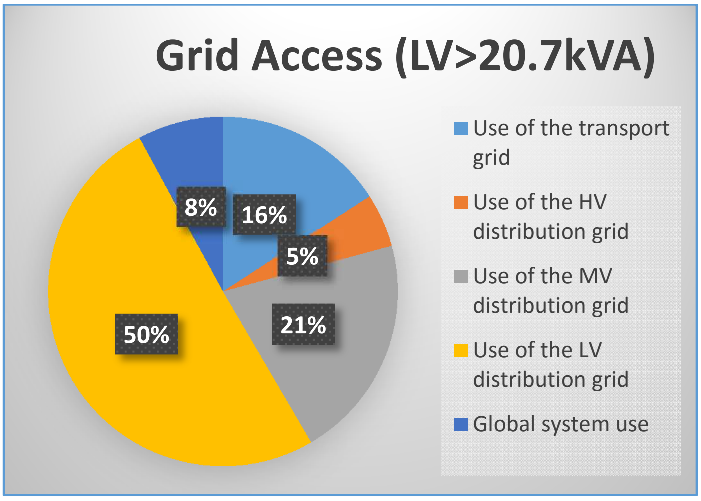


Figure 33. Grid Access divisions from LV>20.7kVA contracted, 2013 (ERSE 2016a)

- Medium Voltage, logically is not operated under LV distribution grids, therefore is exonerated from this charge.

- Rent payment to municipalities is issued to compensate population for the use of hydric resources and the crossing of electric power transmission and distribution lines. Medium voltage is redeemed from this levy.

- Additional cost owing to Especial regime (RE) is exclusively taxed to residential clients because for voltages higher than 20.7kVA fades. It comprises small hydro, wind energy, PV, biomass, biogas, wave energy and urban waste.

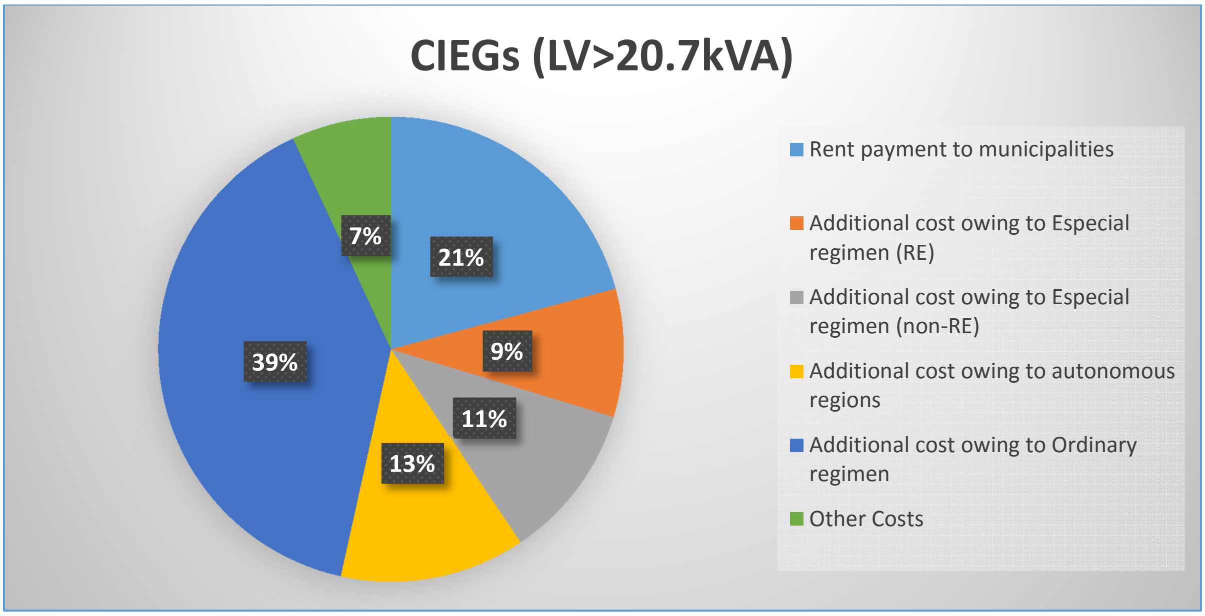


Figure 34. CIEGs divisions from LV>20.7kVA contracted, 201, (ERSE 2016a).

- Additional cost owing to Especial regime is related to CHP.

- Additional cost owing to autonomous regions subsumes the energy transport and distribution to the Azores and Madeira archipelagos.

- Additional cost owing to Ordinary regime consist of the budget overrun from future contracts and capacity markets related to thermic and hydric power plants.

- In Other costs are included tariff deficit payment interest, last resort supplier costs adjustment.

As previously reported, for the energy fed into the grid, which corresponds to the production surplus, the 90% of the value of the simple arithmetic mean of the OMIE on 2014/15 monthly basis has been employed as portrayed in Table 26.

Table 26. Value of the simple arithmetic mean of the OMIE on 2014/15 monthly basis and price of SC surplus (90%)("Inicio | OMIE" 2016)

Months	OMIE Tariff 2014	OMIE Tariff 2015	90%
January		0.05182 €	0.04664 €
February		0.04257 €	0.03831 €
March		0.04322 €	0.03890 €
April	0.02636 €		0.02372 €
May	0.04247 €		0.03822 €
June	0.05119 €		0.04607 €
July	0.04827 €		0.04344 €
August	0.04991 €		0.04492 €
September	0.05891 €		0.05302 €
October	0.05539 €		0.04985 €
November	0.04696 €		0.04226 €
December	0.04769 €		0.04292 €

There are several additional parameters that impact PV economic performance which are beyond the scope of this analysis and are not explicitly assessed in this study in order to simplify calculations and create a homogenous market sectorial benchmark. These include Property tax, or local/state taxes and some financial parameters such as:

- Deposit: First payment made by the potential SC customer during the onset of the purchase of the installation. The rest of the price would be pay through installments.

- Loan duration: Investment loan extension.

- Loan interest rate.

- Discount rate: The rate used to depreciate future PV dividends and costs into an equivalent present value.

Loan interest and discount rate are normally calculate to cancel each other to avert introducing a time value of money to debt-financed capital.

Business Models

Historically, the majority of PV adopters have bought and maintained their own PV system and regained project costs using the savings achieved by their installation. Notwithstanding, innovative business models have appeared with different ownership structures, which can impact economic performance as PPA and solar leases revised in section *2.2.4 ENERGY MARKET EVOLUTION: DRIVERS.* For instance, PV costs and revenues can be taxed and financed differently for third-party or for customer owned PV systems and also might depend on the higher risk of investment based on the nature of the installation, whether is industrial, residential or commercial. For the study, traditional business model, most likely to be adopted in the country, was the one used.

Results

The results are visually supported by the following tables:

Table 27 collects the breaking capacity/mean power consumption and breaking capacity/ mean power consumption ratios under irradiation. Regularly, demand is higher under irradiation excepting the highlighted profiles and better results are achieved when ratios are over one, as it is the case of the accommodation and retail sector and Demand2 (LV_B) which study case gives the best outcome among the residential ones. Higher ratios under irradiation are translated into larger SC% so direct economic benefits on the prosumer.

Table 27. Breaking capacity-mean power consumption/-mean power consumption under irradiation ratios

DEMANDS	RATIOS	
	Breaking capacity/Mean Power consumption	Breaking capacity/Mean Power consumption under irradiation
Demand1	1.11	1.24
Demand2 (LV_S)	0.92	0.86
Demand2 (LV_B)	1.23	1.15
Demand3	0.40	0.53
Hotel1	1.46	1.39
Hotel2	1.58	1.39
Hotel3	1.18	1.04
Retail1	1.95	1.45
Retail2	1.72	1.44
Retail3	1.66	1.31
Retail4	1.78	1.35
Industry1	0.32	0.22
Industry2	0.72	0.66
Industry3	0.60	0.54
Industry4	0.41	0.42

In Table 28, Table 29, Table 30 and Table 31 is presented a summary of results (at the optimized installed capacity) of each sector benchmark and location. A bicolor (green and red) gradual color scale conditional formatting has been applied to depict, from the highest to the lowest value, the results.

Table 32, Table 33, Table 34 and Table 35 , display the summary of the best PV economic and energetic indicator results by exercising the optimization criteria for each demand division and location. The first-rate outcome within each city is highlighted. It has been observed a correlation among PBT, IRR and SC energy results, i.e., the best economic figures correspond to the highest SC %. Normally it also coincides with highest surplus percentage (black font color), in which case, it is not the most favorable outcome, since it is translated into potential grid disturbances (if the SC solar penetration rises) and little monetization. The green font means that there is another orientation/tilt within each demand profile which hold the highest value; e.g. Hotel 1 surplus production in all locations present higher figures for SW compared to the best economically energy self- consumed performing orientation, S.

Red font it has been used to highlight the change of orientation for the optimum PBT and IRR depending on the location (Porto) and tariff (SLV). In Hotel3 and Retail1 Lisbon and Faro share the same orientation for the best IRR (SW), although the maximum value for the self-consumed energy (S) coincides with the optimum economic and energetic indicators or Porto.

Under the information colophon it is compiled the information about the tariff, the power of each inverter, the total installed capacity (breaking capacity) and annual mean power consumption and mean power consumption under irradiation.

Table 38 summarizes the maximum and minimum hourly consumption, the average yearly consumption, global or under irradiation; the average for a summer and winter which has been exemplified by the August and December hourly average respectively and a group of ratios. The most relevant ratios for this study have been:

- Max/min ratio which assess the degree of homogeneity of demand.
- Average consumption under irradiation/yearly consumption, to assess the structure of the consumption along the day.
- Summer/winter ratio.

Broadly, some common aspects to all profiles are the following:

- Due to the economy of scale, normally, larger installations obtain better economic performance, with the exception of extremely favorable tariffs as SLV. On the contrary, energy indicators achieve the lowest figures.

- Climatically, Faro (in the south of Portugal) is characterized for sunnier and milder weather, therefore it possess favorable conditions for PV deployment and therefore would obtain better results than Lisbon and Porto.

- It can be anticipated that the optimum tilt would be 30, since it is closer to Portuguese latitude and the optimum orientation south, unless the consumption profile subjugates it to a specific constant morning (SE) or evening (SW) load.

- Even if the special tariff obtain from the transitory regime was reduced in order to better adequate to theoretically real one, the results when operation under its pricing are very good. The value which is responsible for such as *rara avis* is the levy for peak hours (Table 23), which in SLV is 2.42 times higher than the MLV. Peak hours generally corresponds with solar production, therefore the bill savings would be really high for Retail 1 and Hotel 3.

- Higher discretization between same prosumer profiles as demonstrated in Demand 2 and 3 implies better results because provides the opportunity to manage more efficiently households' loads.

- Apart from the Location, which is the factor with the highest impact on the economic and energetic indicators, it is the orientation, rather than the inclination (except 10^{o}) the aspect more relevant for a better performance. Generally, the hierarchical choice in the absence of a bias demand profile (higher consumption during mornings or evenings) would be S-30 and S-20.

- It is important to mention and reflect upon the self-consumed percentage in each sector to prospectively be able to find solutions to satisfy higher demand by means of complementary RES-E or/and storage, implying higher installed capacity. Retail sector presents the highest self-consumed percentage, reaching numbers over 30%, followed by the accommodation sector. In the case of the domestic sector, owing to low demand and deeply uncoupled prosumer profiles, self-consumed energy decreases to 6-20%. In Industrial sector, Self-consumed percentages show truly low figures, barely surpassing the 10% and sometimes presenting higher percentages of exported energy owing to large Max consumption/min consumption ratios and small Summer/Winter ratios.

The particularities for each demand stratum are subsequently introduced:

Residential

Only simple and bi-hourly tariff are assigned for residential demands, being bi-hourly rates more financially successful owing to discretization.

Demand1

The consumption of Demand1 is so minimal (average of 225W), that only the smallest possible installed capacity has been calculated (250W), which reveals an inability of sizing properly the installation, an smaller inverter would perform better. As a result, it holds the highest surplus among the residential profiles, 7.11% (Faro 30S) and the worst economic indicator of all demand profiles, IRR 6.85% (Porto 10SW) and PBT 9 years.

Demand2

Demand2 holds the better economic and energetic figures out of the residential profiles, IRR 17.7%, 5 years of PBT and 22.93% of SC energy. (Faro 30S). Tariff applied is not to be underestimated, since it can also modify the optimum installed capacity (for better economic performance) i.e. the installed capacity of LV_S is 1.5kW and 2kW for LV_B.

Demand3

The installed capacity is for first time evidently lower than the mean power consumption (installed capacity 250W vs 628W mean consumption) entailing *quasi* no energy fed into the grid (max of 0.25%). It has the same installed capacity as Demand1, but almost a three times larger mean demand. This event reflects the extremely asymmetry between production and demand. Table 38 asserts this uncoupling, where demand under irradiation is still lower than the average and consumption during the summer period diminishes down to one third.

Nevertheless, given that this family type are actively managing their loads to make them coincide with the off-peak tariff, it could be presumed that under the SC regimen, this family would fit their consumption to their generation via programmable devices or consciously *in-situ* adjusted demand and, as a result they could increase their installed capacity.

In the case of an inflexible load management, some kind of energy storage would be recommended.

Hotels

Hotel1

Hotel1 profile is not homogeneous along the year, daily load presents unevenness as referred under the section *4.2.1. DEMAND (Hotels),* plus the demand requested is the smallest among the hospitality benchmark, resulting into inevitable greater fixed cost. Therefore, financially is the most unattractive, but still better than the residential sector due to the same reason, size and a continual demand during weekdays and weekends.

Hotel2&Hotel3

The best economic score derives from Hotel3, holding the highest demand among this category, having ten times more mean power demand than Hotel1 and almost four than Hotel2.

Hotel3 together with Retail1 presents an interesting phenomena: different optimum orientations (based on IRR values) depending on the location. For both cases SW orientation is preferred for Lisbon and Faro while S for Porto. At the same time in all cases, SC % is higher at S, and the energy excess larger at SW. So, even though SC% is larger at S, which shall imply a higher IRR (avoiding energy purchase), and energy exports higher at SW (which could be translated in less SC energy% and under-pricing energy selling), SW shows better IRR. This outcome is built exclusively on the production timing and tariffs. Notwithstanding SC% amount of energy is not that high, it matches with the highly profitable peak periods.

Likewise, Hotel3 has an SLV tariff, which as aforementioned, receives high peak pricing. This tariff is significant for the economic indicators outcome: as it happens within Hotel3 different locations and orietations (S-SW), Hotel2 has significant greater% SC in every location than Hotel3, from 31.34% (Faro 30S-Hotel2) to 24.38% (Faro 30S-Hotel3).

In order to evaluate how decisive SLV tariff is, Table 36 pictures a comparative between Hotel2 and Hotel3 with both tariffs, LV_T and SLV. The best SLV IRR of Hotel2, 26.62% (PBT 3years) remains still lower than the 27.68% reached by Hotel3, even though differences are greatly reduced.

The conclusive factor which gives better results to Hotel3 rather than Hotel2 is the gap between surplus productions. Whilst in all Hotel3 scenarios exports prevails below 1%, in Hotel2 reach 4.95% (Faro 30S). This increase on installed capacity investment and low exports remuneration are the complementary reasons of this lower profitability.

Retail

Retail1

As addressed in *Hotel2* section, this profile shows different optimum orientations depending on the location. Economically, SW orientation is preferred for Lisbon and Faro while S orientation remains the most favorable for

SC%. As realized with the SLV of the accommodation sector, it has been also evaluated how Retail1 would perform under the LV_T tariff (Table 37). Once the tariff is changed to LV_T, peak contracted charge disappears. The leading profile is not anymore the one which maximizes the peak hours coupling (SW), but the one which reports a larger percentage of self-consumed energy (S), obtaining the highest value of SC% among all sectors, 39,14% (Faro 30S).

Retail2,3&4

These profiles are introduced grouped because in essence they have the same consumption tariff (MV), uniform pattern, with low max/min ratios (Table 38) which fits with daily production excluding weekends. The only difference is capacity, increasing gradually: 110kW (Retail2), 200kW (Retail3) and 360kW (Retail4). Accordingly, their economic and energetic indicators are similar, fluctuating between worst case scenario, IRR 14% (Retail2, Porto 10SE) and SC% 26.43% (Retail3, Porto 10SW) to best case scenario IRR 21.50% (Retail3, Faro 30S) and SC% 35.75% (Retail4, Faro 30S). Their installed capacity/mean Power consumption (under irradiation or yearly) also are quite similar (Table 27), with a lower ratio under irradiation, therefore larger serf consumed energy.

Industry

As expected, Industry4 offers the better outcome due to the weekend coupling. It could be surmised that with a regular daily demand which could be supplied in a high percentage by SC and almost no BOS owing to big installations economy of scale, the results should be among the best ones, but is not the case. The SC% is really low, between 4.51% (Industry1, Porto 10SW) and 13.42% (Industry2, Faro 30S). Industry1 and Industry 4 present larger values of exported energy, being the highest 14.52% (Industry 1 Lisbon 30S), which is almost three times greater than its SC% (5.74%).

Industry1

As previously remarked, Industry1 has the smallest SC% and breaking capacity-mean power consumption ratio among the global study and simultaneously the highest exported energy. The prosumer synchronicity is indeed adverse as a consequence of the disparity between the maximum and the minimum consumption, portrayed on Table 38 and the displacement of demand towards winter, whose average consumption is more than the triple.

Industry2,3&4

These industries gather the greatest dissymmetries between max and min demand, up to a ratio of 272 as represented on Table 38 (Industry3), fact that provokes real difficulties on the installation sizing appraisal.

Table 28. Summary of the results (at the optimized installed capacity) of each residential benchmark and location. A bicolor (green and red) gradual color scale conditional formatting has been applied to depict, from the highest to the lowest value, the results.

					LISBOA				PORTO				FARO			
Demand	Information		Tilt	Orientation	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)
Demand1	Tariff:	LV_S	30	S	8	8.74%	17.62%	5.01%	8	8.33%	17.19%	5.13%	7	11.22%	20.00%	7.11%
			20		8	8.56%	17.45%	4.54%	8	8.10%	16.99%	4.41%	7	11.05%	19.84%	6.41%
			10		8	7.95%	16.91%	3.73%	9	7.40%	16.39%	3.45%	7	10.46%	19.26%	5.26%
	Inverter Power(kW):	0.25	30	SW	8	7.76%	16.84%	4.47%	9	7.07%	16.18%	4.37%	7	9.96%	18.89%	6.30%
			20		8	7.82%	16.87%	4.02%	9	7.14%	16.22%	3.77%	7	10.09%	19.00%	5.71%
	Nº of inverters:	1	10		8	7.53%	16.58%	3.42%	9	6.85%	15.95%	3.12%	7	9.91%	18.78%	4.85%
			30	SE	8	8.10%	16.88%	4.90%	8	7.90%	16.69%	4.68%	7	10.83%	19.41%	6.80%
	Breaking capacity(kW):	0.25	20		8	8.07%	16.90%	4.32%	8	7.75%	16.61%	4.00%	7	10.75%	19.41%	6.03%
			10		8	7.65%	16.59%	3.59%	9	7.19%	16.17%	3.21%	7	10.28%	19.02%	5.02%
Demand2	Tariff:	LV_S	30	S	7	12.21%	15.07%	2.22%	7	11.87%	14.79%	1.81%	6	15.15%	17.53%	2.04%
			20		7	11.99%	14.89%	2.02%	7	11.55%	14.53%	1.63%	6	14.89%	17.29%	1.88%
			10		7	11.28%	14.34%	1.78%	7	10.73%	13.91%	1.41%	6	14.12%	16.62%	1.67%
	Inverter Power(kW):	0.25	30	SW	7	11.18%	14.37%	1.92%	7	10.52%	13.84%	1.59%	6	13.74%	16.46%	1.75%
			20		7	11.19%	14.34%	1.81%	7	10.51%	13.81%	1.47%	6	13.81%	16.46%	1.68%
	Nº of inverters:	6	10		7	10.82%	14.03%	1.68%	7	10.14%	13.50%	1.34%	6	13.50%	16.15%	1.57%
			30	SE	7	11.53%	14.44%	2.17%	7	11.35%	14.29%	1.80%	6	14.67%	16.95%	2.11%
	Breaking capacity(kW):	1.5	20		7	11.45%	14.39%	1.96%	7	11.13%	14.15%	1.60%	6	14.50%	16.84%	1.89%
			10		7	10.96%	14.05%	1.73%	7	10.49%	13.70%	1.38%	6	13.89%	16.37%	1.65%
	Tariff:	LV_B	30	S	6	14.00%	19.80%	3.66%	6	13.56%	19.42%	3.27%	5	17.17%	22.93%	3.90%
			20		6	13.76%	19.59%	3.31%	6	13.24%	19.12%	2.90%	5	16.88%	22.65%	3.57%
			10		6	13.04%	18.91%	2.84%	7	12.41%	18.35%	2.45%	5	16.05%	21.83%	3.11%
	Inverter Power(kW):	0.25	30	SW	6	13.05%	18.94%	3.07%	7	12.26%	18.24%	2.73%	5	15.83%	21.62%	3.25%
			20		6	13.03%	18.92%	2.88%	7	12.24%	18.21%	2.52%	5	15.84%	21.64%	3.08%
	Nº of inverters:	8	10		6	12.61%	18.53%	2.61%	7	11.84%	17.84%	2.25%	6	15.45%	21.25%	2.85%
			30	SE	6	13.17%	18.93%	3.77%	7	12.26%	18.75%	3.37%	5	16.49%	22.11%	4.24%
	Breaking capacity(kW):	2	20		6	13.12%	18.93%	3.32%	7	12.24%	18.62%	2.88%	5	16.35%	22.03%	3.72%
			10		6	12.66%	18.53%	2.81%	7	11.84%	18.07%	2.41%	5	15.75%	21.49%	3.14%
Demand3	Tariff:	LV_S	30	S	8	9.42%	6.60%	0.16%	8	9.03%	6.44%	0.19%	7	12.22%	7.65%	0.25%
			20		8	9.19%	6.51%	0.11%	8	8.70%	6.32%	0.13%	7	11.96%	7.54%	0.16%
			10		8	8.47%	6.25%	0.05%	8	7.88%	6.04%	0.06%	7	11.20%	7.24%	0.08%
	Inverter Power(kW):	0.25	30	SW	8	8.38%	6.28%	0.05%	8	7.67%	6.02%	0.10%	7	10.85%	7.17%	0.11%
			20		8	8.38%	6.26%	0.03%	8	7.67%	6.00%	0.06%	7	10.91%	7.17%	0.08%
	Nº of inverters:	1	10		8	8.01%	6.11%	0.02%	9	7.29%	5.86%	0.03%	7	10.60%	7.03%	0.05%
			30	SE	8	8.77%	6.31%	0.14%	8	8.53%	6.23%	0.16%	7	11.78%	7.40%	0.21%
	Breaking capacity(kW):	0.25	20		8	8.66%	6.29%	0.09%	8	8.30%	6.16%	0.10%	7	11.60%	7.35%	0.14%
			10		8	8.15%	6.13%	0.05%	8	7.64%	5.95%	0.06%	7	10.99%	7.13%	0.07%
	Tariff:	LV_B	30	S	7	11.17%	6.60%	0.16%	7	10.69%	6.44%	0.19%	6	14.14%	7.65%	0.25%
			20		7	10.93%	6.51%	0.11%	7	10.36%	6.32%	0.13%	6	13.84%	7.54%	0.16%
			10		7	10.20%	6.25%	0.05%	8	9.54%	6.04%	0.06%	6	13.05%	7.24%	0.08%
	Inverter Power(kW):	0.25	30	SW	7	10.23%	6.28%	0.05%	8	9.41%	6.02%	0.10%	6	12.84%	7.17%	0.11%
			20		7	10.20%	6.26%	0.03%	8	9.38%	6.00%	0.06%	6	12.84%	7.17%	0.08%
	Nº of inverters:	1	10		7	9.78%	6.11%	0.02%	8	8.97%	5.86%	0.03%	6	12.47%	7.03%	0.05%
			30	SE	7	10.37%	6.31%	0.14%	7	10.09%	6.23%	0.16%	6	13.52%	7.40%	0.21%
	Breaking capacity(kW):	0.25	20		7	10.30%	6.29%	0.09%	7	9.89%	6.16%	0.10%	6	13.36%	7.35%	0.14%
			10		7	9.83%	6.13%	0.05%	8	9.26%	5.95%	0.06%	6	12.77%	7.13%	0.07%

Table 29. Summary of the results (at the optimized installed capacity) of each accommodation benchmark and location. A bicolor (green and red) gradual color scale conditional formatting has been applied to depict, from the highest to the lowest value, the results

					LISBOA				PORTO				FARO			
Demand	Information		Tilt	Orientation	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)
Hotel1	Tariff:	**LV_T**	30	S	6	14.43%	22.83%	6.65%	6	14.02%	22.42%	6.14%	5	17.41%	26.07%	8.19%
			20		6	14.16%	22.53%	6.53%	6	13.67%	22.04%	5.92%	5	17.09%	25.69%	8.09%
			10		6	13.46%	21.78%	5.96%	6	12.87%	21.20%	5.30%	5	16.29%	24.79%	7.51%
	Inverter Power(kW):	0.25	30	SW	6	12.62%	21.52%	7.43%	7	11.96%	20.80%	6.78%	6	15.26%	24.24%	8.82%
			20		6	12.88%	21.56%	6.94%	7	12.20%	20.84%	6.24%	6	15.55%	24.34%	8.38%
	Nº of inverters:	20	10		6	12.77%	21.25%	6.11%	7	12.07%	20.54%	5.42%	6	15.47%	24.05%	7.58%
			30	SE	6	14.10%	21.95%	6.25%	6	13.84%	21.76%	5.75%	5	17.11%	25.18%	8.34%
	Breaking capacity(kW):	5	20		6	13.92%	21.91%	5.95%	6	13.54%	21.58%	5.39%	5	16.89%	25.10%	7.83%
			10		6	13.33%	21.45%	5.48%	6	12.80%	20.96%	4.89%	5	16.22%	24.51%	7.16%
Hotel2	Tariff:	**LV_T**	30	S	4	20.46%	27.86%	3.73%	5	19.49%	26.69%	3.75%	4	23.57%	31.34%	4.95%
			20		4	20.19%	27.57%	3.34%	5	19.13%	26.31%	3.25%	4	23.22%	30.96%	4.59%
			10		5	19.37%	26.65%	2.76%	5	18.22%	25.29%	2.62%	4	22.29%	29.90%	3.93%
	Inverter Power(kW):	20	30	SW	5	18.49%	26.54%	3.53%	6	17.25%	24.98%	3.51%	4	21.08%	29.38%	4.82%
			20		5	18.77%	26.55%	3.18%	6	17.51%	25.01%	3.07%	4	21.44%	29.49%	4.38%
	Nº of inverters:	1	10		5	18.61%	26.07%	2.65%	6	17.34%	24.56%	2.51%	4	21.33%	29.08%	3.76%
			30	SE	4	20.10%	26.77%	3.38%	5	19.33%	25.92%	3.30%	4	23.33%	30.40%	4.69%
	Breaking capacity(kW):	20	20		4	19.89%	26.73%	3.04%	5	18.98%	25.72%	2.86%	4	23.03%	30.27%	4.28%
			10		5	19.19%	26.16%	2.56%	5	18.13%	24.96%	2.38%	4	22.18%	29.51%	3.72%
Hotel3	Tariff:	**SLV**	30	S	4	24.53%	21.45%	0.60%	4	23.31%	20.54%	0.63%	3	27.52%	24.38%	0.80%
			20		4	24.27%	21.15%	0.54%	4	22.97%	20.16%	0.55%	3	27.22%	24.02%	0.72%
			10		4	23.40%	20.34%	0.44%	4	22.03%	19.28%	0.42%	3	26.26%	23.06%	0.60%
	Inverter Power(kW):	20	30	SW	4	24.87%	20.36%	0.73%	4	23.26%	19.16%	0.74%	3	27.68%	22.79%	0.99%
			20		4	24.46%	20.32%	0.61%	4	22.88%	19.12%	0.61%	3	27.26%	22.80%	0.83%
	Nº of inverters:	2	10		4	23.49%	19.87%	0.46%	4	21.97%	18.70%	0.43%	3	26.26%	22.38%	0.64%
			30	SE	4	21.57%	20.58%	0.33%	4	20.70%	19.92%	0.31%	4	24.43%	23.68%	0.42%
	Breaking capacity(kW):	40	20		4	22.19%	20.48%	0.35%	4	21.14%	19.67%	0.33%	4	25.07%	23.46%	0.46%
			10		4	22.30%	19.95%	0.34%	4	21.07%	19.00%	0.31%	4	25.15%	22.74%	0.47%

Table 30. Summary of the results (at the optimized installed capacity) of each retail benchmark and location. A bicolor (green and red) gradual color scale conditional formatting has been applied to depict, from the highest to the lowest value, the results

					LISBOA				PORTO				FARO			
Demand	Information		Tilt	Orientation	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)
Retail1	Tariff:	**SLV**	30	S	4	24.16%	34.73%	2.56%	4	23.05%	33.39%	2.21%	3	27.01%	39.14%	3.60%
			20		4	23.92%	34.26%	2.47%	4	22.72%	32.83%	1.96%	3	26.70%	38.57%	3.48%
			10		4	23.12%	33.06%	2.02%	4	21.85%	31.51%	1.49%	3	25.83%	37.19%	2.95%
	Inverter Power(kW):	10	30	SW	4	24.36%	33.16%	2.12%	4	22.93%	31.32%	1.77%	3	27.02%	36.92%	2.87%
			20		4	24.05%	33.11%	1.95%	4	22.61%	31.28%	1.55%	3	26.69%	36.94%	2.75%
	Nº of inverters:	5	10		4	23.20%	32.43%	1.66%	4	21.79%	30.64%	1.25%	3	25.82%	36.26%	2.53%
			30	SE	4	21.31%	33.09%	3.02%	4	20.50%	32.22%	2.38%	4	23.99%	37.61%	4.27%
	Breaking capacity(kW):	50	20		4	21.93%	33.05%	2.64%	4	20.96%	31.97%	1.94%	4	24.65%	37.48%	3.73%
			10		4	22.08%	32.39%	2.05%	4	20.92%	31.04%	1.42%	4	24.77%	36.62%	2.99%
Retail2	Tariff:	**MV**	30	S	5	16.61%	30.90%	1.94%	6	15.66%	29.64%	1.82%	5	19.10%	34.86%	2.89%
			20		5	16.40%	30.58%	1.54%	6	15.37%	29.21%	1.36%	5	18.85%	34.48%	2.42%
			10		6	15.68%	29.52%	1.05%	6	14.56%	28.02%	0.92%	5	18.08%	33.26%	1.83%
	Inverter Power(kW):	10	30	SW	5	16.28%	29.51%	1.49%	6	15.02%	27.79%	1.42%	5	18.51%	32.83%	2.32%
			20		5	16.12%	29.49%	1.22%	6	14.86%	27.78%	1.12%	5	18.37%	32.91%	2.00%
	Nº of inverters:	11	10		6	15.52%	28.90%	0.88%	6	14.27%	27.22%	0.79%	5	17.80%	32.36%	1.62%
			30	SE	6	14.90%	29.60%	1.87%	6	14.19%	28.72%	1.59%	5	17.43%	33.70%	2.97%
	Breaking capacity(kW):	110	20		6	15.17%	29.58%	1.43%	6	14.32%	28.49%	1.16%	5	17.68%	33.62%	2.34%
			10		5	15.01%	28.95%	0.98%	6	14.00%	27.62%	0.79%	5	17.46%	32.80%	1.72%
Retail3	Tariff:	**MV**	30	S	5	18.80%	30.17%	0.83%	5	17.80%	28.90%	0.87%	4	21.50%	34.19%	1.36%
			20		5	18.57%	29.84%	0.50%	5	17.48%	28.43%	0.54%	4	21.24%	33.79%	0.96%
			10		5	17.79%	28.74%	0.23%	5	16.61%	27.23%	0.27%	4	20.38%	32.52%	0.60%
	Inverter Power(kW):	20	30	SW	5	18.51%	28.77%	0.51%	5	17.16%	27.06%	0.59%	4	20.94%	32.14%	0.96%
			20		5	18.30%	28.74%	0.32%	5	16.96%	27.02%	0.40%	4	20.76%	32.19%	0.72%
	Nº of inverters:	10	10		5	17.62%	28.11%	0.16%	5	16.31%	26.43%	0.21%	4	20.10%	31.61%	0.48%
			30	SE	5	16.98%	28.94%	0.64%	5	16.22%	27.99%	0.66%	4	19.71%	33.15%	1.14%
	Breaking capacity(kW):	200	20		5	17.25%	28.87%	0.38%	5	16.34%	27.72%	0.42%	4	19.96%	32.97%	0.81%
			10		5	17.07%	28.18%	0.17%	5	16.00%	26.82%	0.21%	5	19.70%	32.06%	0.51%
Retail4	Tariff:	**MV**	30	S	5	18.60%	31.71%	2.55%	5	17.62%	30.44%	2.38%	4	21.22%	35.75%	3.57%
			20		5	18.42%	31.52%	1.74%	5	17.35%	30.11%	1.53%	4	21.02%	35.55%	2.59%
			10		5	17.68%	30.51%	0.99%	5	16.52%	28.95%	0.87%	4	20.24%	34.43%	1.62%
	Inverter Power(kW):	20	30	SW	5	18.33%	30.39%	1.75%	5	17.01%	28.66%	1.59%	4	20.71%	33.84%	2.52%
			20		5	18.17%	30.47%	1.18%	5	16.85%	28.71%	1.06%	4	20.58%	34.04%	1.84%
	Nº of inverters:	18	10		5	17.53%	29.89%	0.75%	5	16.23%	28.14%	0.69%	4	19.97%	33.53%	1.31%
			30	SE	5	16.79%	30.42%	2.34%	5	16.06%	29.48%	2.19%	5	19.44%	34.64%	3.43%
	Breaking capacity(kW):	360	20		5	17.11%	30.50%	1.58%	5	16.23%	29.36%	1.38%	5	19.75%	34.69%	2.43%
			10		5	16.97%	29.91%	0.93%	5	15.92%	28.52%	0.82%	5	19.56%	33.93%	1.56%

Table 31. Summary of the results (at the optimized installed capacity) of each industrial benchmark and location. A bicolor (green and red) gradual color scale conditional formatting has been applied to depict, from the highest to the lowest value, the results

					LISBOA				PORTO				FARO			
Demand	Information		Tilt	Orientation	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)
Industry1	Tariff:	**MV**	30	S	6	13.12%	5.08%	13.90%	7	12.21%	4.85%	14.12%	6	15.51%	5.74%	14.52%
			20		6	12.90%	5.03%	13.51%	7	11.94%	4.79%	13.51%	6	15.25%	5.67%	14.20%
			10		7	12.24%	4.87%	12.77%	7	11.22%	4.63%	12.54%	3	14.52%	5.48%	13.53%
	Inverter Power(kW):	20	30	SW	6	12.71%	4.83%	13.76%	7	11.54%	4.56%	13.58%	3	14.85%	5.38%	14.40%
			20		6	12.57%	4.85%	13.28%	7	11.41%	4.57%	13.01%	3	14.74%	5.41%	13.94%
	Nº of inverters:	1	10		7	12.06%	4.77%	12.56%	7	10.92%	4.51%	12.21%	3	14.22%	5.34%	13.30%
			30	SE	7	11.66%	4.87%	13.74%	7	10.97%	4.70%	13.95%	4	14.11%	5.56%	14.38%
	Breaking capacity(kW):	20	20		7	11.85%	4.87%	13.23%	7	11.05%	4.68%	13.22%	4	14.25%	5.55%	13.93%
			10		7	11.66%	4.78%	12.56%	7	10.74%	4.57%	12.28%	4	13.99%	5.42%	13.29%
Industry2	Tariff:	**MV**	30	S	5	17.43%	11.86%	9.21%	5	16.46%	11.34%	9.37%	4	20.07%	13.42%	9.85%
			20		5	17.18%	11.73%	8.94%	5	16.15%	11.18%	8.92%	5	19.77%	13.24%	9.60%
			10		5	16.45%	11.33%	8.40%	6	15.36%	10.77%	8.16%	5	18.95%	12.78%	9.04%
	Inverter Power(kW):	20	30	SW	5	16.99%	11.26%	9.30%	5	15.71%	10.60%	9.31%	5	19.35%	12.54%	9.99%
			20		5	16.83%	11.28%	8.89%	6	15.57%	10.63%	8.78%	5	19.20%	12.59%	9.59%
	Nº of inverters:	10	10		5	16.25%	11.09%	8.29%	6	15.03%	10.46%	8.05%	5	18.63%	12.41%	8.98%
			30	SE	5	15.87%	11.44%	8.55%	6	15.15%	11.06%	8.57%	5	18.56%	13.09%	9.09%
	Breaking capacity(kW):	200	20		5	16.05%	11.40%	8.42%	6	15.21%	10.96%	8.27%	5	18.68%	12.99%	9.00%
			10		5	15.83%	11.14%	8.08%	6	14.85%	10.65%	7.76%	5	18.38%	12.64%	8.67%
Industry3	Tariff:	**MV**	30	S	5	17.40%	9.85%	9.61%	5	16.43%	9.43%	9.72%	4	20.01%	11.16%	10.12%
			20		5	17.15%	9.72%	9.48%	5	16.10%	9.27%	9.53%	5	19.72%	11.00%	9.96%
			10		5	16.40%	9.37%	9.15%	6	15.28%	8.88%	9.17%	5	18.89%	10.60%	9.59%
	Inverter Power(kW):	20	30	SW	5	16.96%	9.36%	9.70%	5	15.70%	8.81%	9.67%	5	19.29%	10.44%	10.21%
			20		5	16.80%	9.35%	9.42%	5	15.53%	8.80%	9.40%	5	19.14%	10.46%	9.93%
	Nº of inverters:	21	10		5	16.20%	9.17%	9.07%	6	14.96%	8.63%	9.07%	5	18.56%	10.29%	9.53%
			30	SE	5	15.76%	9.45%	9.43%	6	15.03%	9.13%	9.50%	5	18.45%	10.84%	9.79%
	Breaking capacity(kW):	420	20		5	15.97%	9.42%	9.28%	6	15.10%	9.04%	9.33%	5	18.61%	10.76%	9.65%
			10		5	15.76%	9.20%	9.00%	6	14.74%	8.76%	9.02%	5	18.30%	10.46%	9.39%
Industry4	Tariff:	**MV**	30	S	4	20.07%	6.71%	9.91%	5	16.39%	6.38%	10.57%	4	20.07%	7.60%	10.40%
			20		5	17.20%	6.63%	9.66%	5	16.09%	6.29%	10.07%	4	19.78%	7.51%	10.13%
			10		5	16.45%	6.41%	9.16%	5	15.29%	6.06%	9.35%	5	18.96%	7.24%	9.63%
	Inverter Power(kW):	20	30	SW	5	17.12%	6.43%	9.22%	5	15.77%	6.02%	9.61%	5	19.47%	7.17%	9.71%
			20		5	16.92%	6.42%	9.09%	6	15.59%	6.02%	9.32%	5	19.30%	7.18%	9.58%
	Nº of inverters:	69	10		5	16.29%	6.29%	8.79%	6	15.00%	5.91%	8.92%	5	18.67%	7.05%	9.32%
			30	SE	5	15.72%	6.40%	10.22%	6	14.92%	6.15%	10.80%	5	18.39%	7.33%	10.69%
	Breaking capacity(kW):	1380	20		5	15.96%	6.40%	9.77%	6	15.03%	6.12%	10.15%	5	18.58%	7.30%	10.26%
			10		5	15.78%	6.28%	9.17%	6	14.72%	5.97%	9.31%	5	18.32%	7.13%	9.65%

Table 32. Summary of the best results of each residential benchmark and location. The first-rate outcome within each city is highlighted.

	INFORMATION		LISBOA						PORTO						FARO					
			Tilt	Or.	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)	Tilt	Or.	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)	Tilt	Or.	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)
Demand1	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	LV_S 0.25 1 0.25 0.22 0.20	30	S	8	8.74%	17.62%	5.01%	30	S	8	8.33%	17.19%	5.13%	30	S	7	11.22%	20.00%	7.11%
Demand2	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW):	LV_S 0.25 6 1.5	30	S	7	12.21%	15.07%	2.22%	30	S	7	11.87%	14.79%	1.81%	30	S	6	15.15%	17.53%	2.04%
	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	LV_B 0.25 8 2 1.63 1.74	30	S	6	14.00%	19.80%	3.66%	30	S	6	13.56%	19.42%	3.27%	30	S	5	17.17%	22.93%	3.90%
Demand3	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW):	LV_S 0.25 1 0.25	30	S	8	9.42%	6.60%	0.16%	30	S	8	9.03%	6.44%	0.19%	30	S	7	12.22%	7.65%	0.25%
	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	LV_B 0.25 1 0.25 0.63 0.47	30	S	7	11.17%			30	S	7	10.69%			30	S	6	14.14%		

Table 33. Summary of the best results of each Hotel benchmark and location. The first-rate outcome within each city is highlighted.

	INFORMATION		LISBOA						PORTO						FARO					
			Tilt	Or.	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)	Tilt	Or.	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)	Tilt	Or.	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)
Hotel1	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	LV_T 0.25 20 5 3.42 3.60	30	S	6	14.43%	22.83%	6.65%	30	S	6	14.02%	22.42%	6.14%	30	S	5	17.41%	26.07%	8.19%
Hotel2	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	LV_T 20 1 20 12.632 14.39	30	S	4	20.46%	27.86%	3.73%	30	S	5	19.49%	26.69%	3.75%	30	S	4	23.57%	31.34%	4.95%
Hotel3	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	SLV 20 2 40 33.90 38.48	30	SW	4	24.87%	20.36%	0.73%	30	S	4	23.31%	20.54%	0.63%	30	SW	3	27.68%	22.79%	0.99%

Table 34. Summary of the best results of each retail benchmark and location. The first-rate outcome within each city is highlighted.

	INFORMATION		LISBOA						PORTO						FARO					
			Tilt	Or.	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)	Tilt	Or.	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)	Tilt	Or.	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)
Retail1	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	SLV 10 5 50 25.68 34.45	30	SW	4	24.36%	33.16%	2.12%	30	S	4	23.05%	33.39%	2.21%	30	SW	3	27.02%	36.92%	2.87%
Retail2	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	MV 10 11 110 63.90 76.65	30	S	5	16.61%	30.90%	1.94%	30	S	6	15.66%	29.64%	1.82%	30	S	5	19.10%	34.86%	2.89%
Retail3	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	MV 20 10 200 120.34 152.26	30	S	5	18.80%	30.17%	0.83%	30	S	5	17.80%	28.90%	0.87%	30	S	4	21.50%	34.19%	1.36%
Retail4	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	MV 20 18 360 202.54 266.95	30	S	5	18.60%	31.71%	2.55%	30	S	5	17.62%	30.44%	2.38%	30	S	4	21.22%	35.75%	3.57%

Table 35. Summary of the best results of each Industrial benchmark and location. The first-rate outcome within each city is highlighted.

	INFORMATION		LISBOA						PORTO						FARO					
			Tilt	Or.	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)	Tilt	Or.	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)	Tilt	Or.	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)
Industry1	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	MV 20 1 20 62.02 90.60	30	S	6	13.12%	5.08%	13.90%	30	S	7	12.21%	4.85%	14.12%	30	S	6	15.51%	5.74%	14.52%
Industry2	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	MV 20 10 200 279.36 305.04	30	S	5	17.43%	11.86%	9.21%	30	S	5	16.46%	11.34%	9.37%	30	S	4	20.07%	13.42%	9.85%
Industry3	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	MV 20 21 420 702.72 779.51	30	S	5	17.40%	9.85%	9.61%	30	S	5	16.43%	9.43%	9.72%	30	S	4	20.01%	11.16%	10.12%
Industry4	Tariff: Inverter Power(kW): Nº of inverters: Breaking capacity(kW): Mean Power comsumption(kWh) Mean Power comsumption under irradiation(kWh)	MV 20 69 1380 3371.31 3318.72	30	S	4	20.07%	6.71%	9.91%	30	S	5	16.39%	6.38%	10.57%	30	S	4	20.07%	7.60%	10.40%

Table 36. Hotel 2 and Hotel 3 comparative chart for LV_T and SLV.

	INFORMATION		LISBOA						PORTO						FARO					
			Tilt	Or.	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)	Tilt	Or.	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)	Tilt	Or.	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)
Hotel2	Tariff:	LV_T	30	S	4	20.46%	27.86%	3.73%	30	S	5	19.49%	26.69%	3.75%	30	S	4	23.57%	31.34%	4.95%
		SLV				23.87%					4	22.69%					3	26.62%		
Hotel3	Tariff:	LV_T	30	SW	5	17.57%	21.45%	0.60%	30		5	16.91%	20.54%	0.63%	30	SW	4	19.97%	24.38%	0.80%
		SLV			4	24.87%					4	23.31%					3	27.68%		

Table 37. Comparative chart for Retail1 comparative chart for LV_T and SLV.

	INFORMATION		LISBOA						PORTO						FARO					
			Tilt	Or.	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)	Tilt	Or.	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)	Tilt	Or.	PBT	IRR (25 years)	SC energy (% Total demand)	Surplus (% production)
Retail1	Tariff:	LV_T	30	SW	5	18.72%	33.16%	2.12%	30	S	5	19.75%	33.39%	2.21%	30	SW	4	21.42%	36.92%	2.87%
				S	4	20.65%	34.73%	2.56%								S		23.81%	39.14%	3.60%
		SLV		SW		24.36%	33.16%	2.12%			4	23.05%				SW	3	27.02%	36.92%	2.87%

Table 38. Average consumption values and ratios.

		RESIDENTIAL			HOTELS			RETAIL				INDUSTRY			
	INFORMATION	Demand1	Demand2	Demand3	Hotel1	Hotel2	Hotel3	Retail1	Retail2	Retail3	Retail4	Industry1	Industry2	Industry3	Industry4
	Max (kW)	2.083	4.906	4.729	21.500	22.438	69.063	50.250	98.750	199.250	404.750	320.000	484.563	1360.625	6230.000
	Min (kW)	0.077	0.092	0.111	0.813	5.125	5.250	9.250	26.500	14.500	39.500	3.000	2.375	5.000	37.500
AVERAGE	Yearly (kW)	0.225	1.626	0.628	3.419	12.632	33.902	25.680	63.901	120.336	202.541	62.023	279.362	702.721	3371.315
	Under Irradiation (kW)	0.202	1.735	0.467	3.604	14.394	38.477	34.451	76.648	152.256	266.954	90.602	305.043	779.507	3318.718
	August (kW)	0.204	1.767	0.304	3.154	15.349	38.881	25.628	69.640	132.374	266.643	17.843	265.741	468.771	1681.828
	December (kW)	0.196	1.671	0.891	5.074	11.791	29.748	27.222	60.282	106.562	150.430	58.864	278.264	518.070	2655.709
RATIO	Max/Min	27.030	53.323	42.662	26.462	4.378	13.155	5.432	3.726	13.741	10.247	106.667	204.026	272.125	166.133
	Max/Average	9.268	3.017	7.526	6.289	1.776	2.037	1.957	1.545	1.656	1.998	5.159	1.735	1.936	1.848
	Min/Average	0.343	0.057	0.176	0.238	0.406	0.155	0.360	0.415	0.120	0.195	0.048	0.009	0.007	0.011
	Under Irradiation (kW)/Yearly(kW)	0.899	1.067	0.744	1.054	1.140	1.135	1.342	1.199	1.265	1.318	1.461	1.092	1.109	0.984
	August (kW)/December (kW)	1.041	1.057	0.342	0.622	1.302	1.307	0.941	1.155	1.242	1.773	0.303	0.955	0.905	0.633
	Max/Average Under Irradiation	10.308	2.827	10.117	5.965	1.559	1.795	1.459	1.288	1.309	1.516	3.532	1.589	1.745	1.877
	Min/Average Under Irradiation	0.381	0.053	0.237	0.225	0.356	0.136	0.268	0.346	0.095	0.148	0.033	0.008	0.006	0.011

5. CONCLUSIONS

The implementation of the Portuguese SC directive implies a progress towards EU climate targets hinged upon the individual decisions of the citizens, potential prosumers and grid investors, and upon the development of the technical support required to assured energy transition without further impacts on electricity prices.

As an answer of the research question of this study, which intends to deepen into the production and real demand interaction within the Portuguese self-consumption current scenario, a sort of guidelines to optimize prosumer profiles economically and energetically can be extracted out of this research.

The search of patterns within each demand profile becomes the cornerstone of the analysis. Therefore the utilization of parameters as ratios to assess specific behaviors which induce to seasonal profiles, vacations/weekdays profiles, consumption under production (illumination) profiles help to design the best prosumer strategy in order to maximize economic benefits and SC autonomy. This fact is really important for sectors where demand is extremely unbalanced, as the Industrial one. Here SC% hardly reaches 10% being in many cases surpassed by the energy exports for optimal IRR and PBT values. As a solution, synergies with other types of generation technologies as biomass, the implementation of a microgrid with complementary consumption behavior industries to satisfy demand and accept exports, storage devices and active demand management, which in industries would require a profound analysis of the production processes.

The same prosumer profile with different energy tariffs could lead to different economic indicators which would question its suitability. The existence of a high special tax for peak consumption for MV and SLV, being SLV double than MV special peak rate increases its economic indicators. In fact, the best prosumer profile corresponds to Retail 1, which is analyze under SLV and gives an IRR of 27.07%, a SC% of 36.92% and a PBT of 3 years.

In rough outlines, accommodation and retail sectors are the profiles whose consumption patterns tailor better to production. i.e., regular unfluctuating demand during the day (retail), combined with demand during weekends (hotels). As a result they gather the best economic and energetic indicators.

Best location, orientation and tilt belong to Faro, 30S through the whole study.

Residential benchmark has a great divergence among profiles as different family typologies exist, and present the worst performance, Demand1 Porto (10SW) with an IRR 6.85% and a PBT of 9 years. This is due to low consumptions heavily uncoupled. Generally within this sector some type of energy storage or demand management shall be encourage, since residential loads are normally prone to be shifted.

Comprehending renewables' profiles and accounting for their potential deviations seem to be vital in forecasting energy prices and costs and in appraising the risks for ideal investment planning and portfolio optimization. In addition, cater an enormous productivity benefit for the electricity industry globally and especially to renewables being contemplated as the first steps towards converting alternative energies into a new base load.

6. FUTURE WORK

Within the OTGEN project, to typify and hierarchy the potential adopters of PV SC in Portugal, Portuguese PV SC adoption and diffusion curve along the next 15 years has been inferred based on micro and minigeneration results (ANNEX A: POTENTIAL PV SELF-CONSUMPTION MARKET IN PORTUGAL). Therefore, as a future work, the data obtained out of this study will be extrapolated to build analogous curves which shall deliver a more accurate PV SC adoption and diffusion scenario in order to accurate appraise Portuguese market evolution and the grid sustainability.

Furthermore, ongoing studies should involve further knowledge on:

- A more profound analysis of the demand and generation data to rank the different profiles in order to identify patterns which could help to a better understanding of the *prosumer* .i.g., Summer/Winter different profiles to each demand…

- A larger production spectrum with more Portuguese locations and inclinations. i.g., 40° panel tilt.

- Effects of the diverse demand management approaches available and the different ways to perform storage (thermal, electrochemical…)

- Potential distributed production sources associations to improve SC range, as the introduction of a backup biomass energy generation.

- The prospect of Spanish SC, in terms of analyzing a more complete picture of the Iberian market as a whole. To that end, a parallel techno-economic study could be realized assuming actual Spanish SC adverse legislation.

7. BIBLIOGRAPHY

"3.5. Transporte Del Gas Natural Por Gasoducto." 2016. Accessed February 6. http://www.energiaysociedad.es/ficha/3-5-transporte-del-gas-natural-por-gasoducto.

"2030 Energy Strategy - Energy - European Commission." 2016. *Energy*. Accessed July 21. http://ec.europa.eu/energy/en/topics/energy-strategy/2030-energy-strategy.

"About Us | Ofgem." 2016. Accessed February 26. https://www.ofgem.gov.uk/about-us.

Amorim, F., J. Vasconcelos, I. C. Abreu, PP da Silva, and V. Martins. 2013. "How Much Room for a Competitive Electricity Generation Market in Portugal?" *Renewable and Sustainable Energy Reviews* 18: 103–118.

Amorim, F., J. Vasconcelos, I. Abreu, P. Silva, and V. Martins. 2012. "Assessment of Legacy Generation Contracts' Costs in the Future Portuguese Electricity System." In *European Energy Market (EEM), 2012 9th International Conference on the*, 1–4. doi:10.1109/EEM.2012.6254647.

Anthony Faiola. 2013. "European Carbon Market´s Trouble Darkens Outlook for Remedying Climate Change," May 5. https://www.washingtonpost.com/world/europe/european-carbon-markets-trouble-darkens-outlook-for-remedying-climate-change/2013/05/05/0178ccea-b30f-11e2-9fb1-62de9581c946_story.html.

Arnaud Coibion, John Pickett. 2014. "Capacity Mechanism. Reigniting Europe´s Energy Market." Linklaters. http://www.linklaters.com/Insights/ThoughtLeadership/Energy-generation-adequacy-capacity-mechanisms/Pages/Index.aspx.

Association, European Wind Energy, and others. 2011. *EU Energy Policy to 2050*. EWEA. https://books.google.es/books?hl=es&lr=&id=HyWEI1cqXboC&oi=fnd&pg=PA15&dq=+EU+Energy+Policy+to+2050+&ots=u4TaNP-Q1S&sig=3h-Vu_xVJgls09QAlbifV4Qb3KE.

Carbon Market Watch. 2015. "FLEXIBILITIES IN THE EU'S 2030 EFFORT SHARING DECISION." Carbon Market Watch. http://carbonmarketwatch.org/wp-content/uploads/2015/06/Flexibilities-in-the-EU%E2%80%99s-2030-Effort-Sharing-Decision_Poicy-Brief_final-June-2015.pdf.

Carlo Stagnaro. 2015. *Power Cut? How the EU Is Pulling the Plug on Electricity Markets*. Institute of Economic Affairs. http://www.iea.org.uk/publications/research/power-cut-how-the-eu-is-pulling-the-plug-on-electricity-markets.

Christos Papadopoulos. 2015. "Evaluating the Operational and Market Risks for Complex Energy Portfolios and New Energy Investments Optimisation in Europe Employing the Power of Hybrid Integrated Modelling." *Energy Business Review*, May 20. http://utilitiesnetwork.energy-business-review.com/suppliers/energy-exemplar/whitepapers/evaluating-the-operational-and-market-risks-for-complex-energy-portfolios-and-new-energy-investments-optimisation-in-europe-employing-the-power-of-hybrid-integrated-modelling.

Ciarreta, Aitor, and Carlos Gutiérrez-Hita. 2009. "Entering Renewable Energy Sources in the Spanish Electricity Market: The Effects of Regulatory Reforms." In *International Association for Energy Economics Energy Forum, Third Quarter*, 21–23. http://www.iaee.org/en/publications/newsletterdl.aspx?id=76.

"Combustion Engine vs Gas Turbine- Startup Time." 2016. Accessed February 5. http://www.wartsila.com/energy/learning-center/technical-comparisons/combustion-engine-vs-gas-turbine-startup-time.

Commission, E. U., E. U. Commission, and others. 1997. “White Paper for a Community Strategy and Action Plan—-Energy for the Future: Renewable Sources of Energy.” *COM (97)* 599.

Corinna Klessmann. 2014. “Experience with Renewable Electricity (RES-E) Support Schemes in Europe. Current Status and Recent Trends.” http://www.leonardo-energy.org/sites/leonardo-energy/files/documents-and-links/ecofys-support_policies_2014_04.pdf.

Cristina M Herce Villar. 2015. “Solar Photovoltaic Technologies: State-of-the-Art.”

David Robinson. 2013. “Pulling the Plug on Renewable Power in Spain.” Oxford Energy Comment. The Oxford Institute for Energy Studies. https://www.oxfordenergy.org/wpcms/wp-content/uploads/2013/12/Pulling-the-Plug-on-Renewable-Power-in-Spain.pdf.

Delbeke, Jos, and Peter Vis. 2015. *EU Climate Policy Explained*. Routledge.

“Descontos Sociais de Eletricidade.” 2016. Accessed July 26. https://www.edpsu.pt/pt/destaques/Pages/TarifaSocialeAsece.aspx.

Dimova-Malinovska, D. 2010. “The State-of-the-Art and Future Development of the Photovoltaic Technologies – the Route from Crystalline to Nanostructured and New Emerging Materials.” *Journal of Physics: Conference Series* 253 (1): 12007. doi:10.1088/1742-6596/253/1/012007.

Domínguez, E. Fernández, and J. Xiberta Bernat. 2007. “Restructuring and Generation of Electrical Energy in the Iberian Peninsula.” *Energy Policy* 35 (10): 5117–5129.

Dr. Dörte Fouquet, Jana Viktoria Nysten. 2015. “The Legal Helpdesk. Energy Taxation in the EU.” BECKER BÜTTNER HELD. http://www.keepontrack.eu/contents/virtualhelpdeskdocuments/energy-taxation_1718.pdf.

Duscha, Vicki, Mario Ragwitz, Barbara Breitschopf, Wolfgang Schade, Rainer Walz, Matthias Pfaff, I. S. I. Fraunhofer, et al. n.d. “Employment and Growth Effects of Sustainable Energies in the European Union.” *Final Report. ENER C* 1.

Easan Drury, Paul Denholm, and Robert Margolis. 2011. “The Impact of Different Economic Performance Metrics on the Perceived Value of Solar Photovoltaics.” National Renewable Energy Laboratory (NREL). http://www.nrel.gov/docs/fy12osti/52197.pdf.

“Emissions Trading Worldwide. Status Report 2015.” 2015. International Carbon Action Partnership (ICAP). https://icapcarbonaction.com/images/StatusReport2015/ICAP_Report_2015_02_10_online_version.pdf.

“Energy Saving Statistics - Statistics Explained.” 2016. Accessed February 5. http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_saving_statistics.

ERSE. 2012. “Recomendação Nº 1/2012. Informação Do Imposto Especial de Consumo Na Fatura de Electricidade.” http://www.erse.pt/pt/aerse/actosdaerse/recomendacoes/Documents/Recomenda%C3%A7%C3%A3o_IEC_6jan2012.pdf.

———. 2016a. “Composição Dos Preços de Electricidade, Incluindo Os Custos de Interesse Económico Geral.” Accessed February 26. http://www.erse.pt/pt/electricidade/tarifaseprecos/precosdeelectricidade/Documents/Apres%20Composi%C3%A7%C3%A3o%20Pre%C3%A7os%20Electricidade%20(CIEG).pdf.

———. 2016b. “Entidade Reguladora Do Sector Eléctrico. DESPACHO Nº 21496-A/99.” Accessed January 16. http://www.erse.pt/pt/legislacao/legislacao/attachments/853/resd9b1ab93038a432eac4dbf4c19cfee09.pdf.

“EU over-Achieved First Kyoto Emissions Target, on Track to Meet 2020 Objective - European Commission.” 2016. Accessed February 24. http://ec.europa.eu/clima/news/articles/news_2013100901_en.htm.

“EUR-Lex - l28060 - EN - EUR-Lex.” 2016. Accessed February 24. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=URISERV%3Al28060.

European Comission. 2014. “EU Energy Markets in 2014.” http://ec.europa.eu/energy/sites/ener/files/documents/2014_energy_market_en_0.pdf.

European Commission. 2010. “Guidance on Intepretation of Annex I of the EU ETS Directive.” Directorate-General Climate Action. Directorate B. european and International Carbon Markets. http://ec.europa.eu/clima/policies/ets/docs/guidance_interpretation_en.pdf.

———. 2011a. “Communication from The Commission to the European Parliament and the Council. Renewable Energy: Progressing towards the 2020 Target.” http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0031:FIN:EN:PDF.

———. 2011b. “Communication from The Commission to the European Parliament, the Council, the European Economic and Social Committee and Thecommittee of the Regions. A Roadmap for Moving to a Competitive Low Carbon Economy in 2050.” http://eur-lex.europa.eu/resource.html?uri=cellar:5db26ecc-ba4e-4de2-ae08-dba649109d18.0002.03/DOC_1&format=PDF.

———. 2011c. “Communication from The Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Energy Roadmap 2050.” http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0885:FIN:EN:PDF.

———. 2012. “Communication from The Commission to the European Parliament, the Council, the European Economic and Social Committee and Thecommittee of the Regions. Renewable Energy: A Major Player in the European Energy Market.” http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52012DC0271&from=EN.

———. 2013a. “Communication from The Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Renewable Energy Progress Report.” http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52013DC0175&from=EN.

———. 2013b. “GREEN PAPER. A 2030 Framework for Climate and Energy Policies.” http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2013:0169:FIN:en:PDF.

———. 2013c. “Communication from The Commission- Delivering the Internal Electricity Market and Making the Most of Public Intervention.” https://ec.europa.eu/energy/sites/ener/files/documents/com_2013_public_intervention_en.pdf.

———. 2014. “Communication from The Commission to the European Parliament, the Council, the European Economic and Social Committee and Thecommittee of the Regions. A Policy Framework for Climate and Energy in the Period from 2020 to 2030.” http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2014:0015:FIN:EN:PDF.

———. 2015a. “ENERGY UNION PACKAGE. Communication from The Commission to the European Parliament, the Council, the European Economic and Social Committee and Thecommittee of the Regions and the European Investment Bank. A Framework Strategy for a Resilient Energy Union with a Forward-

Looking Climate Change Policy." http://eur-lex.europa.eu/resource.html?uri=cellar:1bd46c90-bdd4-11e4-bbe1-01aa75ed71a1.0001.03/DOC_1&format=PDF.

———. 2015b. "Report from The Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Renewable Energy Progress Report." http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52013DC0175&from=EN.

———. 2015c. "Commissions Staff Working Document. Best Practices on Renewable Energy Self-Consumption. Accompanyng the Document: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Delivering a New Deal for Energy Consumers." https://ec.europa.eu/energy/sites/ener/files/documents/1_EN_ACT_part1_v8.pdf.

———. 2015d. "Communication from The Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Delivering a New Deal for Energy Consumers." https://ec.europa.eu/energy/sites/ener/files/documents/1_EN_ACT_part1_v8.pdf.

———. 2015e. "Communication from The Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions and the European Investment Bank. State of the Energy Union 2015." http://eur-lex.europa.eu/resource.html?uri=cellar:ebdf266c-8eab-11e5-983e-01aa75ed71a1.0008.02/DOC_1&format=PDF.

"European Commission - PRESS RELEASES - Press Release - State Aid: Commission Authorises UK Aid Package for Renewable Electricity Production." 2016. Accessed February 4. http://europa.eu/rapid/press-release_IP-14-866_en.htm.

"European Commission : CORDIS : News and Events : Action Plan on Renewable Energy Sources in Europe: Conference Proceedings." 2016. Accessed January 20. http://cordis.europa.eu/news/rcn/2429_en.html.

European Council. 2014. "Conclusions. 2030 Climate and Energy Policy Framework." EUCO 169/14. http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/145397.pdf.

"Eutrophication." 2016. *Wikipedia, the Free Encyclopedia*. https://en.wikipedia.org/w/index.php?title=Eutrophication&oldid=704626939.

"Exciton | Physics | Britannica.com." 2016. Accessed July 21. https://global.britannica.com/science/exciton.

"EY - Renewable Energy Country Attractiveness Index." 2016. Accessed January 27. http://www.ey.com/GL/en/Industries/Power---Utilities/Renewable-Energy-Country-Attractiveness-Index.

"F-Alpha.net: Experiment 4 - Photovoltaic Effect." 2016. Accessed April 19. http://en.f-alpha.net/physics/semiconductor-physics/photovoltaic-effect/lets-go/experiment-4-photovoltaic-effect/.

"File:Electricity Prices for Household Consumers, Second Half 2014 (^{1}) (EUR per kWh) YB15.png - Statistics Explained." 2016. Accessed February 9. http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Electricity_prices_for_household_consumers,_second_half_2014_(%C2%B9)_(EUR_per_kWh)_YB15.png#filehistory.

"File:Price History of Silicon PV Cells since 1977.svg." 2016. *Wikipedia, the Free Encyclopedia*. Accessed February 6. https://en.wikipedia.org/wiki/File:Price_history_of_silicon_PV_cells_since_1977.svg#metadata.

Fischer, Carolyn. 2005. “Project-Based Mechanisms for Emissions Reductions: Balancing Trade-Offs with Baselines.” *Energy Policy* 33 (14): 1807–1823.

Forstner, H., and others. 2015. “International Technology Roadmap for Photovoltaic (ITRPV) 2014 Results.” *SEMI Europe, Berlin, Germany*, 32.

Ghislaine Kieffer, Toby D. Couture. 2015. “Renewable Energy Target Setting.” IRENA (International Renewable Energy). http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Target_Setting_2015.pdf.

Giotitsas, Chris, Alex Pazaitis, and Vasilis Kostakis. 2015. “A Peer-to-Peer Approach to Energy Production.” *Technology in Society* 42: 28–38.

“Global Trends in Coal to 2020.” 2016. *World Coal*. Accessed February 10. http://www.worldcoal.com/special-reports/14012016/Global-trends-in-coal-to-2020-52/.

GmbH, Sunbeam. 2016. “Conergy Enters Residential Solar Leasing Market.” *Pv Magazine*. Accessed March 1. http://www.pv-magazine.com/news/details/beitrag/conergy-enters-residential-solar-leasing-market_100018071/.

Goswami, D. Yogi, and Frank Kreith. 2015. *Energy Efficiency and Renewable Energy Handbook*. CRC Press. http://www.crcnetbase.com/isbn/9781466585096.

Green, Martin A., Keith Emery, Yoshihiro Hishikawa, Wilhelm Warta, and Ewan D. Dunlop. 2015. “Solar Cell Efficiency Tables (Version 45).” *Progress in Photovoltaics: Research and Applications* 23 (1): 1–9.

“Green Papers - European Commission.” 2016. Accessed January 23. http://ec.europa.eu/green-papers/.

Gross, Daniel. 2015. “Wind Energy Is Having a Railroad Moment.” *Slate*, August 21. http://www.slate.com/articles/business/the_juice/2015/08/clean_line_energy_wind_transmission_lines_ambitious_wind_infrastructure.html.

Gudas, Karolis. 2015. “Promotion of Renewable Energy in the EU: Critical Assessment of Grid-Related Incentives.” SSRN Scholarly Paper ID 2532927. Rochester, NY: Social Science Research Network. http://papers.ssrn.com/abstract=2532927.

Gupta, Anshuman, and Surbhi Arora. 2015. “Control the Oil, Rule the World: The Energy Games Nations Play.” *IUP Journal of International Relations* 9 (1): 52.

Hagfeldt, Anders, Gerrit Boschloo, Licheng Sun, Lars Kloo, and Henrik Pettersson. 2010. “Dye-Sensitized Solar Cells.” *Chemical Reviews* 110 (11): 6595–6663.

Harvey, Fiona. 2015. “EU Energy Consumption Level Falls to 20-Year Low.” *The Guardian*, February 9, sec. Environment. http://www.theguardian.com/environment/2015/feb/09/eu-energy-consumption-level-falls-to-20-year-low.

“Henbest: Fix the EU ETS, and Carbon Markets Can Be Serious Business.” 2015. *Bloomberg New Energy Finance*. March 31. http://about.bnef.com/blog/fix-eu-ets-carbon-markets-can-serious-business/.

“How to Lose Half a Trillion Euros | The Economist.” 2016. Accessed February 6. http://www.economist.com/news/briefing/21587782-europes-electricity-providers-face-existential-threat-how-lose-half-trillion-euros.

Hsu, David D., Patrick O’Donoughue, Vasilis Fthenakis, Garvin A. Heath, Hyung Chul Kim, Pamala Sawyer, Jun-Ki

Choi, and Damon E. Turney. 2012. “Life Cycle Greenhouse Gas Emissions of Crystalline Silicon Photovoltaic Electricity Generation.” *Journal of Industrial Ecology* 16 (s1): S122–S135.

“IEA - Portugal.” 2016. Accessed March 31. http://www.iea.org/policiesandmeasures/pams/portugal/name-21206-en.php.

“IEA - Renewable Energy.” 2016. Accessed January 17. http://www.iea.org/policiesandmeasures/renewableenergy/?country=Spain.

“IEA WIND 2014 Annual Report.” 2015. IEA Wind. https://www.ieawind.org/annual_reports_PDF/2014/2014%20AR_smallfile.pdf.

IEA-PVPS, PVPS. 2014. “Report Snapshot of Global PV 1992-2013.” *Report IEA-PVPS T1-24*.

Indian Energy Exchange. 2016. “Congestion Management.” Accessed March 23. http://www.iexindia.com/pdf/dam_appendix2.pdf.

Ingrid Jegou, Luca Rubini. 2011. “The Allocation of Emission Allowances Free of Charge: Legal and Economic Considerations.” 18. Transition to a Low Carbon Future Series. International Centre for Trade and Sustainable Development. http://www.ictsd.org/downloads/2011/08/the-allocation-of-emission-allowances-free-of-charge.pdf.

“Inicio | OMIE.” 2016. Accessed July 22. http://www.omie.es/inicio.

IRENA. 2012. “Renewable Energy Tariff-Based Mechanisms.” IRENA. https://www.irena.org/DocumentDownloads/events/2012/November/Tariff/1_Rabia_Ferroukhi.pdf.

Jäger-Waldau, Arnulf, Márta Szabó, Nicolae Scarlat, and Fabio Monforti-Ferrario. 2011. “Renewable Electricity in Europe.” *Renewable and Sustainable Energy Reviews* 15 (8): 3703–3716.

Jean, Joel, Patrick R. Brown, Robert L. Jaffe, Tonio Buonassisi, and Vladimir Bulović. 2015. “Pathways for Solar Photovoltaics.” *Energy & Environmental Science* 8 (4): 1200–1219.

Joanna Cabello, Ricardo Coelho, and Tamra Gilberston. 2013. “Extractive Energy. How the EU ETS Exacerbates Climate Change?” Carbon Trade Watch. http://www.carbontradewatch.org/downloads/publications/Extractive_energy_report.pdf.

Jorge Aguirregomezcorta, Lluis Recoder, and Francisco Montes José Mari. 2015. “Electricity Self-Consumption.” KPMG. https://home.kpmg.com/content/dam/kpmg/pdf/2015/12/tnf-spain-electricity-dec2-2015.pdf.

Kammen, Daniel M., Kamal Kapadia, and Matthias Fripp. 2004. “Putting Renewables to Work: How Many Jobs Can the Clean Energy Industry Generate.” *RAEL Report, University of California, Berkeley* 13. http://community-wealth.org/sites/clone.community-wealth.org/files/downloads/paper-kammen-et-al.pdf.

Kitson, Michael, and Jonathan Michie. 2014. “The Deindustrial Revolution: The Rise and Fall of UK Manufacturing, 1870-2010.” *The Cambridge Economic History of Modern Britain* 2. http://josharcher.uk/wp-content/uploads/2013/07/Industrial-Performance-1870-2010.pdf.

Kyriakides Georgopoulos & Daniolos Issaias Law Firm. 2012. “Feed-In Tariff vs. Feed-in Premium.” In . Institute of Energy for South-East Europe. http://www.iene.gr/6thSEEED/articlefiles/sessionV/Douklias.pdf.

Lee Robinson. 2016. “A Summary of Diffusion of Innovations.” Accessed January 21. http://www.europarl.europa.eu/sides/getDoc.do?type=TA&reference=P6-TA-2006-

0603&language=EN.

"Lignite in Europe: Fighting Back Renewables." 2015. *EnergyPost.eu*. June 30. http://www.energypost.eu/lignite-europe-fighting-back-renewables/.

"List of Annex I Parties to the Convention." 2016. Accessed February 25. http://unfccc.int/parties_and_observers/parties/annex_i/items/2774.php.

"List of Non-Annex I Parties to the Convention." 2016. Accessed February 25. http://unfccc.int/parties_and_observers/parties/non_annex_i/items/2833.php.

Lothar Balling. 2011. "Fast Cycling and Rapid Start-Up> New Generation of Plants Achieves Impressive Results." Siemens. http://www.energy.siemens.com/br/pool/hq/power-generation/power-plants/gas-fired-power-plants/combined-cycle-powerplants/Fast_cycling_and_rapid_start-up_US.pdf.

Luthander, Rasmus, Joakim Widén, Daniel Nilsson, and Jenny Palm. 2015. "Photovoltaic Self-Consumption in Buildings: A Review." *Applied Energy* 142: 80–94.

M. Dogushan Kara. 2014. "Renewable Energy in European Union: The Reveal of Development Plans for Environment." EPPEn. http://www.eppen.org/resim/haber_resim/EPPEN2.pdf.

Marcantonini, Claudio, and A. Denny Ellerman. 2013. "The Cost of Abating CO2 Emissions by Renewable Energy Incentives in Germany." In *European Energy Market (EEM), 2013 10th International Conference on the*, 1–8. IEEE. http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6607312.

Maria João dos Santos Rodrigues. 2009. "BUILDING-INTEGRATED PHOTOVOLTAIC (BiPV) TECHNOLOGY DIFFUSION INTO PORTUGUESE URBAN AREAS." UNIVERSIDADE TÉCNICA DE LISBOA INSTITUTO AND SUPERIOR TÉCNICO.

MIT. 2016. "The Future of Solar Energy: An Interdisciplinary MIT Study." MIT. Energy Initiative Massachusetts Institute of Technology. Accessed April 13. https://mitei.mit.edu/system/files/MIT%20Future%20of%20Solar%20Energy%20Study_compressed.pdf.

Natascha Trennepohl. 2013. "Renewable Energy Policy Database and Support-RES-LEGAL EUROPE. National Profile: Portugal." RES LEGAL Europe. http://www.res-legal.eu/.

Nathanson, Rachel Ann. 2012. "The Revocation of Clean-Energy Investment Economic-Support Systems as Indirect Expropriation Post-Nykomb: A Spanish Case Analysis." *Rachel Nathanson, The Revocation of Clean-Energy Investment Economic-Support Systems as Indirect Expropriation Post-Nykomb: A Spanish Case Analysis* 98. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2063294.

"National Renewable Energy Laboratory (NREL)." 2016. Accessed April 6. http://www.nrel.gov/.

NAVARRO, JAVIER GONZÁLEZ. 2013. "España Tiene 107.615 MW de Potencia Eléctrica Y Sólo Necesita La Mitad." *ABC.es*. October 21. http://www.abc.es/economia/20131021/abci-espana-tiene-potencia-electrica-201310211202.html.

"Nuclear Power in Germany - World Nuclear Association." 2016. Accessed April 16. http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/germany.aspx.

Ofgem. 2015. "Annual Report on the Operation of the Capacity Market." Ofgem. https://www.ofgem.gov.uk/sites/default/files/docs/2015/06/annual_report_on_the_operation_of_the_cm_final_0.pdf.

"OMIE." 2016. Accessed March 23. http://www.omie.es/inicio.

Peng, Jinqing, Lin Lu, and Hongxing Yang. 2013. "Review on Life Cycle Assessment of Energy Payback and Greenhouse Gas Emission of Solar Photovoltaic Systems." *Renewable and Sustainable Energy Reviews* 19: 255–274.

"Photovoltaics Report." 2014. Fraunhofer ISE. http://www.ise.fraunhofer.de/en/downloads-englisch/pdf-files-englisch/photovoltaics-report-slides.pdf.

"Portal ERSE - Períodos Horários." 2016. Accessed May 13. http://www.erse.pt/pt/electricidade/tarifaseprecos/periodoshorarios/paginas/default.aspx.

"Portal ERSE - Tarifas de Acesso Às Redes Em 2015." 2016. Accessed May 13. http://www.erse.pt/pt/electricidade/tarifaseprecos/2016/Paginas/TarifasdeAcesso%C3%A0sRedesem2016.aspx.

"Preços de Referência No Mercado Liberalizado de Energia Eléctrica E Gás Natural Em Portugal Continental." 2015. Entidade Reguladora dos Serviços Energéticos (ERSE). http://www.erse.pt/pt/Simuladores/Documents/Pre%C3%A7osRef_BTN.pdf.

"PVGIS Photovoltaic Software : Free Tool to Assess the PV Output Power in Europe, Africa and Asia for Electrical Stand Alone or Connected to the Grid Systems." 2016. Accessed May 11. http://photovoltaic-software.com/pvgis.php.

"PVprices. Energytrend." 2016. *EnergyTrend/PV*. Accessed February 26. http://pv.energytrend.com/pricequotes.html.

REN21. 2016. "Renewables 2014 GLOBAL STATUS REPORT." Renewable Energy Policy Network for the 21th Century REN21. Accessed February 26. http://www.ren21.net/Portals/0/documents/Resources/GSR/2014/GSR2014_full%20report_low%20res.pdf.

"Renewable Energy Road Map." 2007. *EUR-Lex Access to European Union Law*. January 10. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3Al27065.

Rodrigues, Miguel, Manuel Valdez, and Dulce Coelho. 2013. "Analysing Different Microgeneration Systems for Portuguese Residential Sector." *Journal of Energy and Power Engineering* 7 (2): 250.

Rogers, Everett M. 2003. *Diffusion of Innovations, 5th Edition*. Simon and Schuster.

Sacha Alberici, Sil Boeve, and Pieter van Breevoort et Al. 2014a. "Subsidies and Costs of EU Energy. Annex 1-3." DESNL14583. Ecofys by order of: European Commission. https://ec.europa.eu/energy/sites/ener/files/documents/DESNL14583%20Final%20report%20annexes%201-3%2011%20Nov.pdf.

———. 2014b. "Subsidies and Costs of EU Energy. Final Report." DESNL14583. Ecofys by order of: European Commission. https://ec.europa.eu/energy/sites/ener/files/documents/ECOFYS%202014%20Subsidies%20and%20costs%20of%20EU%20energy_11_Nov.pdf.

Saygin, Hasan, and Füsun Çetin. 2010. "New Energy Paradigm and Renewable Energy: Turkey's Vision." *Insight Turkey* 12 (3): 107.

Snaith, Henry J. 2013. "Perovskites: The Emergence of a New Era for Low-Cost, High-Efficiency Solar Cells." *The*

Journal of Physical Chemistry Letters 4 (21): 3623–3630.

Solanki, Chetan Singh. 2015. *Solar Photovoltaics: Fundamentals, Technologies and Applications*. PHI Learning Pvt. Ltd. https://books.google.com/books?hl=es&lr=&id=y1W2CAAAQBAJ&oi=fnd&pg=PP1&dq=Solar+Photovoltaics:+Fundamentals,+Technologies+And+Applications.&ots=DcZHIUSRsk&sig=a_sYMU3WD30wxA_g2Ei7UTGENh8.

"Solar Leasing Boosted in Europe with RWE, Conergy Deal." 2014. *Renew Economy*. July 8. http://reneweconomy.com.au/2014/solar-leasing-boosted-in-europe-with-rwe-conergy-deal-72109.

"Spanish Energy Minister: 'Spain Could Be the Solution' for Europe's Gas Woes." 2016. *Foreign Policy*. Accessed July 21. https://foreignpolicy.com/2014/09/12/spanish-energy-minister-spain-could-be-the-solution-for-europes-gas-woes/.

Stern, Jonathan, Simon Pirani, and Katja Yafimava. 2009. "The Russo-Ukrainian Gas Dispute of January 2009: A Comprehensive Assessment." *Oil, Gas & Energy Law Journal (OGEL)* 7 (2). https://www.ogel.org/article.asp?key=2876.

"Tarifas de Baixa Tensão Especial." 2016. Accessed March 9. http://www.edpsu.pt/pt/tarifasehorarios/Pages/TarifasBTE.aspx.

"Texts Adopted - Thursday, 14 December 2006 - A European Strategy for Sustainable, Competitive and Secure Energy - P6_TA(2006)0603." 2016. Accessed January 21. http://www.europarl.europa.eu/sides/getDoc.do?type=TA&reference=P6-TA-2006-0603&language=EN.

The Economist. 2013. "ETS, RIP?," April. http://www.economist.com/news/finance-and-economics/21576388-failure-reform-europes-carbon-market-will-reverberate-round-world-ets.

"The EU Emissions Trading System (EU ETS) - European Commission." 2016. Accessed February 24. http://ec.europa.eu/clima/policies/ets/index_en.htm.

"Third-Party Solar Financing." 2016. *SEIA*. Accessed March 1. http://www.seia.org/policy/finance-tax/third-party-financing.

"Transmission System Operator - EnergyWiki - Userwikis Der Freien Universität Berlin." 2016. Accessed February 17. http://userwikis.fu-berlin.de/display/energywiki/transmission+system+operator.

Turney, Damon, and Vasilis Fthenakis. 2011. "Environmental Impacts from the Installation and Operation of Large-Scale Solar Power Plants." *Renewable and Sustainable Energy Reviews* 15 (6): 3261–3270.

"UK 'capacity Market' Is Not a Market – It's State Aid (£1 Billion/year)." 2015. *EnergyPost.eu*. January 26. http://www.energypost.eu/uk-capacity-market-market-state-aid-1-billionyear/.

US Department of Commerce, NIST. 2016. "Smart Gride: A Beginner's Guide." Accessed May 31. http://www.nist.gov/smartgrid/beginnersguide.cfm.

U.S. Department of Energy. 2015. "Insights into Advanced Distribution Management Systems." Office of Electricity Deliverty and Energy Reliability. https://www.smartgrid.gov/files/ADMS-Guide_2-11.2015.pdf.

Van der Linden, N. H., M. A. Uyterlinde, C. Vrolijk, K. Ericsson, J. Khan, L. J. Nilsson, K. Astrand, and R. Wiser. 2005. "Review of International Experience with Renewable Energy Obligation Support Mechanisms."

ECN-C--05-025. Energy research Centre of the Netherlands ECN. http://inis.iaea.org/Search/search.aspx?orig_q=RN:36071535.

VGB Powertech. 2015. “Levelised Cost of Electricity LCOE 2015.” VGB PowerTech Service GmbH. https://www.vgb.org/en/lcoe2015.html?dfid=74042.

Vincent Bourgeais. 2015. “Share of Renewables in Eneregy Consumption to 15% in the EU in 2013.” Eurostat Press Office. http://ec.europa.eu/eurostat/documents/2995521/6734513/8-10032015-AP-EN.pdf/3a8c018d-3d9f-4f1d-95ad-832ed3a20a6b.

“Whatever Happened to Electricity Market Liberalisation?” 2016. *EnergyPost.eu*. January 27. http://www.energypost.eu/whatever-happened-electricity-market-liberalisation/.

Winkel, Thomas, Max Rathmann, Mario Ragwitz, Simone Steinhilber, Jenny Winkler, Gustav Resch, Christian Panzer, Sebastian Busch, Inga Konstantinaviciute, and others. 2011. “Renewable Energy Policy Country Profiles.” *Report Prepared within the Intelligent Energy Europe Project RE-Shaping. Www. Reshaping-Respolicy. Eu*. http://www.reshaping-res-policy.eu/downloads/RE-Shaping_CP_final_18JAN2012.pdf.

Wirth, Harry, and Karin Schneider. 2013. “Recent Facts about Photovoltaics in Germany.” *Report from Fraunhofer Institute for Solar Energy Systems, Germany*. http://bpva.org.uk/media/171535/2015_may_25_recent_facts_about_pv_in_germany.pdf.

Yong, Jia Ying, Vigna K. Ramachandaramurthy, Kang Miao Tan, and N. Mithulananthan. 2015. “A Review on the State-of-the-Art Technologies of Electric Vehicle, Its Impacts and Prospects.” *Renewable and Sustainable Energy Reviews* 49: 365–385.

ANNEX A: POTENTIAL PV SELF-CONSUMPTION MARKET IN PORTUGAL

This annex describe the grounds of Roger diffusion model which is employed under the OTGEN project to derive a 2030 PV SC scenario based on the micro and minigeneration evolution.

Roger Diffusion Model of Innovation

Rogers diffusion model of innovation is the theoretical methodology operated to analyze the Portuguese solar potential until 2030 (Rogers 2003). Diffusion of Innovations pursues to explain how, why and at what rate new technologies and concepts are taken up in a culture. It is a process by which a novelty is disclosed through certain routes over time among the players in a social system. The aforementioned sentence collects the four main elements that influence the expansion of a leading edge: the innovation itself, the communication channels, time and the social environment.

Rogers Model proposes three relevant insights which shall be taken into consideration for a successful technology wide social drainage (Lee Robinson 2016):

DEEPLY UNDERSTANDING THE CATALYST VECTORS TO BE IMPLEMENTED

Why do certain innovations proliferate more quickly than others? And why do others fail? The following characteristics determine between 49-87% of the variation in the endorsement of a new commodity. The rate of adoption is faster if the innovation is:

- Perceived by the user as an asset and overrides competitors.

- Consistent with the existing values and practices.

- Simple to use.

- Trialable on a limited basis.

- It offers tangible results, which lower uncertainty.

By iterating this checklist the technology is reinvented until maximize diffusion. In a way, interpreting the career of microgeneration (2008-2014) and minigeneration (2011-2014) schedules, the new SC projection might be better estimated or at least lawmakers might have been thought about these past experiences while legislating for Decree Law 153/2014.

RECOGNIZING THE NEEDS OF DIFFERENT USER SECTORS

Based on the propensity to adopt a specific innovation, society is standardized into five categories. Technology expands when it evolves to meet the demands of these successive segments:

- Innovators: Small group of people (2.5%), with high risk tolerance exploring new ideas and technologies. The status and financial liquidity of the subsequent group members declines just as the innovation moves forward.

- Early adopters: Opinion leaders with a central communication position who try carefully new products. They consolidate the 13.5% of the share.

- Early Majority: Thoughtful people but more premature accepters than the average. 34%

- Late Majority: Skeptics, who will only use the new products only when a majority is doing so. 34%

- Laggards: Traditional people, with a lack of opinion. Typically hold aversion to change and have reduce contact, only family and close friends. 16%

Normally, diffusion paths take the form of S-shaped curves in which adoption proceeds at a slow rate in the beginning, accelerates to an inflection point, begins to decelerate, then tapers off to saturation as pictured in Figure 35.

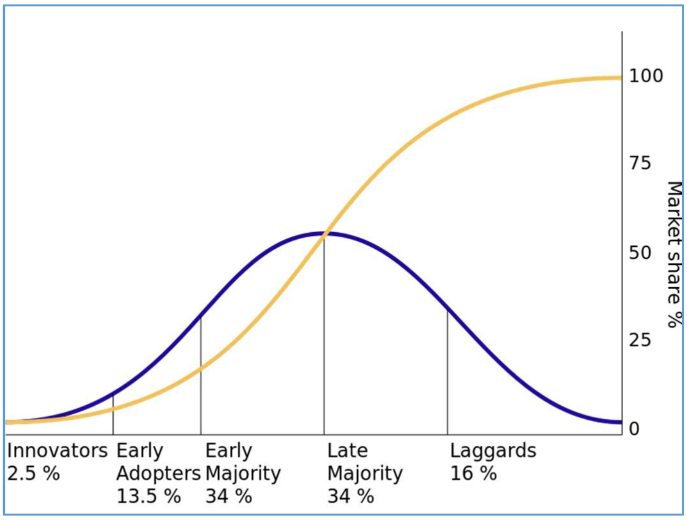


Figure 35. The diffusion of innovations according to Rogers. Blue line reflects the groups of consumers embracing a new technology, adoption curve; and the yellow curve, being the logistic function or S curve, represents the diffusion of an innovation reflected by the market share (Rogers 2003).

Conceptually there are 3 adoption models:

- Model of internal influence, where the main drivers are those that arise from the influence of social interaction, by imitation. This latter influence is stronger where populations are more dense; and the product concept, more compelling.

- In the Model of external influence, the key guide are the change agents such as advertising messages that lie outside the social system.

- The combination of the two models constitutes the third model.

PEER-PEER NETWORKING

The early adopters, who are always on the lookout for advantages, the embracement of innovations involves the management of risk and unpredictability, so it is through personal communication rather than marketing methods how adopters are convinced. Nevertheless, diffusion manifests itself in various ways in assorted cultures and fields and is highly subject to the type of individual and the innovation-decision process.

Adoption Curve and Deployment Prognosis for Self-Consumption in Portugal

It is the case for the PV micro and minigeneration expired regimes, where the data of the adopters per year has been consulted, the best diffusion fitting curve corresponds to the internal influence model. The analysis performed allowed also to deduce the relative velocity at which the technology was adopted by consumers, being known as the adoption rate. In order to project the SC diffusion curve, it has been made use of the prior indicated key parameters reported by the micro and mini generation curves. The adoption rate of microgeneration has been extrapolated for residential, and for Industrial. For Hotels and retail, minigeneration adoption rate has been used. These hypothesis are resulting to be too moderated, as the figures available for SC reveal an initial evolution of the technology adoption faster than expected. Howbeit, the period interpreted is too short clearly infer for longer temporary durations.

With the object of estimating the diffusion curve for 2030, it has been assumed a percentage of adherents 1%, 2%, 3% and 5% of the total final consumers in each sector. The cumulative capacity installed presumed to be for the residential segment the 16.7% of the contracted power and for the rest divisions the 41.3%.

The study affirms that between November 2022 and June 2024, SC installed capacity will attain the 1% of the total Portuguese installed capacity of 2014, being the 3% and the 5% of the final incumbents. For the 1% forecasted total Portuguese installed capacity of 2020, SC penetration of that magnitude will be attaint between July 2023 and February 2026 as captures Figure 36.

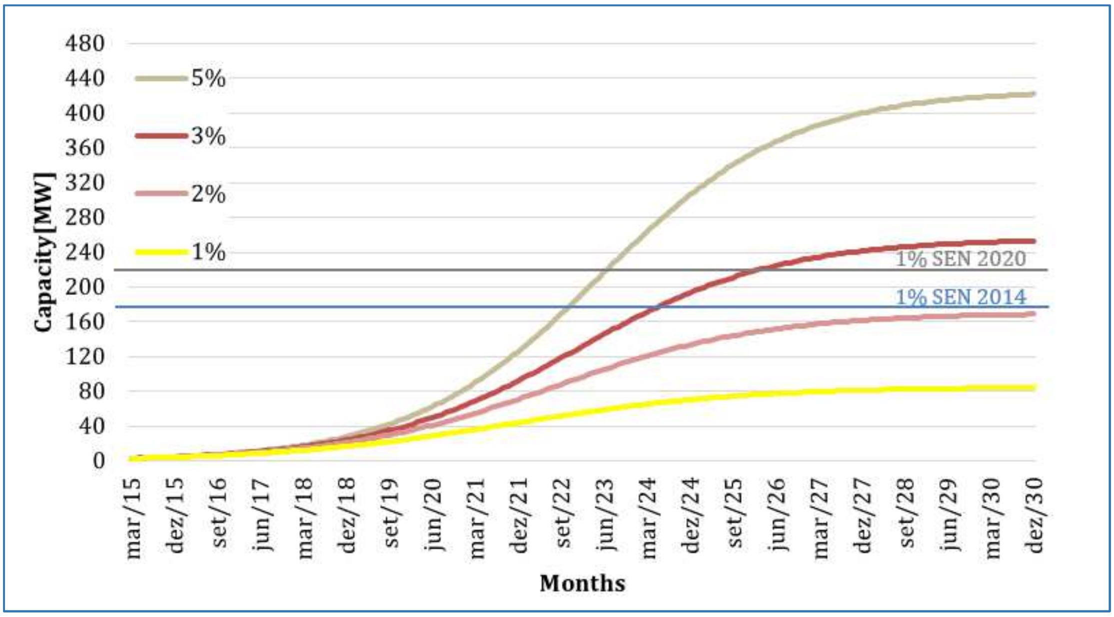


Figure 36. Diffusion curve.